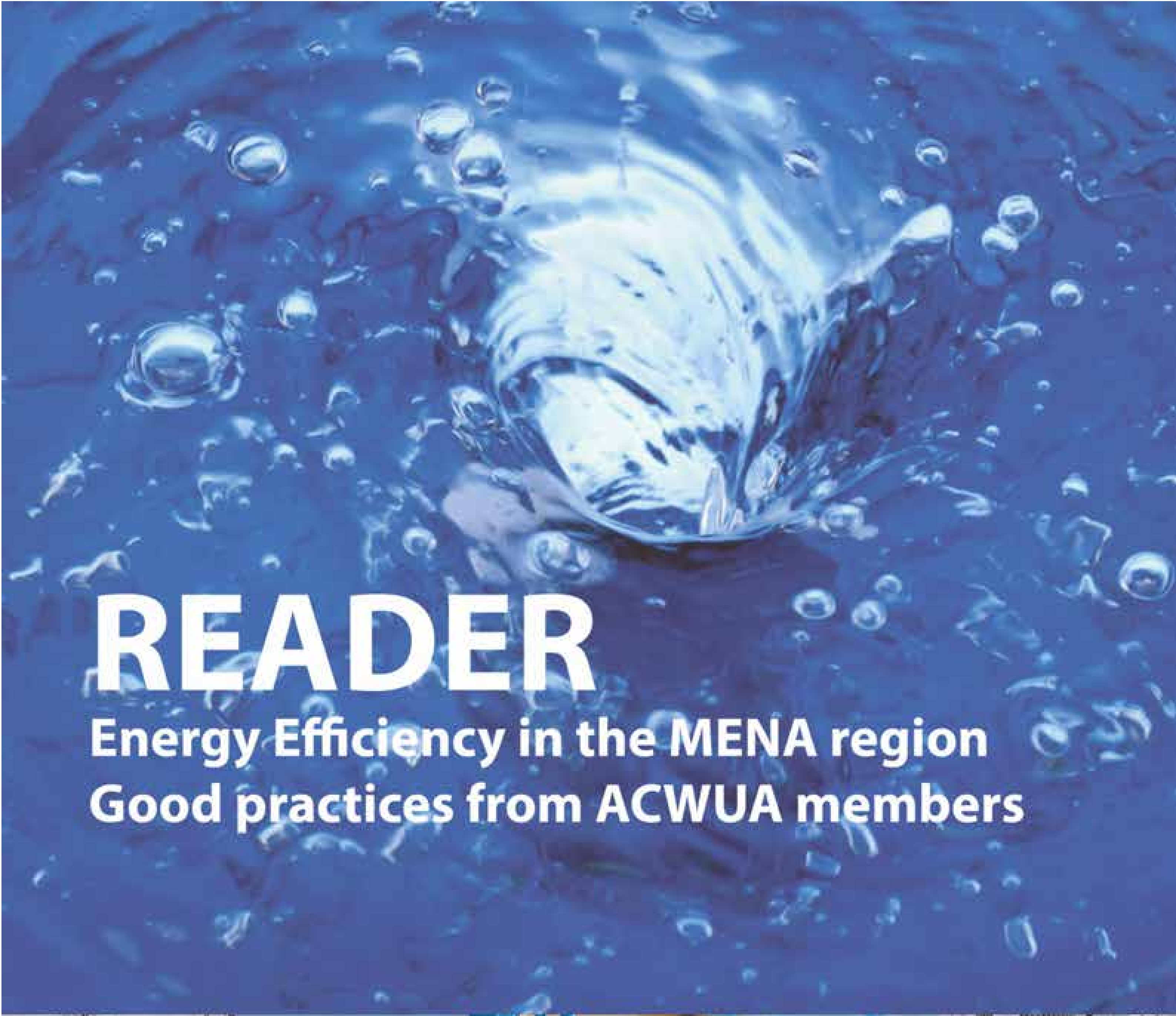


READER

Energy Efficiency in the MENA region
Good practices from ACWUA members

September 2015

ACWUA
Arab Countries Water
Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

READER

Energy Efficiency in the MENA region

Good practices from ACWUA members

Reader
Energy Efficiency in the MENA region
Good practices from ACWUA members

Published by
The Arab Countries Water Utilities Association (ACWUA)
under the guidance of the ACWUA Task Force Energy Efficiency
with support from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
ACWUA in Amman, Jordan
GIZ in Bonn and Eschborn, Germany

Implemented by
Strengthening the MENA water sector through regional networking and training (**ACWUA WANT**) program
www.mena-water.net or www.acwua.org/training or www.acwua.org/node/413

Arab Countries Water Utilities Association (ACWUA)
19A, Umm Umarah Street
Al-Rashed Area
P.O.Box 962449 Amman
11196 Jordan

and

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
65760 Eschborn, Germany
Dag-Hammarskjöld-Weg 1-5
Division 3300 Near East
On behalf of the
German Federal Ministry for Economic Cooperation and Development (BMZ)

Editor
Hans Hartung, Weikersheim. Germany

Program supervision
Thomas Petermann (GIZ Germany)
Abdellatif Biad (ONEE, Chairperson ACWUA Task Force Energy Efficiency)
Mustafa Nasereddin (ACWUA Jordan)

Photo credits
Thomas Petermann

Disclaimer

Energy Efficiency – A strategic objective and assigned target of ACWUA

In most cases energy is the number one cost within all water and wastewater service utilities O&M costs, and a controllable one at that. In addition, it has been reported that the potential for energy savings at utilities in the developing world can reach between 30-40%, depending on the baseline situation, and that many energy efficiency (EE) measures have a payback period of less than five years (Feng Liu et al, 2012). This means that investing in energy efficiency would enable the utility to expand and/or improve its services because of the gains achieved.

Financial benefits may be the number one priority for any utility when considering system improvements, but reducing energy consumption not only reduces costs and operating expenditures; it also has a direct impact on reducing Green House Gas (GHG) emissions, and reducing the pressure of adding or sustaining power generation capacity on the national level. Consequently, improving EE in WWS utilities is the right way to save money, extend the life of existing infrastructure, and contribute to environmental sustainability.

There is no one-size-fits-all EE indicator in the WWS industry, as each utility is unique in terms of the types of processes and technology it applies; which water resources it utilizes, the size of the communities it serves, how they are dispersed, applicable standards and regulatory requirements, as well as the availability and price of energy sources. Each utility needs to evaluate its own goals, financial situation and commitment to improving EE.

In July 2014, ACWUA issued a Best Practices Guide on utilities management listing the main pillars for managing water utilities: 1. Cost Recovery; 2. Non-revenue Water Management; 3. Asset Management; 4. Serving the Poor; 5. Energy Efficiency. The Energy Efficiency section addressed the importance of enabling an environment for applying energy efficiency, the types of energy efficiency programs, and technical aspects for those programs. That was the start for tackling energy management issues with guiding principles for water utilities within ACWUA membership.

Today the Guidelines on Energy Efficiency and the associated Reader of Good Practices from ACWUA members present a detailed and thorough review of current energy consumption patterns at water and wastewater utilities in the Arab region. The documents are based on field visits and analysis of different pilot sites within ACWUA membership. The exclusivity of the guideline comes from its development process, with the support of GIZ regional capacity development program (ACWUA WANT) and the voluntary work of ACWUA Energy Efficiency Task Force. It reflects the current situation and what should be done at the operational level to implement energy efficiency measures and aim to reduce energy consumption at even higher levels.

Today ACWUA membership comprises 108 utilities from 18 Arab countries. ACWUA is very proud of the energy efficiency program outcomes and will advocate and share its findings with all members. With the support of GIZ and other international partners, ACWUA will work forward to scale-up a plan for the implementation of energy efficiency measures, improve financial performance and protect the environment.

Eng. Khaldon Khashman
ACWUA Secretary General

Eng. Mustafa Nasereddin
ACWUA Director of Program and Technical Services

Foreword

The present reader is concerned with a selection of good practices within water and wastewater utilities in the MENA region, within the framework of activities of the Energy Efficiency Task Force (EE-TF), which was established in December 2013 at the ACWUA 6th Best Practice Conference in Algiers. The EE-TF has delegated members from water and wastewater utilities throughout the MENA region.

The GIZ capacity development program ACWUA WANT is supporting this EE-TF with ACWUA and its more than 110 members during the period 2013-1015. The main objective of its activities is to increase knowledge, disseminate experience and assist in advocating for energy efficiency programs in ACWUA water and wastewater utilities. The task force members agreed in Algiers to share the state of knowledge related to energy management systems (EMS), and to develop regional guidelines for energy checks and energy analysis in water and wastewater utilities alongside a program of capacity building for the EE-TF members.

To assess good practices in energy efficiency in the MENA region, ACWUA launched an invitation to submit papers, focusing on lessons learnt and individual practices deemed exemplary and capable of contributing to collective learning in the MENA region. The selection process of submitted papers was based on criteria such as success, relevance, sustainability, innovation, etc.

The good practices presented in this reader vary widely from one country or utility to another. Further, the reader shows that there is a real interest for utilities to perform better energy efficiency in the water sector.

I hope that this reader will contribute to a better comprehension of energy efficiency in the water sector in the MENA region and will be a useful tool for any relevant person working in energy efficiency in the water sector. The members of the EE-TF and the authors will be happy to respond to any questions arising from the practical experiences presented in this document.

Eng. Abdellatif Biad

Chair, ACWUA Energy Efficiency - Task Force Rabat, September 2015

Introduction

Water and wastewater systems are significant energy consumers and water energy issues are of growing importance, because the operating costs of water supply and wastewater treatment plants are significantly determined by energy costs. These issues are addressed by the Energy Efficiency Task Force (EE-TF) of the Arab Countries Water and Wastewater Utilities Association (ACWUA).

The Task Force was founded at the ACWUA 6th Best Practice Conference in Algiers (November 2013) and includes 14 experts nominated by ACWUA member utilities throughout the MENA region. The ACWUA Task Force aims at:developing regional guidelines for energy checks and energy analysis that guide the process to optimize the use of energy in water and wastewater utilities

1) developing regional guidelines for energy checks and energy analysis that guide the process to optimized energy use in water and wastewater utilities.
2) sharing experiences on relevant ISO standards, energy management systems (EnMS) and energy audits.
3) disseminating good practices already applied in utilities in the MENA region and ACWUA members.

The ACWUA WANT project of GIZ supported the EE-TF during the period 2014-2015 through a process of capacity development that aims to develop instruments to enhance energy performance at utility level and to promote them among ACWUA members. The publication of this ACWUA Reader is one of the key products of the EE-TF.

Water and wastewater utilities in the region have already made many efforts to increase energy performance in the water and wastewater sector. The ACWUA EE-Task Force asked their members to share experiences in energy optimization for this Good Practice Reader. The TOR for submitting papers were published by ACWUA and the Task Force in August 2014.

16 draft papers were submitted by the end of 2014 to the EE-TF and ACWUA for peer review. These papers are now published at the ACWUA and ACWUA WANT websites.

http://acwua-ee.mena-water.net/

http://www.acwua.org/node/413

http://www.mena-water.net/energy-efficiency/good-practices

Some of the case studies were presented during the period 2014-2015 at ACWUA Best Practice Conferences, the ACWUA Arab Water Forum and further discussed in special sessions at the International Water Fairs of IFAT Munich and Water Berlin.

Eventually ten papers from experts of six MENA countries were selected to provide evidence that there is increasing expertise and experience in the region. The selection was based on a number of criteria outlined in the TOR, such as successful implementation, relevance, sustainability, replicability, innovation, and a set of additional optional criteria.

The “Good Practices for Energy Efficiency in the MENA region” were clustered in four groups:

Approaches to the Water Sector

Operating expenses have always posed problems for many companies and water service providers, especially in developing countries. *Mokhdar Sid Ahmed* of ADE (Algerian Waters) illustrates the difficulties faced by the sector in terms of high electrical energy use. He shows easy to implement and cost effective actions to reduce energy consumption.

Khaled Zaabar of SONEDE, the National Company of Exploitation and Distribution of Water in Tunisia, shows three of many SONEDE efforts to reduce the cost of energy: (1) Optimization of electricity contracts and operation of pumping stations (2) Optimization of energy cost of isolated and autonomous sites (3) A study of the economic effects when switching from a three to a four cycle tariff.

Pumping and reducing water losses

The articles under this heading show that the sustainability of energy efficiency projects in the water sector can be assured by having high quality equipment and adequate operation and maintenance. *Daniel Busche* and *Bassam Hayek* explain the step-wise approach that was followed in Jordan. After an initial audit in one area showed promising energy saving potential, a country-wide assessment was done covering major pumping stations. High saving potentials of 33% were found and pilot plants were done.

Salah Shaika and *Amal Hudhud* discuss another aspect in energy saving. The mountainous town of Nablus in Palestine changed its whole distribution system from pumping zones into 28 pressure zones and thus reduced energy consumption from 0.93 kwh to 0.59 kwh per cubic meter.

A similarly impressive decrease in energy consumption is shown by *Fuad Saleh Al-Awzari* in Sana'a's Water and Sanitation Local Corporation in Yemen. His detailed study shows that the specific energy of the system can decrease from 2.05 kwh/m3 to 1.27 kwh/m^3. *Mohamed Ahmed Talaat* puts the emphasis on power factor correction and shows concrete steps to achieve substantial reductions on electricity bills.

Water treatment

The papers are both by Egyptian authors from HCWW. They show the various treatment methods of raw water by Potassium Ferrate and by backwashing with granular media filters. *Mahmoud Abd Al Rahman Saad* explains how Potassium Ferrate can simultaneously perform as an oxidant, coagulant and disinfectant. It is more powerful than other oxidants, can replace traditional coagulants and outperforms the usual disinfectants. The quantity of slurry produced is also reduced.

Mohamed Abodief explains practical steps in backwash optimization of sand filters. It is the most effective action in saving both energy and water in conventional water treatment plants.

Studies

The two study papers are from Tunisia and Palestine. While one highlights potential energy savings in the island of Kerkennah (Tunisia) the other gives an overview of the wastewater treatment plant in Nablus (Palestine), emphasizing the application of biogas and photovoltaic approaches. The purpose of the study of the desalination plant in Tunisia by *Slim Besbes* was to illustrate practical steps for the reduction of energy consumption. He indicates many single steps, which add up to a good potential for saving energy: replacement of membranes, decreasing pump pressure, variable speed drives, use of highly efficient motors.

Mohammad Homeidan follows the trend of treatment plants aiming to save energy by discussing how to use renewable energy. He suggests biogas utilization and photovoltaic cells as a future green scenario for the wastewater treatment plant in Nablus West.

TABLE OF CONTENT

Approaches to the Water Sector

1. Mokhdar Sid Ahmed, Algeria: Guide de Bonnes Pratiques pour une Efficience Energétique dans le Secteur de l’Eau EN ALGERIE
2. Khaled Zaabar, Tunisia: Contribution à la mise en place de plans d'action perennes de maitrise d'énergie

Pumping and reducing water losses

3. Bassam Hayek/Daniel Busche, Jordan: Energy Efficiency in Water Pumping in Jordan
4. Salah Shaikha and Amal Hudhud, Palestine: Switching from pumping zones to pressure zones – case study of Nablus city
5. Fuad Saleh Saleh Al-Awzari, Yemen, Improving Energy Efficiency in Pumps and Pumping System in Sana'a Water and Sanitation Local Corporation (SWSLC)
6. Mohamed Talaat, Egypt: Power Factor Correction

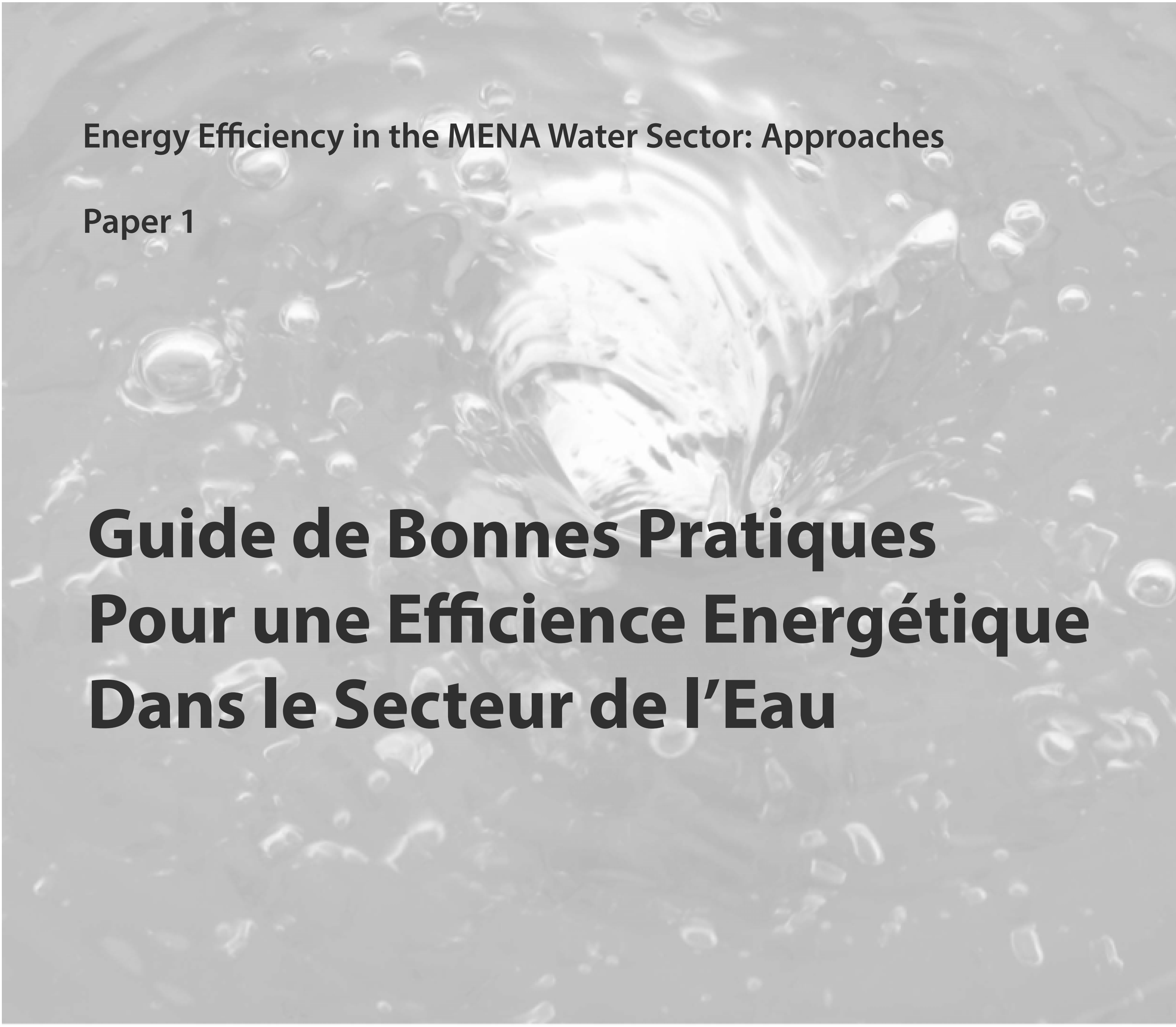
Water Treatment

7. Mahmoud Abd Al Rahman Saad, Egypt: Energy conservation and water quality improvement using a novel oxidizing agent Potassium Ferrate
8. Mohammed Abodief, Egypt: Optimize duration of filter backwash

Studies

9. Slim Besbes. Tunisia: Réhabilitation de la station de dessalement de l'ile de Kerkennah et réduction de la consommation d'énergie
10. Mohammad Homeidan et al., Palestine: Study of Renewable Energy Applications in Nablus-West Wastewater Treatment Plant

Note: All papers are in the original French or English languages with English summaries



Energy Efficiency in the MENA Water Sector: Approaches

Paper 1

Guide de Bonnes Pratiques Pour une Efficience Energétique Dans le Secteur de l'Eau

Fait par :
Mokhdar Sid Ahmed, Décembre 2014

ACWUA
Arab Countries Water Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german cooperation
DEUTSCHE ZUSAMMENARBEIT
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Abstract

Good Practice Guide for Energy Efficiency in the Water Sector

by Mokhdar Sid Ahmed

Expenses related to operating costs have always posed problems for many companies and providers of water services especially in developing countries where the provision of water gets more difficult and where the cost is growing permanently unlike its selling price is always administered and subsidised by the governments.

In this respect, the kWh used to produce 1 m^3 has always been a priority and research focus for the operator manager to reduce the price at fair value.

In Algeria, the water sector is ranked second after industry sector and 42% of the turnover of the national company of the water distributor ADE «Algerian waters" is used to pay electric bills hence its debt amounts to 22 billion Algerian dinars end of 2013 financial year.

This perfectly illustrates the difficulties faced by companies in the sector in terms of use of electrical energy to operate the equipment .And because the bills are salted and incomes of these organizations are not sufficient to cover all the charges.

Saving energy in hydraulic systems is now an economic necessity that is combined with an environmental necessity.

Most actions to reduce energy consumption are easy to implement and very quickly cost effetive.

Substantial gains could be reaped in terms of expenditure by the rigorous implementation of a set of actions and good practices to adopt which we treat major in this manuscript as a practical guide that aims to support responsible Local energy cell within ADE units "Algerian waters" in the development of an energy policy based on economies and financial gain that may be substantial.

This guide is not an end but the starting point, the foundation stone of a comprehensive approach based on the mobilization of all including the continuous support officials up in the hierarchy within units of the company.

To accompany the reflection of the department responsible for energy that is already there at the unit level, this guide takes the form of recommendations around the following key themes:

- Good knowledge of the balance of energy consumption of the installations
- Appropriate choice of the energy billing price and of "power demand"
- Monitoring and continuous monitoring of energy invoices
- Need to establish and implement preventive and corrective maintenance schedules
- Use other alternatisve such as renewable energy
- Adopt simple gestures and behaviors
- Conclusion

SOMMAIRE

Tableau des Abréviations :

ADE : L'Algérienne Des Eaux (ADE) est un établissement public national à caractère industriel et commercial .il est chargé sur tout le territoire national, de la prise en charge des activités de gestion des opérations de production, de transport, de traitement, de stockage, d'adduction, de distribution et d'approvisionnement en eau potable et industrielles ainsi que le renouvellement et le développement des infrastructures.

Sonatrach : Société Nationale pour la Recherche, la Production, le Transport, la Transformation, et la Commercialisation des Hydrocarbures. Sonelgaz : Société nationale de l'électricité et du gaz, est une compagnie chargée de la production, du transport et de la distribution de l'électricité et du gaz en Algérie.

GEP : Groupe électropompe

AEP : Alimentation en Eau Potable.

TP : Cote trop plein du réservoir

CR : Cote Radier du réservoir

TC : Rapport du transformateur de courant : Selon la définition de la Commission électrotechnique internationale, un transformateur de courant est « un transformateur de mesure dans lequel le courant secondaire est, dans les conditions normales d'emploi, pratiquement proportionnel au courant primaire et déphasé par rapport à celui-ci d'un angle voisin de zéro pour un sens approprié des connexions1 ».La notion de « transformateur de courant » est un abus de langage, mais elle a été popularisée dans l'industrie. L'expression « transformateur d'intensité » est probablement plus exacte. On utilise fréquemment les abréviations TC ou TI.

Tg φ : Le facteur de puissance de l'installation est le quotient de la puissance active en kW consommée par l'installation sur la puissance apparente en kVA fournie à l'installation. Il est égal au cosinus de l'angle de déphasage ϕ entre la puissance active et la puissance apparente.

cos φ = = facteur de puissance. Le cos ϕ est compris entre 0 et 1.
Un facteur de puissance proche de 1 optimise le fonctionnement d'une installation.

Il est possible d'exprimer la tg φ avec

$$tg\varphi = \frac{Q}{P}$$

La valeur la plus faible de tg φ optimise l'installation.

DA : Dinars Algérien ,1DA =111€ Euro date du 05/01/2015

BT : Basse tension : le courant distribué est livré à la tension nominale 220/380 V qui sera porté progressivement à 230/400 V.

Ce guide est un recueil des bonnes pratiques a observer dans le cadre d'une politique de l'efficience énergétique mise en oeuvre par le secteur de l'eau. Vous trouverez dans ce document un rappel des pratiques à réaliser au quotidien et de conduite à tenir. nous présentons les pistes et les axes d'améliorations qui ont était /et qui devront êtres explorer par les utilitaires fournisseurs des services de l'eau et d'assainissement qui vont contribuer à la diminution de leurs facture d'énergie qui grève lourdement leur portefeuille de dépenses et par la suite provoquant une augmentation directe de leurs revenus permettant d'offrir un service de qualité à leurs clients .

Par conviction et dans le but d'obtenir des résultats significatifs, il est important que le gestionnaire exploitant établisse un programme d'économies reposant sur les termes suivants :

1 Une Bonne connaissance du bilan de la consommation énergétique des installations

Une bonne connaissance du bilan de la consommation énergétique permet de gérer les priorités au niveau des économies réalisables et les investissements futurs. Dans ce contexte il faut établir toutes les bases de données informatiques utiles au suivi de l'énergie consommée par les installations gérées.

Faire un bilan de la répartition de votre consommation en interne ou consulter un spécialiste pour la réalisation d'un pré diagnostic énergétique est une nécessité qui va vous permettre de classer vos équipements et par la suite tracer un plan d'action a fin de réduire autant que possible cette consommation.

Ce bilan est un outil indispensable qui aide à la décision vis à vis la gestion énergétique des installations.

Très souvent les priorités de l'exploitation des installations notamment celles du solutionnement des problèmes techniques qui surgis et le stresse de la continuité de la production de l'eau l'emportent bien souvent sur les problématiques de la gestion de l'énergie, c'est ainsi que les informations sur les différentes énergies consommés par les équipements abrités dans ces infrastructures sont absentent et même si elles existent sont mal identifiées et analysées. Et dé fois on oublie de procéder à la résiliation des contrats d'abonnement de forages et autres infrastructures abandonnées.

Pourtant il s'agit du premier pas vers une gestion plus rationnelle de l'énergie. À partir de ces informmations, les couts énergétiques des sites sont établis, et un éventail de mesures visant la réduction de la consommation d'énergie est mise en place.

Intégrer l'efficacité énergétique dans les nouveaux projets d'alimentation eau potable et d'assainissement relève aussi d'un bon sens des affaires .Ce pendant cette notion devra être l'un des paramètres principaux lors de l'analyse des variantes retenues. A titre d'exemple intégrer dans les études d'AEP1, la possibilité d'augmenté des capacités de stockage en amont et en aval des stations afin de permettre les arrêts de pompage pendant les heures de pointes sans réduction de la production et sans perturbation de la distribution.

2 Le Choix judicieux et révision périodique du mode tarifaire de la facturation de la consommation d’énergie

Des économies peuvent être réalisées en adoptant un tarif mieux approprié, encore faut-il le comprendre car la plupart du temps le choix judicieux du tarif de la facturation pour chaque site permette de réduire les consommations d’énergie de façon significative et très rapidement rentable.

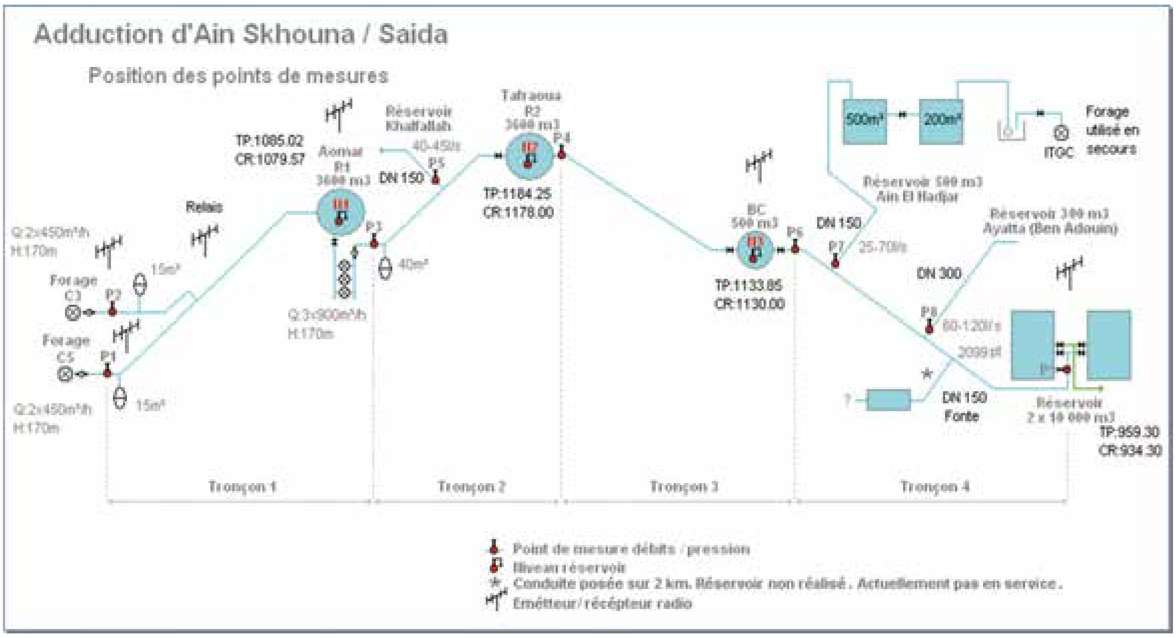
Le tarif choisis obéi aux règles du mode de fonctionnement (Nuit, Jour, hors pointe, pointe) et à la puissance installée. La demande de révision sera établi après simulation des différents tarifs de facturation (en Algérie les tarifs fournis par le distributeur de l’énergie « Sonelgaz[1]» sont 41[1] 42[1], 43[1], 44[1], 31[1] et 32[1] selon le type d’alimentation HT haute tension, MT moyenne tension en question) sur la consommation annuelle de l’installation considérée et le tarif le plus avantageux (le moins couteux) sera adopté.

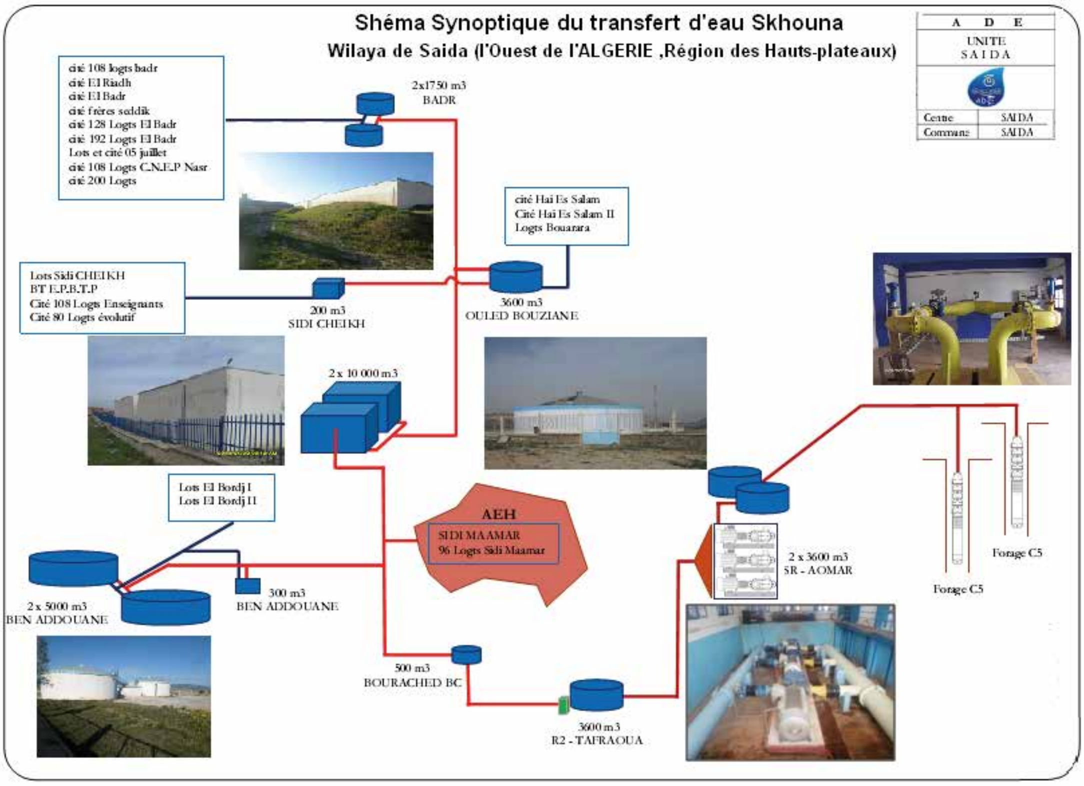
Dans ce contexte nous présentons des exemples sur l’impact du changement du tarif sur une installation hydraulique représenté par une station de pompage, ou l’étude de ce cas montre clairement que des gains substantiels pourraient être engorgés par le choix judicieux du tarif de la facturation de l’énergie.

S’agissant du transfert d’eau de skhouna, une chaine de production d’eau qui concourt à l’alimentation en eau potable du groupement urbain des villes algériennes de Saida et Ain Hadjar situé au Nord Ouest du pays de l’Algérie (population desservies 163 720 habitants) .

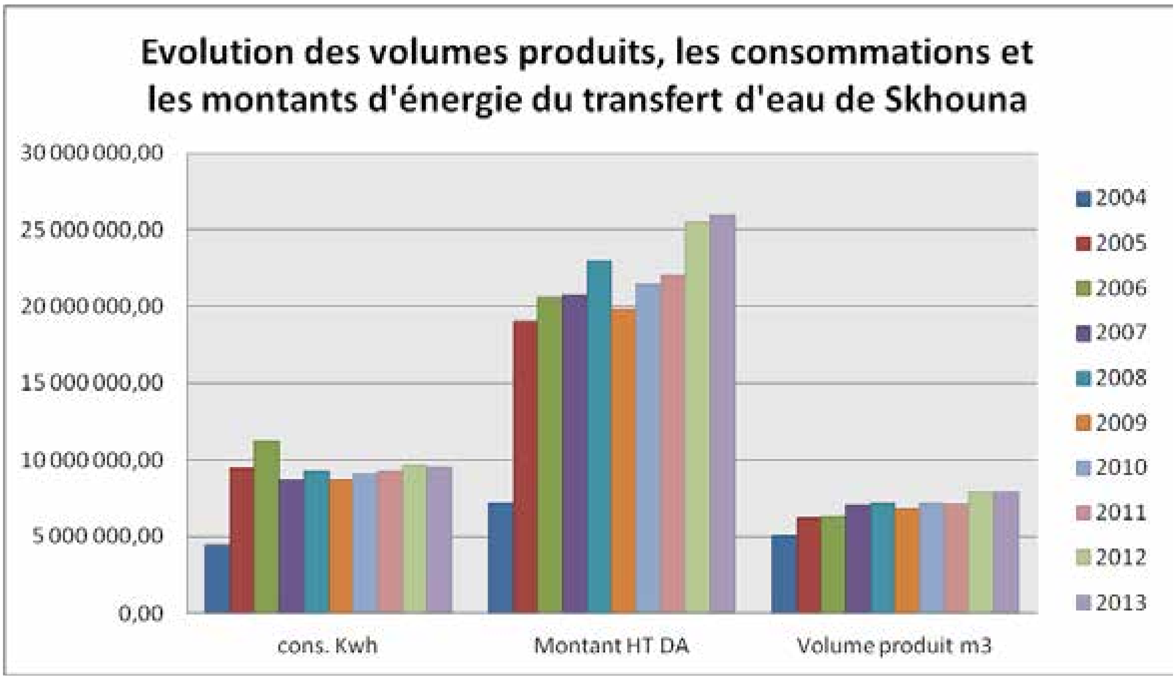
Ce système est constitué de :

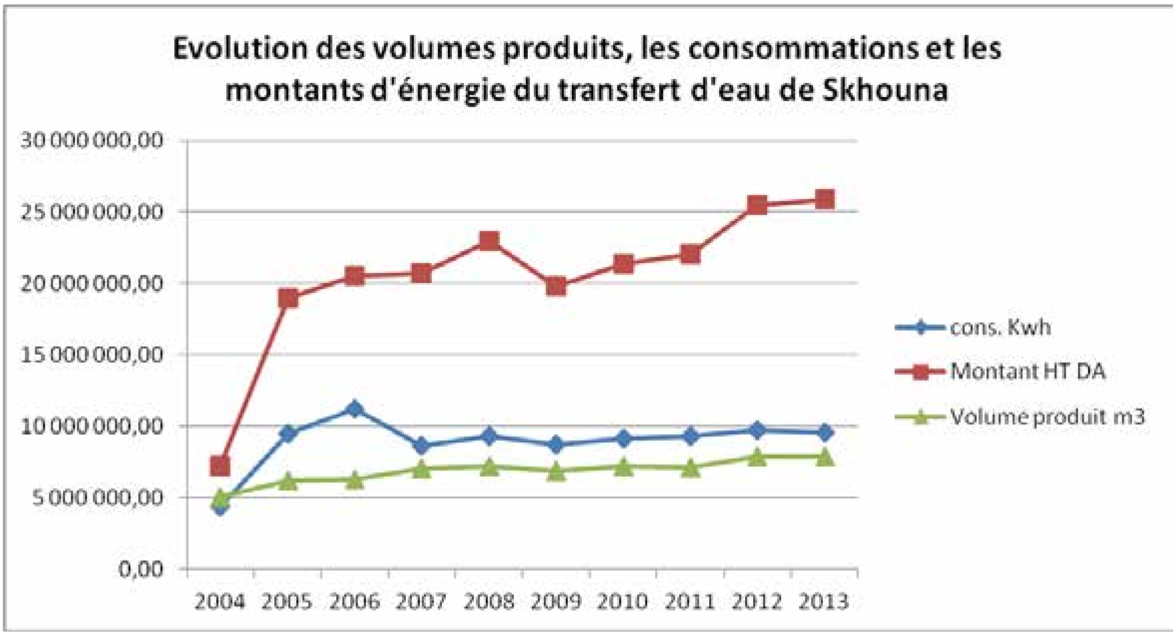
- Deux forages C3 et C5 équipés chacun de deux pompes immergées de 125 l/s.
- Une station de reprise (Ben Omar) équipée de trois GEP[1] à axe horizontale (Groupe électropompe) dont un en secours de 250 l/s chacun
- Quatre réservoirs respectivement de capacité R1 3600m^3, R2 3600 m^3, brise charge 500 m^3, et R3 2 x 10 000 m^3
- Des conduites d'adduction de diamètre 500, 600 et 700 mm en fonte d'un linéaire total de 80 Km (tronçon1, 2, 3 et 4 égal respectivement à 30.5 km, 32.5 km, 14 km, 3km).


Adduction d'Ain Skhouna / Saida
Position des points de mesures
Q:2x450m³/h
H:170m
Forage
C3
P2
15m³
Relais
Forage
C5
P1
15m³
Q:2x450m³/h
H:170m
TP:1085.02
CR:1079.57
Aomar
R1
3600 m3
P3
40m³
Q:3x900m³/h
H:170m
Réservoir
Khalfallah
40-45l/s
P5
DN 150
Tafraoua
R2
3600 m3
P4
TP:1184.25
CR:1178.00
BC
500 m3
P6
TP:1133.85
CR:1130.00
500m³
200m³
ITGC
Forage utilisé en secours
Réservoir 500 m3
Ain El Hadjar
DN 150
P7
25-70l/s
Réservoir 300 m3
Ayatta (Ben Adouin)
DN 300
P8
80-120l/s
2099 pl
?
DN 150
Fonte
Réservoir
2 x 10 000 m3
TP:959.30
CR:934.30
Tronçon 1
Tronçon 2
Tronçon 3
Tronçon 4
Point de mesure débits / pression
Niveau réservoir
★ Conduite posée sur 2 km. Réservoir non réalisé. Actuellement pas en service.
Emétteur/récépteur radio


Shéma Synoptique du transfert d'eau Skhouna
Wilaya de Saida (l'Ouest de l'ALGERIE ,Région des Hauts-plateaux)
A D E
UNITE
SAIDA
Centre SAIDA
Commune SAIDA
cité 108 logts badr
cité El Riadh
cité El Badr
cité frères seddik
cité 128 Logts El Badr
cité 192 Logts El Badr
Lots et cité 05 juillet
cité 108 Logts C.N.E.P Nasr
cité 200 Logts
2x1750 m3
BADR
cité Hai Es Salam
Cité Hai Es Salam II
Logts Bouarara
Lots Sidi CHEIKH
BT E.P.B.T.P
Cité 108 Logts Enseignants
Cité 80 Logts évolutif
200 m3
SIDI CHEIKH
3600 m3
OULED BOUZIANE
2 x 10 000 m3
Lots El Bordj I
Lots El Bordj II
AEH
SIDI MAAMAR
96 Logts Sidi Maamar
2 x 5000 m3
BEN ADDOUANE
300 m3
BEN ADDOUANE
500 m3
BOURACHED BC
3600 m3
R2 - TAFRAOUA
2 x 3600 m3
SR - AOMAR
Forage C5
Forage C5

Les volumes annuels produits et les consommations d'énergie ainsi que les montants y afférents au niveau des stations de pompage de ce transfert sont présentés par les graphes suivants :





L'analyse des graphes ci-dessus indique clairement la réussite des efforts conjugués en matière de contrôle des factures de la consommation d'énergie.

En effet, on constate que la consommation d'énergie au niveau des stations de pompage est relativement stable depuis 2007 jusqu'au 2013 et ce malgré la progression des volumes mobilisés provoqués par l'augmentation de la demande. Cette situation est le résultat d'un train de mesures prises par l'exploitant, parmi eux :

Le tarif « **42**[1] » choisis par l'opérateur locale ADE1 (Algérienne des Eaux) unité Saida pour gérer ce transfert , en matière d'énergie qui adopte un prix unitaire différent pour le KWh pour deux périodes de fonctionnement, pointe et hors pointe, et qui donne l'avantage aux arrêts de service pendant les heures ou le réseau d'énergie est trop sollicité, heures de pointe (de 17h00 à 21h00).

C'est le cas du transfert depuis sa mise en service à ce jour, les trois stations de pompages (C3, C5 et Ben Omar) s'arrêtent durant cette période. Cela a généré un gain sur la facture de **19 millions DA[1]/an** et qui peut être au-delà de ce montant si la chaine travaille à pleine capacité à raison du prolongement des heures d'arrêts.

Notons que les arrêts total ou /et partiel du service (pompage,…) pendant les heures de pointes ou le réseau d'énergie est trop sollicité favorise efficacement la réduction des montants des factures d'énergie. Cette situation n'est réalisable que si la continuité du service public (alimentation en eau potable des agglomérations) est assurée par des capacités de stockage importantes (réservoirs) et dans le cas contraire ou les conditions de stockage sont in insuffisantes (cas de quelques installations en Algérie) on peut jouer sur le transfert total ou partiel du pompage des heures de pointe (17h-21h) aux heures creuses (22h30 au 6h) et ce sans réduction de la production journalière ni incidence sur la distribution. De ce fait le taux des consommations d'énergie en pointe et en creuse par rapport à la consommation totale de l'installation doivent être respectivement inferieur à 16,67% et supérieur à 31,25%.toujours dans le cadre de cette idée, pour les stations de traitement, à programmer le lavage des filtres, agitateurs pour la préparation des solutions de produits de traitement en dehors des heures de pointes ainsi le délestage des transformateurs de secours afin d'éviter les pertes actives et réactives à vide même pour les autres installations hydrauliques.

Ce petit geste simple de négociation du contrat d'abonnement (choix du tarif) contribue de façon énergétique à la diminution de cette charge d'exploitation.

3 Le Choix et la révision périodique des PMD (puissances mises à disposition)

A partir des paramètres suivants :

- ✓ du bilan de puissance exhaustif calculé
- ✓ du régime d'exploitation (nombre de pompes à mettre en service et horaire de fonctionnement)
- ✓ de la puissance des transformateurs installés
- ✓ de type de comptage installé (A, B, ou C)
- ✓ du rapport du transformateur de courant (TC[1])

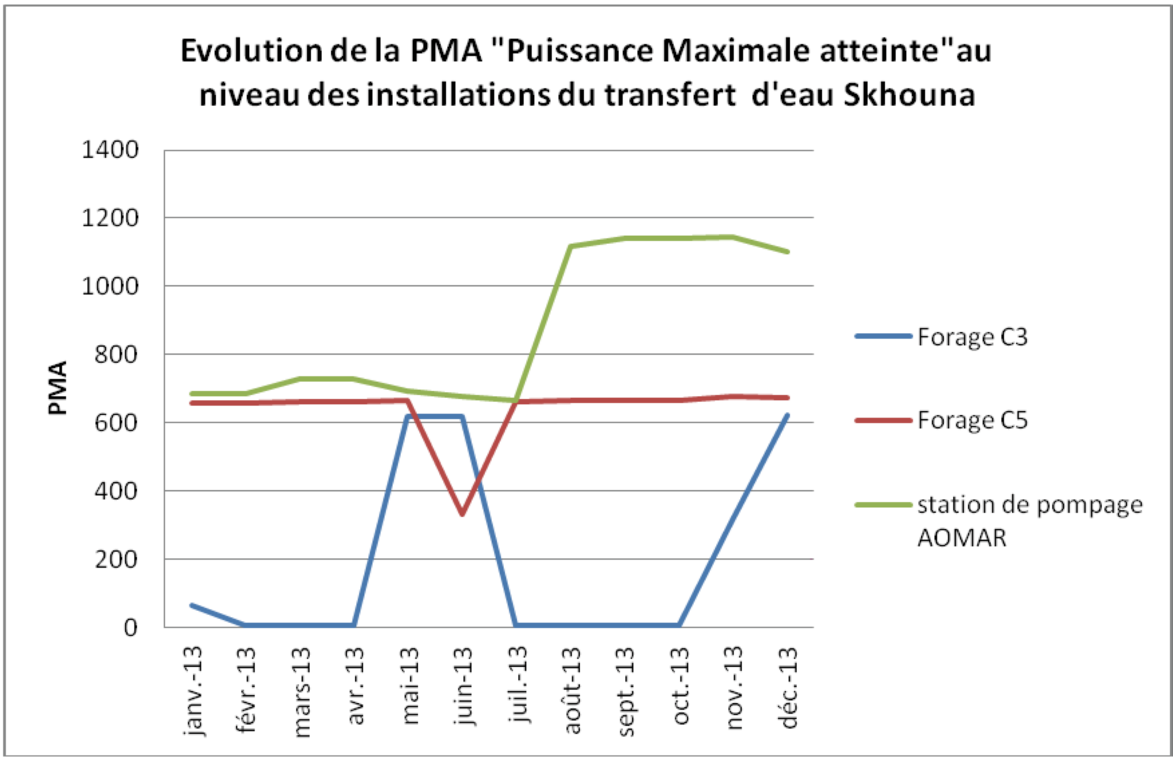
le gestionnaire exploitant choisit et transmit les valeurs des puissances qui seront misent à sa disposition par le fournisseur d'énergie. Ces valeurs normalisées fournies doivent être proches des besoins en puissances exprimés. Pendant le fonctionnement, ces valeurs en aucun cas ne doivent pas être dépassées, si non des pénalités peuvent être retenues au niveau des factures.

Par ailleurs il ya lieu de signaler que cette situation, si elle se répète deux foie, les PMD arrêtées sont revues automatiquement à la hausse sans concertation de l'exploitant ce qui va générer une augmentation des montants des factures des consommations d'énergie.

A titre d'exemple toujours sur le cas du transfert skhouna Trois valeurs de la PMD ont été arrêtées :

Forage C3 =750kW, forage C5 =750kW et station de reprise Ben Omar =1500 KW. C'est ainsi que les puissances maximales atteintes au niveau de ces stations sont au dessous de ces valeurs (voir le graphe ci-dessous).

Cependant sur la période 2003-2005, la PMD au niveau de la station de Ben Omar été 1000 kW suite à la conviction de l'exploitant que cette chaine ne seras pas mis en pleine capacité. A partir de cette date le jugement de l'opérateur à changé et cette PMD à été revue à la hausse ce qui à provoqué une progression des montants des factures (voir le graphe). Cette décision jugée très prématurée par l'exploitant, étant donné que le débit véhiculé demeure inchangé depuis la mise en service à ce jour.



4 Le Suivi et contrôle permanant de la facturation

Mêmes les grandes entreprises peuvent faire des erreurs de facturation, ne pas vérifier les factures peut engendrer des pertes et des surfacturations. Des économies peuvent être réalisées en adoptant un simple contrôle permanent de l'ensemble des éléments constituant les factures :

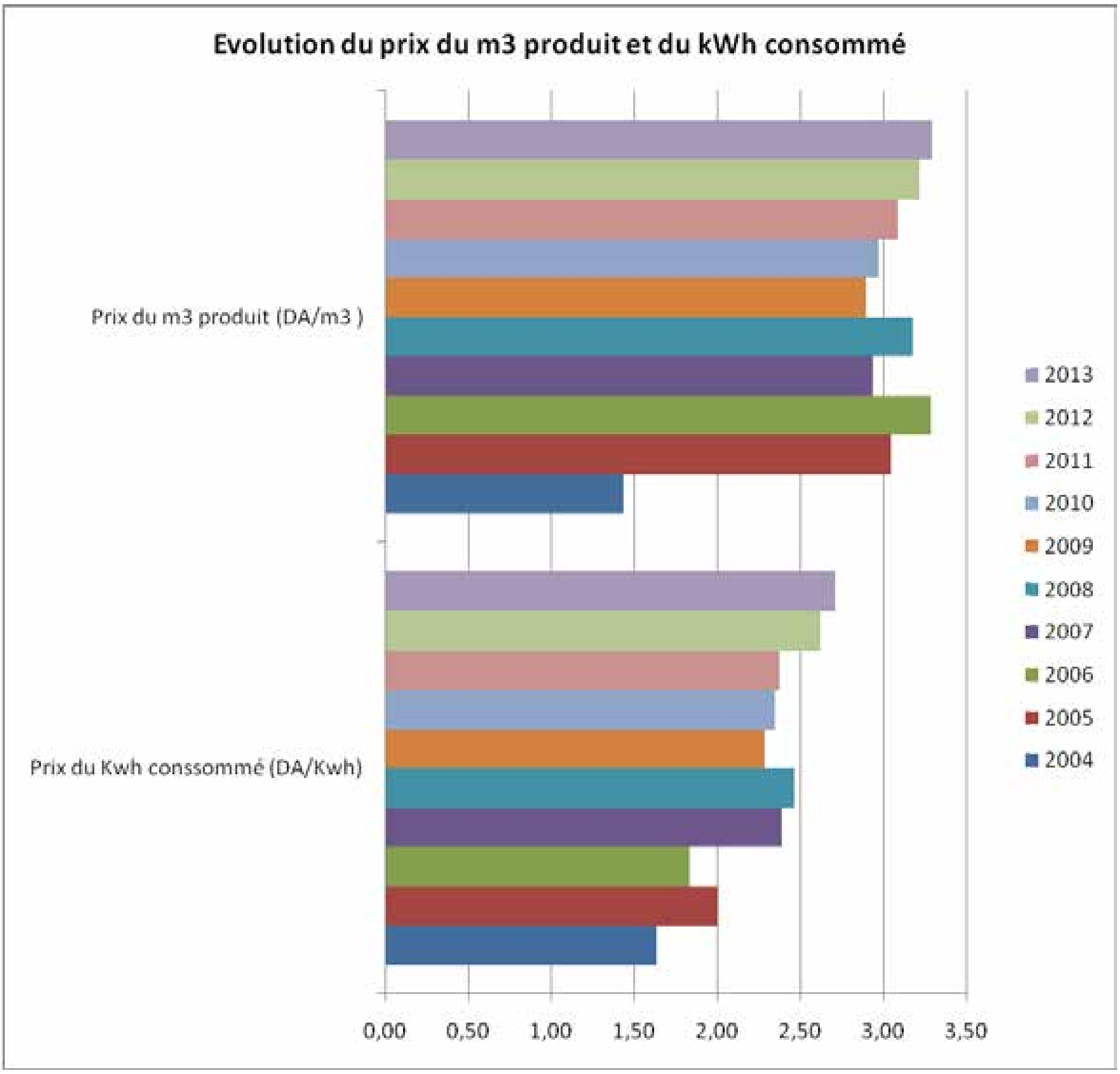
- ✓ Les relevés d'index des compteurs
- ✓ Les valeurs des PMD
- ✓ Les tarifs contractés
- ✓ Arrêt des heures de pointe
- ✓ Facteur de puissance,……..

Car l'expérience a montré que ce contrôle régulier permettre de déceler des anomalies dans certaines factures, qui ont fait l'objet de rejet du payement des montants surfacturés des consommations d'énergie.

Toujours sur l'exemple du cas cité, le contrôle permanant de la facturation sonelgaz de l'énergie de ce dit transfert à permet de détecter certaines anomalies dont quelque factures ont fait l'objet de contestation et de rejet pour des motifs erreurs de relevés (index) et de forfaits. Ce suivi a évité le payement d'une surfacturation de **6 millions DA[1]** sur la période considérée.

Aussi il ya lieu de signaler un contention entre les deux parties qui est en cours à ce jour au niveau de la justice. S'agissant d'un montant de **13 millions de DA[1]** qui à été payé à la sonelgaz1 et qui représente les factures du forage C3 sur une période allant du mois de janvier 2003 jusqu'au mois d'octobre 2007, la date ou l'exploitant à découvert une erreur de paramétrage du poste comptage (Valeur du rapport TC[1]) et ce qui à généré une double facturation au niveau de ce forage contrairement a celui du forage C5 qui abrite les mêmes équipements.

De ce qui précède, il faut noter qu'au regard du volume produit, la facture énergie du transfert semble être satisfaisante. Le prix du kWh consommé et du m3 produit sont au dessous de la moyenne nationale ADE qui sont respectivement de plus de 3.5 DA[1] et 3 DA[1].



5 La Nécessité d’établir des plannings de la maintenance préventive et corrective

Investir dans la maintenance aujourd'hui permettra d'obtenir des avantages financiers très important pendant de nombreuses années. Les actions de maintenance, quelque soit son type ont pour but de réduire les arrêts de production très couteux pour les unités des services des eaux afin de conserver les équipements de production à un niveau équivalent aux performance initiales et aussi remettre en service la chaine en cas de panne. Certes ces actions vont produire des économies d’énergies qui seront traduites en bénéfices.

Gardez les équipements en parfait état de fonctionnement en établissant un calendrier de maintenances contribue de façon remarquable dans la gestion énergétique des installations hydrauliques.

Il est primordial de commencer par évaluer la consommation énergétique existante pour repérer les installations hydrauliques, les équipements qui sont les plus gros consommateurs d’énergie et où il devrait être possible d’améliorer l’efficacité énergétique. Il faut impérativement continuer à surveiller régulièrement la consommation énergétique. Des contrôles quotidiens ou hebdomadaire permettent de déceler une consommation anormale d’où la nécessité d’intervenir et de procéder au renouvellement ou à l’installation d’autres d’équipements plus efficaces avec un rendement élevé. A titre d’exemple nous citons quelques cas les plus identifiants dans le secteur :

- Un Corps de pompe mal aligné consomme l’énergie plus de 2% par rapport à la normale
- Non respect des conditions nominales d’exploitation des installations (point de fonctionnement nominale et point de rendement optimale).
- Des mauvais serrages au niveau des appareils électriques et des raccordements incorrectes des câbleries provoquent une surconsommation qui peut aller jusqu’au 5%.
- Mauvais choix de la section du câble électrique qui peut engendrer une surconsommation plus de 3%
- Mauvais choix du mode démarrage électrique (direct (BT/MT), étoile triangle (BT), démarreur électronique, type sikostart (BT) et Auto-transfo (MT) ainsi que contre vanne ouvert ou contre vanne fermée).
- Acquisition des équipements avec un rendement faible. Notons que ,le coût des moteurs haut rendement n’est pas toujours plus élevé que celui des moteurs standards. La consommation d'électricité des moteurs peut coûter l'équivalent de son prix d'achat rien que le premier mois. Des gains de quelques pourcents sur l'efficacité du moteur peuvent aboutir à des économies substantielles selon les puissances (ces pourcents cités ci-dessous peuvent être réalisés bien sur si on achète des moteurs avec des hauts rendements au lieu des moteurs standards):

  - 5 % d’économie pour les moteurs de 10 kW et moins ;

  - de 2 à 5 % d’économie pour les moteurs de 10 kW à 100 kW ;

  - 1 % d’économie pour les moteurs de plus de 100 kW.
- Renouveler les anciens équipements par d’autres qui consomment moins d’énergie (économique) .ici il faut signaler la nécessité impérieuse dans une première phase, en agissant seulement sur l’éclairage des sites, avec l’utilisation rationnelle de l’éclairage en général, il est possible de réaliser des économies d’énergie substantielles en consentant un très faible investissement qui peut être très rapidement amorti. En effet, l’éclairage dans les locaux à usage administratif et technique étant assuré quasi exclusivement par des lampes à

incandescence et projecteurs classiques qui consomment beaucoup d’énergie électrique, le remplacement (progressif) de ces derniers par des lampes électroniques à basse consommation et des interrupteurs crépusculaires, …doit permettre de réaliser d’importantes économies d’énergie électrique

- Absence de la compensation de l’énergie réactive, qui n’a pas d’utilité énergétique, est facturée par le distributeur d’électricité ; elle est comptabilisée au même titre que l’énergie active par le compteur installé au poste de livraison. Des bonifications importantes au niveau des factures sont accordées à l’exploitant si tel système de compensation existe au niveau des installations. En Algérie Des frais supplémentaires au niveau des factures dus aux majorations sont appliqués par le distributaire d’énergie SONELGAZ[1] suite aux consommations excessives d’énergie réactive (dépassement de 50% de compensation d’énergie réactive par rapport à l’énergie active enregistrée, bonification pour Tg φ[1] <0.5 et Majoration pour Tg φ[1] >0.5).pour cela l’exploitant l’algérienne des eaux « ADE[1] » à demandé à ces unités opérationnelles d’instaurer un programme pour l’installation des batteries de condensateurs qui vont permettre d’améliorer le facteur de puissance Cos φ [1] élevé ou Tg φ[1] faible, étant donné que ces dernières sont amorties au bout de seulement quelques mois.

- Présences des fuites sur les conduites d’adductions (collecteurs d’aspirations et de refoulements) ainsi les débordements des réservoirs et les châteaux d’eau par absence ou défaillance du système de télégestion et d’automatisation.

6 Le recourt à d’autres sources d’énergie (photovoltaïque,…..)

Le recours aux énergies renouvelables permettant de réduire la dépendance envers le réseau qui transporte l’énergie d’origine fossile surtout en période de forte demande et éviter les perturbations de la production de l’eau. Aussi il permet d’effectuer alors une économie financière associée à un gain pour l’environnement.

Profiter des technologies moderne et procéder à la mise en place d’un programme ambitieux qui vise essentiellement une rapide intégration des énergies renouvelables (solaire photovoltaïque et thermique, hydraulique, éolienne, géothermique, biomasse) dont dispose en abondance l’Algérie.

Dans cette démarche, étape par étape, profiter de l’ensoleillement très fort de la région (avec plus de 3 000 heures d’ensoleillement par an), et acquérir des équipements qui fonctionnent avec cette énergie, on opérant par exemple sur l’éclairage des sites hydrauliques, service ment des pompes, fonctionnement des pompes doseuses des produits chimiques, ……..etc. Prévoir cette source d’énergie surtout au niveau de la région Sud du pays constitue une meilleure réponse aux besoins du secteur de l’hydraulique en la matière et les meilleurs gains financiers qui peuvent engrangées l’entreprise de distributeur de l’eau ADE[1] « algérienne des eaux »

Dans ce contexte, un programme national de développement des énergies renouvelables a été tracé pour la période 2011-2030, ambitionnant, à terme, de produire 40% de la consommation nationale d'électricité à partir des filières solaire et éolien. Ainsi, ce programme prévoit l'installation d'une puissance de près de 22 000 MW, avec 12 000 MW destinés à la demande nationale et 10 000 MW à l'exportation.

Il sera mené en trois étapes :

1. la réalisation de projets pilotes pour tester les technologies disponibles (2011-2013),
2. un début du déploiement du programme (2014-2015),
3. enfin, un déploiement à grande échelle (2016-2020).

Il inclut la réalisation d'une soixantaine de centrales solaires photovoltaïques et solaires thermiques, de fermes éoliennes et de centrales hybrides. Actuellement, en accompagnement de ce programme, Sonelgaz1 entreprise nationale oeuvre pour le développement d'une industrie nationale du solaire photovoltaïque avec la construction d'une usine de fabrication de modules photovoltaïques et d'un complexe de fabrication du Silicium.

Et pour rendre encore plus performant ce programme d’introduction des énergies renouvelables, un autre programme national d’efficacité énergétique à été mis en oeuvre.

Le programme d'efficacité énergétique consiste en la réalisation des actions suivantes:

- L’isolation thermique des bâtiments.
- Le développement du chauffe-eau solaire.
- La généralisation de l’utilisation des lampes basse consommation.
- L’introduction de l’efficacité énergétique dans l’éclairage public.
- L’aide à l’introduction de l’efficacité énergétique dans le secteur industriel et les établissements grands consommateurs d’énergie, par la réalisation d’audits et l’aide aux projets d’économie d’énergie.
- L’augmentation de la part de marché du Gaz de pétrole liquéfié carburant et la promotion du Gaz Naturel Carburant la conversion des centrales électriques au cycle combiné quand cela est possible .
- La réalisation de projets pilotes de climatisation au solaire.
- le dessalement des eaux saumâtres.

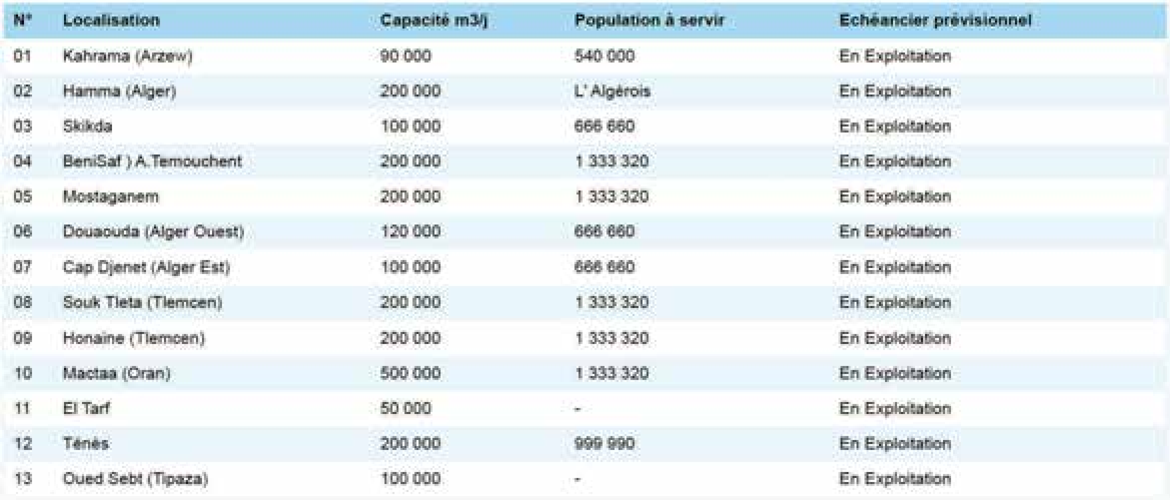
Cette dernière action mérite d'être détaillée étant donné qu’on parle sur l’efficacité énergétique dans le secteur de l’eau.

Le dessalement de l’eau de mer à mis l’Algérie à l’abri du « stress hydrique », il est devenu indispensable pour sécuriser l’alimentation en eau potable des populations des villes côtières et ce compte tenu de la limitation des ressources hydriques Tout d’abord, pour des raisons climatiques : la pluviométrie, irrégulière, oscille entre 100 et 600 mm/an seulement et l’accroissement rapide de la demande en eau dans les secteurs de l’agriculture et de l’industrie.

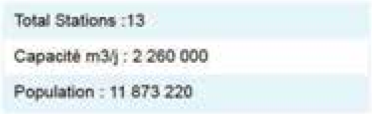
Un programme ambitieux d’installation d’unités de dessalement de l’eau de mer a ainsi été arrêté puis rapidement mis en oeuvre. L’Algérienne des Eaux, entreprise publique, en assure le suivi pour le compte du Ministère des Ressources en Eau en association avec l’Algerian Energy Company,société créée par les groupes Sonatrach[1] et Sonelgaz[1].

A ce titre, 13 stations de dessalement d’eau de mer d’une capacité globale de production de 2,3 millions de m3 par jour (tableau n°1) et 12 stations monoblocs de capacité totale de 57 000 m3/j ont été réalisées (tableau n°2).

Tableau N° 1 : Les grandes stations de dessalement.



N°	Localisation	Capacité m3/j	Population à servir	Echéancier prévisionnel
01	Kahrama (Arzew)	90 000	540 000	En Exploitation
02	Hamma (Alger)	200 000	L' Algérois	En Exploitation
03	Skikda	100 000	666 660	En Exploitation
04	BeniSaf) A.Temouchent	200 000	1 333 320	En Exploitation
05	Mostaganem	200 000	1 333 320	En Exploitation
06	Douaouda (Alger Ouest)	120 000	666 660	En Exploitation
07	Cap Djenet (Alger Est)	100 000	666 660	En Exploitation
08	Souk Tleta (Tlemcen)	200 000	1 333 320	En Exploitation
09	Honaine (Tlemcen)	200 000	1 333 320	En Exploitation
10	Mactaa (Oran)	500 000	1 333 320	En Exploitation
11	El Tarf	50 000	-	En Exploitation
12	Ténès	200 000	999 990	En Exploitation
13	Oued Sebt (Tipaza)	100 000	-	En Exploitation

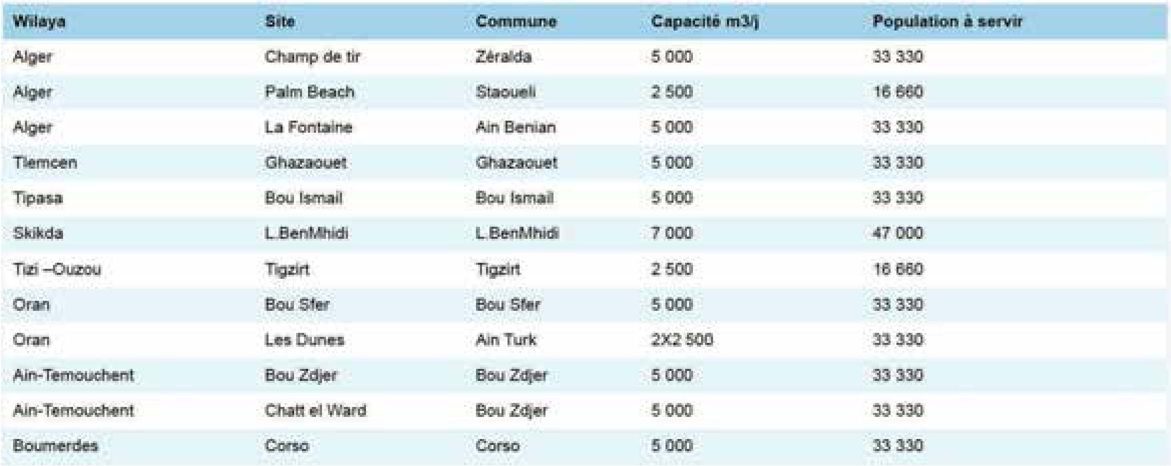


Total Stations :13

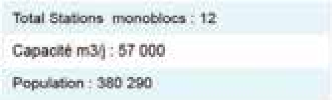
Capacité m3/j : 2 260 000

Population : 11 873 220

Tableau N°2 : Les Stations Monoblocs de dessalement.



Wilaya	Site	Commune	Capacité m3/j	Population à servir
Alger	Champ de tir	Zéralda	5 000	33 330
Alger	Palm Beach	Staoueli	2 500	16 660
Alger	La Fontaine	Ain Benian	5 000	33 330
Tlemcen	Ghazaouet	Ghazaouet	5 000	33 330
Tipasa	Bou Ismail	Bou Ismail	5 000	33 330
Skikda	L.BenMhidi	L.BenMhidi	7 000	47 000
Tizi –Ouzou	Tigzirt	Tigzirt	2 500	16 660
Oran	Bou Sfer	Bou Sfer	5 000	33 330
Oran	Les Dunes	Ain Turk	2X2 500	33 330
Ain-Temouchent	Bou Zdjer	Bou Zdjer	5 000	33 330
Ain-Temouchent	Chatt el Ward	Bou Zdjer	5 000	33 330
Boumerdes	Corso	Corso	5 000	33 330



Total Stations monoblocs : 12

Capacité m3/j : 57 000

Population : 380 290

7 L'Adoption des simples gestes

Rappeler ci après au personnel des entreprises du secteur des petits gestes malins et des comportements simples a adopter au quotidien et qui vont participer à modérer avec plus d'attention nos consommations d'énergies et alléger les montants des facteurs ont les maintenir au plus bas niveau possible :

- Éteindre la lumière en sortant de son bureau, d'une salle de réunion ou des sanitaires.
- En cas d'absence prolongée, éteindre l'ordinateur mais aussi l'imprimante et la télévision.
- Il ne suffit pas de les mettre en veille : ces appareils doivent être complètement éteints.
- Un moyen pratique pour cela : éteindre d'abord l'unité centrale, puis la prise multifonctions à laquelle ces appareils sont raccordés si cette prise dispose d'un interrupteur.
- Saviez vous que... ? le poste bureautique d'un salarié consomme autant que 5 réfrigérateurs domestiques ? Alors choisissons du matériel performant : un écran LCD consomme 1.5 fois moins qu'un écran cathodique ; et l'utilisation du mode veille d'un PC le fait consommer plus de 2 fois moins !
- Sur l'ordinateur… … je paramètre les mises en veille de mon PC
- Utiliser son thermostat si le bureau en dispose pour réguler la température ambiante.
- Passer de 20 à 19°C permet d'économiser 7% de l'énergie. Eviter 10 minutes d'éclairage inutile 3 fois par jour, c'est économiser l'équivalent de 5 jours d'éclairage en continu au bout d'un an. Le saviez-vous ?
- Régler la température des climatiseurs sur 25°C.
- Ne pas laisser un chargeur (de téléphone portable ou d'ordinateur portable) branché sur secteur, alors même que l'appareil dont il convient de recharger la batterie n'est pas connecté. En effet le chargeur, même non relié à un appareil, consomme de l'énergie !
- Ne pas couvrir son radiateur avec des dossiers ou autres objets.
- Ne pas laisser le chauffage allumé alors que la fenêtre est ouverte. Le conseil peut paraître évident mais…
- Lorsque cela est possible, utiliser l'escalier de préférence à l'ascenseur. Au démarrage, un ascenseur a une intensité équivalente à 800 ampoules de 100 watts (Soit 400 ampères).

Conclusion:

Aujourd'hui, la maîtrise des coûts et la continuité de service publique de l'eau sont des facteurs clés pour déterminer le succès de certaines entreprises par rapport à d'autres.

Pour atteindre ces objectifs, il faut en savoir plus sur le fonctionnement des installations et infrastructures hydrauliques.

Parmi les dépenses importantes liées aux charges d'exploitation après les salaires du personnel sont les consommations d'énergies, c'est pourquoi il faut instaurer une politique énergétique qui vise à réduire autant que possible ces frais.

L'entreprise du secteur de l'eau qui va réussir dans ce domaine, et pourra prétendre à l'exemplarité que si elle adopte des pratiques d'économie en agissant sur les items déjà cités.

Commencer par évaluer la consommation énergétique existante pour repérer les sites et les installations qui sont les plus gros consommateurs d'énergie et où il devrait être possible d'améliorer l'efficacité énergétique.

Effectuer des contrôles et un entretien réguliers de toutes les machines de manière à en optimiser le fonctionnement. Moderniser les installations techniques anciennes peu performantes ou les remplacer par des technologies plus récentes.

La majorité des économies peut être réalisée en regardant (contrôle simple) une facture d'électricité.

Une économie additionnelle peut être réalisée pour une meilleure utilisation de l'équipement et en évitant les achats importants et inutiles.

Encore un autre pourcentage peut être trouvé en améliorant la fiabilité et donc la disponibilité (continuité) du système d'alimentation (Points de production) par l'intégration d'autres sources comme les énergies renouvelables notamment le photovoltaiilique.

Et en fin, Ce travail entre dans le cadre de la quantification du gisement d'économie d'énergie électrique existant potentiellement au niveau du secteur hydraulique en Algérie.

Des travaux futurs viendront compléter ce guide de bonnes pratiques des économies d'énergie dans le service publique de l'eau en prenant en compte l'intégration des énergies renouvelables, notamment le solaire, pour agir directement sur la baisse des besoins énergétiques globaux du secteur .

Nous espérons que cette communication à restituer toute la richesse des expériences vécue dans ce domaine et espérons quelle offriras une vision plus large des principaux enjeux et défis rencontrés.

Bibliographie

[1] Article de journal Liberté Écrit par Dr Abderrahmane Mebtoul le 05/06/2013 "l'Algérie visage à la transition énergétique"

[2] Séminaire sur l'Économie d'énergie dans Le service public de l'eau Organisé par l'entreprise l'ADE "Algérienne des Eaux" sous le parrainage de Monsieur le Ministre des ressources en eau "en date du 07/07/2013 Hôtel Hilton / Algerie

[3] Discour du Directeur Général de la Sonelgaz /société algérienne de l'Energie , Lundi 23 juin 2014, Auditorium IFEG – Ben Aknoun-Alger

[4] Bilan d'activités de l'entreprise l'ADE "Algérienne des Eaux"

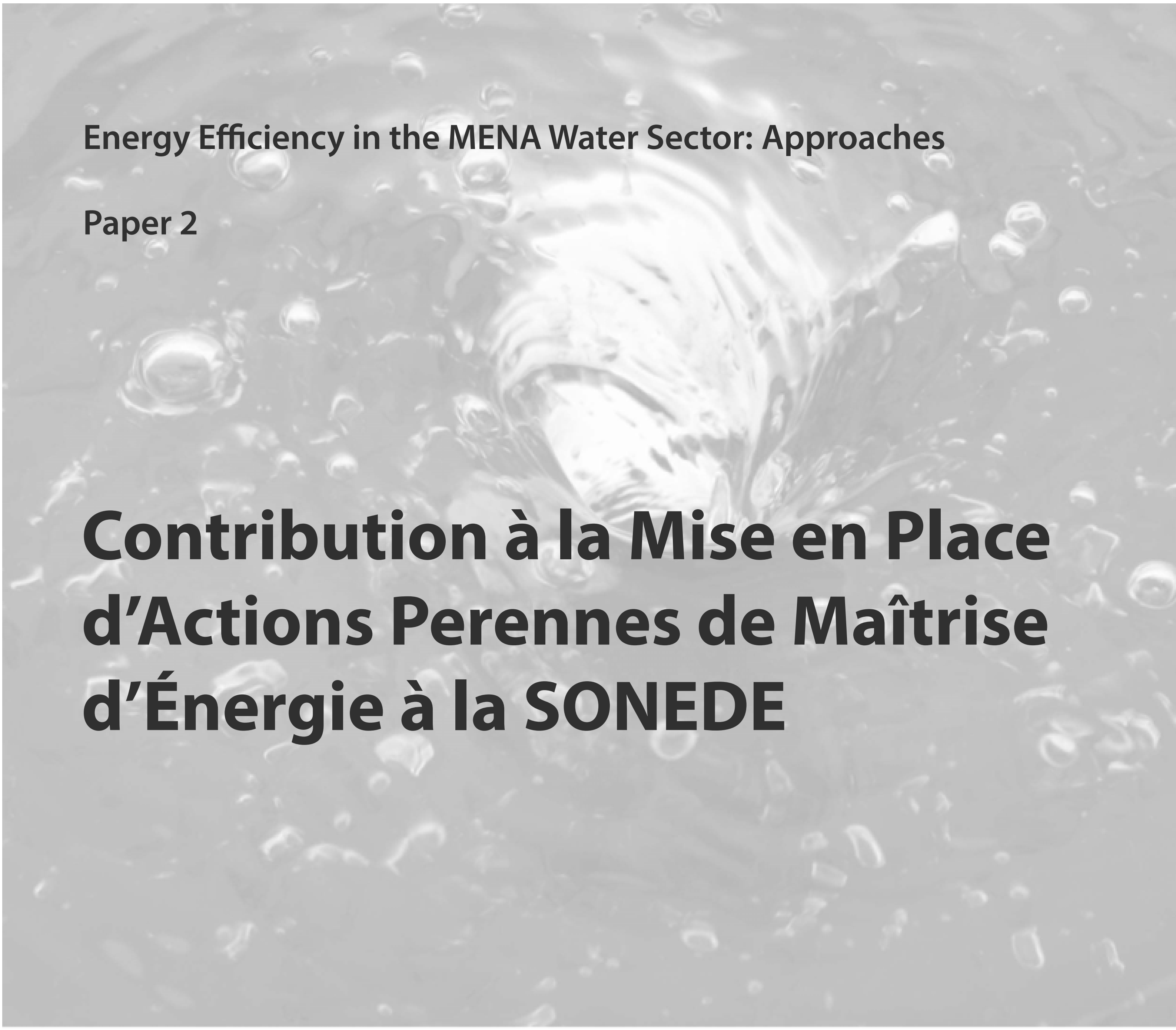
[5] Rapport AEP ville de Saida établit par l'ADE Zone Saida

[6] WWW.mre.dz Ministère Algérien des ressources en Eau

[7] WWW.ade.dz Algérienne des eaux « ADE » entreprise algérienne de distribution de l'eau

[8] WWW.sonelgaz.dz Entreprise algérienne de distribution de l'énergie

[9] WWW.portail.cder.dz Portail Algérien des ENERGIES RENOUVELABLES



Energy Efficiency in the MENA Water Sector: Approaches

Paper 2

Contribution à la Mise en Place d’Actions Perennes de Maîtrise d’Énergie à la SONEDE

Fait par :
Khaled Zaabar, Chef de la Division Maîtrise de l’Énergie Électrique SONEDE

ACWUA
Arab Countries Water
Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german
cooperation
DEUTSCHE ZUSAMMENARBEIT
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Abstract

CONTRIBUTION TO THE IMPLEMENTATION OF PERENNIAL ACTIONS ON ENERGY EFFICIENCY IN SONEDE

by KHALED ZAABAR

The mission of the National Company for Exploitation and Distribution of Water (SONEDE) is to supply drinking water on the whole country. SONEDE has worked for decades to achieve, extension and maintenance of a complex and diverse water infrastructure covering the whole country. This perspective has achieved a coverage rate of 100% in urban areas and 94% in rural areas. This gigantic infrastructure requires high energy consumption to ensure the production transfer and distribution of water, placing SONEDE as one of the largest consumers of energy in Tunisia. Indeed its consumption reached in 2014, 28 million euros, representing 24% of turnover of the company. This consumption is divided as follows:

- 370 GWh of electricity for an amount of € 27 million,
- 2 Ktep of fuels for 1 Million €.

Being aware of the stakes of energy costs in its financial balance, SONEDE conducted since 1998 several actions to control energy costs, mainly through:

- a judicious choice of electricity pricing and optimization of pumping according to the hourly price of electricity,
- strengthening energy diagnostics operations,
- Strengthening the energy component in the choice of feeding method in drinking water,
- improving the energy performance of several pumping stations and desalination plants,
- the realization of the largest photovoltaic plant in Tunisia (212kWc) in the desalination plant of Ben Guerden (inaugurated in June 2013),
- The establishment of a GPS tracking system for 450 vehicles,
- continuous training of SONEDE agents on energy efficiency.

In this article I will develop the methodology that led to the relative success of the energy control program. I will also present the results obtained for some actions.

ACTION 1: optimization of electricity contracts and operation of pumping stations taking into account the hourly electricity pricing

In 1998, the energy costs represented 9% of revenue SONEDE which already implied a relatively large load. However monitoring of electricity bills, programming the operation of pumping equipment and the choice of electricity contracts are modest and not optimized. I therefore objectified through a series of analyzes that there was significant potential for saving on the cost of purchasing electricity through small investments but require greater mobilization of stakeholders. So I started an energy efficiency program in 1300 stations SONEDE through the following steps:

- Collect all the technical information on the pumping complex,
- conduct energy audits of several major stations,
- discuss with stakeholders to identify the system operating constraints and determine the optimization boundary conditions
- make the necessary simulations and define appropriate management rules

- Conduct meetings with top officials, technical staffs and operational staffs of the 50 districts of SONEDE to present the studies and take decisions and necessary measures to implement the proposed program,
- monitor the implementation of the program (installation of pumping offloading systems, new equipment for pumping, automatic control, updating of electricity contracts, installation of capacitor banks, ...)
- check the results and make adjustments to improve or correct the guidelines of pumping,
- improve the working methods and techniques adopted through the experience feedback.

The steps outlined above are repeated each year following the PDCA model in Figure No. 4, which helped to achieve significant savings on energy costs during the period 1999-2014. The results obtained are presented in chapter III.4 of the article.

This first great action induced the outbreak of a sustainable energy control program that SONEDE has gradually enriched through the experiences acquired during several years. The creation of central structures for the control of energy was the direct consequence of the economic and political opportunity provided by the energy control component in this large public company.

ACTION 2: optimization of energy cost in the isolated and autonomous sites short-term forecasting of water supply

The pricing of electricity set by STEG (Tunisian Company of Electricity and Gas) is based on the Schedule "DAY and NIGHT TIP". As the price of electricity is more expensive during peak periods of the day and it is therefore necessary to promote the pumping outside these periods mainly the peak period, while considering the water storage capacity and flow equipment.

This chapter presents the design and construction of an electronic card for optimization of the operation of pumping station according to the timetable posts costs. The work consists of three parts:

- Develop a simplified model for forecasting daily water distribution: (. Computation time, memory, mathematical operators, precision, autonomy of decision ...) choose the best forecasting method suitable for an embedded system and determine a mathematical model ,
- determine a control strategy to manage and optimize load shedding of pumping water into a reservoir taking into account the capacity of the latter, the forecast of water consumption, and operational limits and safety conditions
- design and implement a control board suitable for the model chosen, primarily processor speed, memory capacity, the number of analog or digital inputs essential to the operation of the optimization algorithm such as flow and level Water logic inputs and outputs. This device must provide other specific options as the stop time display and saving data captured through sensors (voltage, current, temperature, suction flow rates, flow discharge ...). The card will allow to manage and optimize the operation of pumping equipment taking into account pricing schedules positions. It will also include a portion for acquiring real-time data from the pumping station and reservoir.

The advantage of this system also lies in simplifying the optimization method and reducing the cost of hardware and software necessary for such applications.

ACTION 3: study of the advisability of switching from the 3 posts tariffs to the 4 posts tariffs

The 4 posts tariffs adopted by STEG in 2001 to replace the one at 3 posts, given the change in the structure of demand and the emergence of a new morning peak electricity during the summer due to the business and industrial customers to boost the use of air conditioning.

SONEDE estimated in 2001 Following this study, the transition to 4 posts tariffs will be binding for economic management point of view of equipment operation and lead to an increase in electricity bills by 5%. After negotiations, SONEDE agreed with STEG and the Ministry of Industry (responsible for energy) to grant him a special rate called the pumping of water pricing to 3 posts tariffs.

However this new pricing saw the schedule change boundaries and tariff schedules its positions from 2006 resulting in renewed interest, as estimated in this study, for its use to SONEDE. That is why it has agreed with STEG and the Ministry of Industry in 2011 to adopt the pricing to 4 posts tariffs from 1 January 2014 for SONEDE. Indeed, the present study demonstrated a gain of 4% (€ 1 million per year) can be expected after this passage, especially with the improvement of means of control and equipment management.

The difficulty lies in estimating the future distribution of energy consumption on the 4 posts tariffs from the billing data of the 3 posts tariffs.

It should be noted that the methodology adopted in this study was similar to the calculations made in 2001 and 2011. Only rates and hourly positions boundaries of the 4 posts tariffs have changed.

In this chapter I will detail the SONEDE study leading to the adoption of pricing to 4 positions from 01 January 2014.

It is noteworthy that after a year of operation of this new 4 posts tariffs and analyzing utility bills of 2014, we observe a gain (€ 1 million per year) this which corresponds to a 3% difference between the estimated value of the gain in this study and the one carried out.

CONCLUSION

The success and sustainability of these actions during the last 16 years were provided by the coordination, technical assistance and dialogue among stakeholders, especially by direct contact through meetings, seminars, periodic training.

However, although the actions presented in this article have allowed to reduce energy costs, these latter remain relatively high compared to revenues of SONEDE. This is explained in part by the low rate of increase in the water tariff compared to that of electricity. In addition, there were constraints to promote energy management programs, in effect:

- the regulatory framework of incentives for actions to control energy was not mature enough
- national expertise in the field of energy control at the level of the drinking water sector, do not have to give an additional contribution to the existing program of SONEDE
- International cooperation and partnership program were underdeveloped
- technologies for energy efficiencies adapted to the drinking water sector were costly and not mature.
- The energy prices were relatively low and do not promote the development of such projects

In addition to the above difficulties, the future projections of changes in costs of energy are worrying given the rapid and sustained increase in energy prices, and given the trend of increasing energy consumption, following the growth of economic activity and population and the obligation to improve the coverage rate of drinking water (in rural areas) require the extension of the pumping and distribution network and connecting inaccessible areas.

Indeed, SONEDE is obliged to have recourse to high energy solution for pumping and water production to preserve the balance between supply and demand for water in the future. Future projects will mainly concern the mobilization of all available resources, strengthening of water transfers from North to South, and the use of non-conventional resources such as desalination of brackish water and seawater.

Faced with this situation and these prospects inducing high energy cost that weigh increasingly on the cost of water and with an energy prices persistently high and volatile, SONEDE has established, in parallel to efforts saving water, an energy strategy. For this purpose a master energy plan for the period 2012-2030 to:

- limit the specific consumption (Wh / m3) to 85% of its estimated value in a normal evolution scenario for 2030,
- integrate renewable energy up to 30% of the total energy consumption in 2030 (objective of the Tunisian government)
- further optimize the pumping of water taking into account the tariff of electricity positions costs, with a goal to reduce the purchase price per kWh by 10% by 2018 (based on constant price of the year 2012),
- reduce fuel consumption by 20% by 2016,
- establish by 2017 an energy management system according to ISO 50001.

To help ensure the sustainability of the energy control program to SONEDE, a working team of young and motivated multidisciplinary engineers, was established at central and regional level. This team attend periodically high-level training in the field of energy management provided mainly by ANME (National Energy Control Agency), STEG (Tunisian Company of Electricity and Gas) and GIZ (German International Cooperation Agency).

ABREVIATION

GIZ :	Gesellschaft für Internationale Zusammenarbeit (Agence Allemande de Coopération Internationale).
ANME :	Agence Nationale de Maitrise d’énergie.
SONEDE :	Société Nationale d’Exploitation et de Distribution des Eaux.
STEG :	Société Tunisienne de l’Electricité et du Gaz.
CSEE:	Commission Spéciale pour l’Economie d’Energie.
UPSE :	Unité de Programmation et de Suivi Energétique.
DME :	Direction de maîtrise d’énergie.
GMAO :	Gestion de la Maintenance assistée par ordinateur.
DT :	Dinars Tunisien (1 € = 2,3 DT).
MW :	Méga Watt.
GWh :	Giga Watt-heure , 1 GWh= 1 million de KWh (Kilo Watt-heure)
HT :	Hors Taxes.
kTep :	kilo Tonne équivalent pétrole, c’est une unité servant, dans les bilans énergétiques, pour comparer les sources d'énergie au pétrole brut, pris comme référence. (Selon les estimations, une tonne de pétrole équivaut à environ 1,3 à 1,4 t de charbon, 1 000 m3 de gaz naturel et 11 250 kWh thermique).
MT :	Moyenne Tension.
BT :	basse tension.
TPH :	tarification à postes horaires.
TU :	tarification à poste unique ou tarification uniforme.

SOMMAIRE

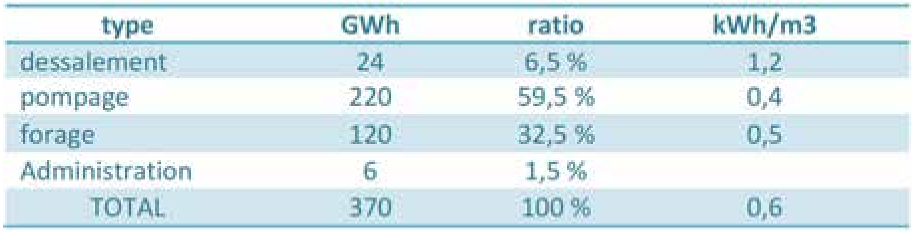
1 INTRODUCTION GÉNERALE

La Société Nationale d'Exploitation et de Distribution des Eaux (SONEDE) a pour objet l'approvisionnement en eau potable sur tout le territoire tunisien. La SONEDE a oeuvré durant des décennies pour la réalisation, l’extension et le maintien d’une infrastructure hydraulique complexe et diversifiée couvrant la totalité du pays. Cette perspective a permis d’atteindre un taux de desserte de 100% en milieu urbain et de 94 % en milieu rural. Cette gigantesque infrastructure nécessite une grande consommation d’énergie pour assurer la production le transfert et la distribution d’eau, ce qui place la SONEDE comme l’un des plus grands consommateurs d’énergie en Tunisie. En effet sa consommation a atteint, en 2014, 370 GWh d’électricité soit l’équivalent de 28 Millions d’euros, ce qui représente 24% du chiffre d’affaires de la société. Cette consommation est répartie comme suit:

- 370 GWh d’électricité (98kTep primaire) pour un montant de 27 Millions €,
- 2 kTep de carburants pour un montant de 1 Millions de €.

La majorité de cette consommation est destinée pour la production et le transfert d’eau comme le montre le tableau suivant:

Tableau N°1 : répartition de la consommation d’énergie électrique par type d’utilisation



type	GWh	ratio	kWh/m3
dessalement	24	6,5 %	1,2
pompage	220	59,5 %	0,4
forage	120	32,5 %	0,5
Administration	6	1,5 %	
TOTAL	370	100 %	0,6

Etant consciente des enjeux des coûts d’énergie dans son équilibre financier, la SONEDE a réalisé depuis 1998 plusieurs actions visant des frais énergétiques sur l’ensemble de ses stations de pompage et de production d’eau, essentiellement à travers :

- le choix judicieux des contrats de fourniture d’électricité en fonction des tarifs préférentiels de la STEG,
- l’optimisation du pompage en fonction des coûts des postes horaires de tarification de l’électricité,
- l’amélioration du facteur de puissance,
- l’amélioration des programmes de maintenance (affiner le programme préventif suivant les conditions de fonctionnement et consolider les opérations de diagnostics techniques),
- le renforcement des opérations de diagnostics techniques,
- l’acquisition d’équipements de plus en plus performants,
- le renforcement de la composante énergétique dans le choix du mode d’alimentation en eau potable
- le contrôle et le suivi des véhicules
- la sensibilisation et la formation continues et ciblées de son personnel sur les techniques de maîtrise d’énergie.

Ces actions ont permis d’obtenir des résultats substantiels essentiellement en maitrisant le coût d’achat de l’électricité à une valeur inférieure à la moyenne du prix de vente aux clients MT de la STEG.

En plus, et pour palier à l'augmentation des prix d'énergie notée depuis 2004, j'ai développé d'autres projets dans le domaine de l'efficacité énergétique et des énergies renouvelables (les audits énergétiques, les variateurs de vitesses, le photovoltaïque, l'éolien, la mini-hydroélectricité,…) et oeuvré pour développer la coopération technique surtout avec la GIZ et l'ANME (Agence Nationale de Maîtrise d'Energie).

La réussite et la durabilité de ces actions durant les 16 dernières années ont été assurées par la coordination et le dialogue entre les parties prenantes, surtout par le contact direct à travers des réunions des rencontres des séminaires et des formations périodiques, l'assistance technique, les événements sportifs de la SONEDE (j'étais président d'une association sport et travail à la SONEDE et j'organisais fréquemment des tournois de football pour environ 200 personnes. Je profitais de ces occasions pour diffuser les bonnes pratiques sur la maîtrise d'énergie dans un environnement sportif destiné vers une majorité des agents impliqués directement dans le programme de maîtrise d'énergie).

J'ai aussi constitué une équipe de travail de jeunes ingénieurs multidisciplinaires et très motivés, et j'ai oeuvré pour que ce groupe puisse assister à des formations périodiques de haut niveau assurées surtout par l'ANME, la STEG (Société Tunisienne de l'électricité et du Gaz) et la GIZ pour garantir la pérennité du projet de maîtrise d'énergie.

Dans cet article je vais développer la méthodologie utilisée qui a conduit à la réussite relative de ce programme de maîtrise d'énergie. Je vais aussi présenter les résultats obtenus.

2 METHODOLOGIE DE TRAVAIL DE 1998 A 2014

INTRODUCTION

En 1998, Les frais énergétiques représentaient 9% du chiffre d'affaires de la SONEDE ce qui impliquait déjà une charge relativement importante. Cependant le suivi des factures d'électricité, la programmation du fonctionnement des équipements de pompage et le choix des contrats d'électricité sont modestes et non optimisés. J'ai objectivé donc à travers une série d'analyses qu'il y avait un potentiel important d'économie sur les frais énergétiques moyennant de petits investissements mais nécessitant une grande mobilisation des parties prenantes. J'ai aussi tôt convaincu mon hiérarchie d'entamer un programme d'efficacité énergétique dans les 1300 stations de la SONEDE et je suis passé aux étapes suivantes :

- préparer la méthodologie de travail et la technique d'optimisation,
- collecter toutes les données nécessaires pour l'étude,
- effectuer des diagnostics énergétiques de plusieurs stations importantes (350 stations),
- écouter et discuter avec les différents intervenants (les gardiens pompistes, les maintenanciers, les chefs secteurs, les ingénieurs d'études, et les responsables..) concernant les contraintes d'exploitation
- préparer les études et les simulations,
- effectuer des réunions avec les premiers responsables, les staffs techniques et les staffs d'exploitation les 50 districts de la SONEDE pour présenter les études et prendre les décisions et les dispositions nécessaires pour l'application du programme énergétique,
- suivre l'exécution du programme (installation des équipements de délestage du pompage, des nouveaux équipements de pompages, de régulation automatique et des vanne motorisées, mise à jour des contrats d'électricité, installation des batteries de condensateurs, ...),

- vérifier les résultats obtenus et effectuer les ajustements nécessaires pour améliorer ou pour corriger les consignes de gestion du pompage,
- améliorer les méthodes de travail et les techniques adoptées à travers les retours d’expériences.

Les étapes présentées ci-haut sont répétées chaque année, ce qui a permis de réaliser d’importantes économies des frais énergétiques durant la période 1999-2014.

Le présent chapitre a pour objet donc de décrire la méthodologie de travail.

Cette première grande action a induit le déclanchement d’un programme de maîtrise d’énergie durable à la SONEDE qui s’est enrichi progressivement à travers les expériences acquises durant plusieurs années. La création de structures centrales pour la maîtrise d’énergie était la conséquence directe de l’intérêt économique et politique que présentait le volet maîtrise de l’énergie dans cette grande entreprise publique.

II. MISE EN PLACE DE STRUCTURES CENTRALES RESPONSABLES DE LA MAITRISE D’ENERGIE

II.1 mise en place d’une commission spéciale pour l’économie d’énergie et d’une unité de programmation et de suivi d’énergie en 1999

Le 01/11/1999 une commission spéciale pour l’économie d’énergie (CSEE) a été créée pour la mise en place d’une politique énergétique et d’un programme de maîtrise d’énergie à la SONEDE par :

- L’élaboration d’une stratégie énergétique à la SONEDE.
- La prise des décisions d’ordre stratégique dans le domaine d’énergie.

Une unité de programmation et de suivi énergétique (UPSE) a également été créée et rattachée à la CSEE assurant les rôles suivants :

- L’orientation des exploitants dans le choix des programmes d’actions, visant la réduction des frais énergétiques.
- La supervision des audits énergétiques externes et internes.
- Le contrôle des consommations d’énergie des différentes unités consommatrices.
- L’organisation de tables de discussion à l’échelle régionale et nationale sur la maîtrise d’énergie à la SONEDE.
- La préparation des différents rapports SONEDE sur l’énergie.

En tant que coordinateur principal de la CSEE et chef de la UPSE j’ai procédé alors au diagnostic des mécanismes existants de suivi des consommations électriques et de carburants, des procédures de vérification et de payement des factures d’énergie, des cahiers de charge d’achats des équipements, j’ai également mis en place un plan de travail et j’ai proposé une stratégie pour la période 2000-2015 tenant compte de la législation Tunisienne, des normes internationales, des projections de production et de distribution d’eau potable, des orientations énergétiques de la Tunisie, du système de facturation des énergies ainsi que des évolutions technologiques. Cette stratégie repose sur sept axes :

1 L’économie d’énergie électrique

- Le choix judicieux des équipements consommateurs d’énergie
- Le choix convenable des modes d’alimentation et de distribution des eaux
- L’utilisation des technologies visant la réduction de la consommation d’énergie surtout dans le domaine du pompage et du dessalement des eaux.
- L’amélioration des programmes d’entretien préventif.

2- La réduction des frais d’énergie électrique

- L'orientation du choix des types des contrats de fourniture d'énergie électrique
- L'orientation du choix du mode de fonctionnement économique en tenant compte des possibilités du transfert des consommations d'énergie des tranches horaires les plus coûteuses vers les moins coûteuses.
- La généralisation des nouvelles technologies visant la gestion optimale d'énergie surtout dans le domaine du pompage (télégestion, régulation intelligente).

   3- l'introduction des énergies renouvelables

   4- La mise en place d'un système d'information pour l'amélioration des procédures de suivi des consommations et de payement des factures d'énergie.

   5- La mise à jour des directives concernant le suivi et le payement des factures d'énergie.

   6- La préparation d'un programme complet de formation visant l'application du plan énergétique de la SONEDE.

   7- L'économie des carburants

- La mise en place d'un système de suivi par satellite de la flotte de véhicules
- La mise en place d'une application GMAO pour le matériel roulant
- Le renforcement des critères de choix des performances énergétiques lors de l'acquisition du matériel roulant

II.2 Création de la Direction de maîtrise de l'énergie en 2007

A partir de 2007 une Direction de maîtrise d'énergie (DME) a été créée au sein de la SONEDE et a été rattachée directement à la Direction Générale. Elle assurera désormais toutes les tâches de la CSEE et de la UPSE. Elle sera la locomotive de l'application et du développement de la stratégie énergétique de la SONEDE.

III. ACTION 1 : optimisation des contrats d'électricité et du fonctionnement des stations de pompage tenant compte de la tarification horaire de l'électricité

Pour réduire les charges d'exploitation et programmer la marche des stations au moindre coût, la composante tarification d'électricité a été particulièrement étudiée et analysée pour aboutir aux résultats les plus économiques, et ce, compte tenu du régime de fonctionnement de chaque station de pompage, selon les saisons et en fonction de la capacité des réservoirs de distribution et du nombre de points d'eau.

J'ai donc mené une étude approfondie pour l'ensemble des stations de pompage alimentées en moyenne tension (M.T). Cette étude est répartie en deux grandes étapes :

- Analyse des factures et étude des pénalités de dépassement de la puissance souscrite, des pénalités sur le facteur de puissance (cos j) et des anomalies des factures STEG.
- Adoption d'une méthodologie pour la révision des contrats STEG en vue de profiter au maximum des différents tarifs M.T en satisfaisant plusieurs contraintes (les besoins en consommation d'eau des abonnés, les capacités des réservoirs liées à ces stations, la régulation, les contraintes hydrauliques…).

III.1 Révision des contrats d’électricité

Lors du dépouillement des factures STEG et des fiches de fonctionnement des stations de pompage, j’ai constaté que la gestion du fonctionnement des stations n'est pas assurée en prenant en considération le tarif d’électricité MT le plus avantageux. En effet :

- Les stations de pompage qui sont en mode de régulation automatique continuent à fonctionner durant la période tarifaire de pointe d’électricité, bien que leur fonctionnement ne soit pas nécessaire durant cette période (réserve d’eau suffisante).
- Des stations souscrites en tranche unique alors que le fonctionnement à poste horaire est beaucoup plus avantageux.

En conséquence, j’ai démarré un programme visant l’optimisation des coûts de l’énergie, essentiellement en procédant au changement de plusieurs contrats d’électricité et en installant des automatismes de délestages.

III.1.1 Choix du type de tarification d’électricité

Cette étude concerne seulement les stations bénéficiant de la tarification MT. En effet 97% de la consommation d’énergie de la SONEDE est facturée sur la tarification moyenne tension.

Nous présentons à droite (Figure N°1) le schéma technique de la facturation de l’électricité en MT avec comptage BT. Il est à remarquer que dans le cas d’un comptage MT, les pertes en charge et les pertes à vide sont enregistrées directement par le compteur d’électricité.

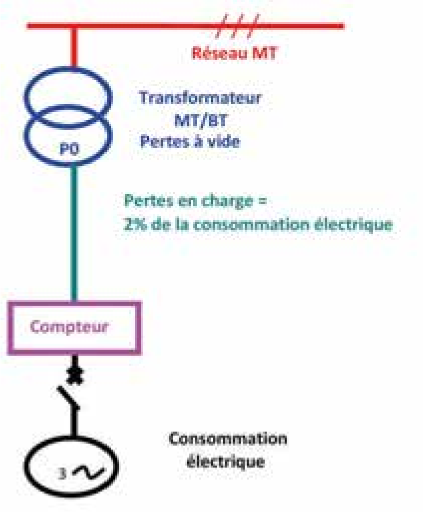
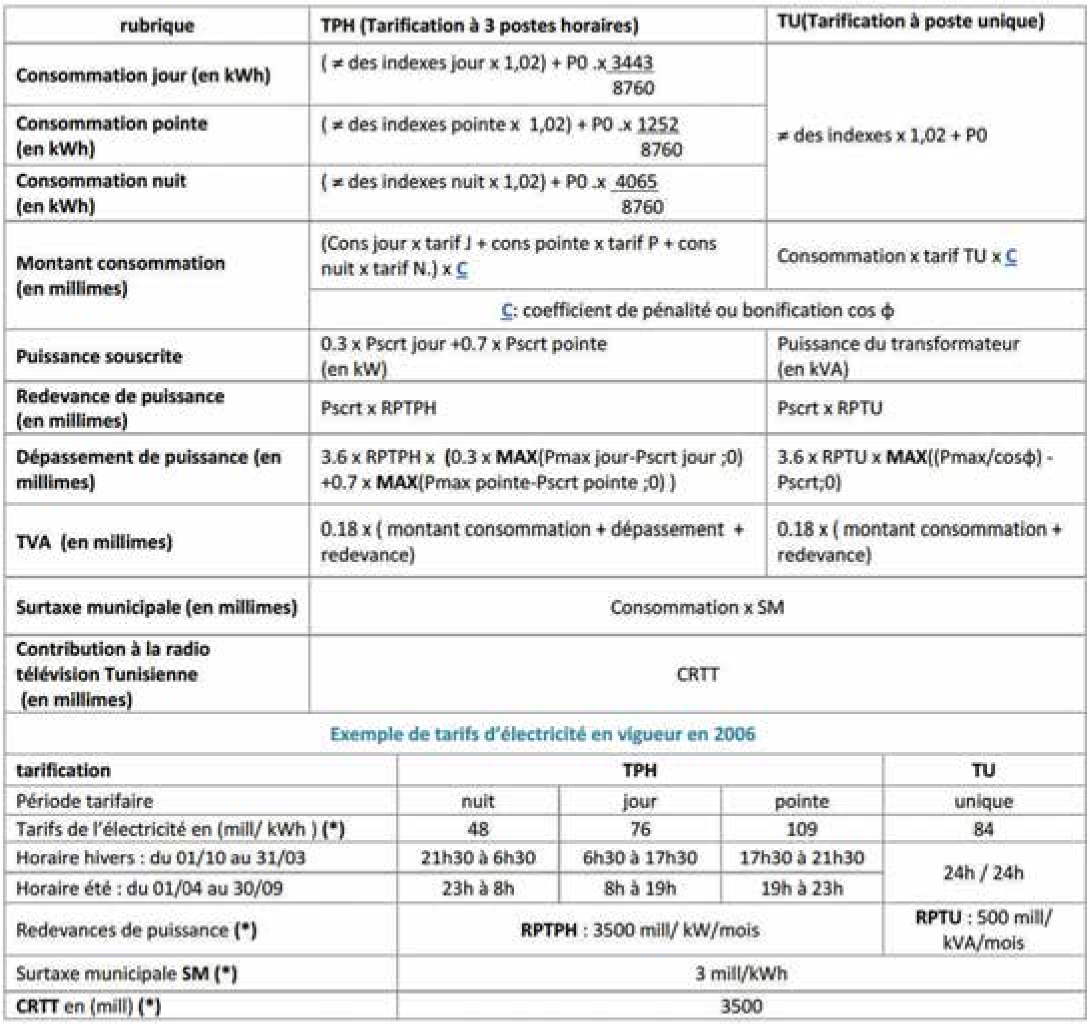


Figure N°1 schéma technique de la facturation de l’électricité en MT

Choix entre le tarif à poste horaire (TPH) et le tarif à tranche unique (TU):

Le tableau ci-dessous présente les deux modes de tarification au choix pour les stations raccordées au réseau STEG MT :

Tableau N°2 : tableau des éléments de facturation en MT



rubrique	TPH (Tarification à 3 postes horaires)	TU(Tarification à poste unique)
Consommation jour (en kWh)	(≠ des indexes jour x 1,02) + P0 .x $\frac{3443}{8760}$	≠ des indexes x 1,02 + P0
Consommation pointe (en kWh)	(≠ des indexes pointe x 1,02) + P0 .x $\frac{1252}{8760}$	
Consommation nuit (en kWh)	(≠ des indexes nuit x 1,02) + P0 .x $\frac{4065}{8760}$	
Montant consommation (en millimes)	(Cons jour x tarif J + cons pointe x tarif P + cons nuit x tarif N.) x C	Consommation x tarif TU x C
	C: coefficient de pénalité ou bonification cos ϕ	
Puissance souscrite	0.3 x Pscrt jour +0.7 x Pscrt pointe (en kW)	Puissance du transformateur (en kVA)
Redevance de puissance (en millimes)	Pscrt x RPTPH	Pscrt x RPTU
Dépassement de puissance (en millimes)	3.6 x RPTPH x (0.3 x **MAX**(Pmax jour-Pscrt jour ;0) +0.7 x **MAX**(Pmax pointe-Pscrt pointe ;0))	3.6 x RPTU x **MAX**((Pmax/cosϕ) - Pscrt;0)
TVA (en millimes)	0.18 x (montant consommation + dépassement + redevance)	0.18 x (montant consommation + redevance)
Surtaxe municipale (en millimes)	Consommation x SM	
Contribution à la radio télévision Tunisienne (en millimes)	CRTT	

Exemple de tarifs d'électricité en vigueur en 2006

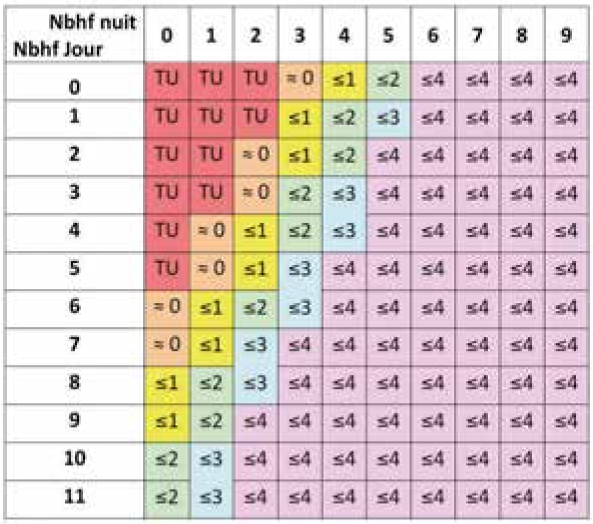
tarification	**TPH**			**TU**
Période tarifaire	nuit	jour	pointe	unique
Tarifs de l'électricité en (mill/ kWh) **(*)**	48	76	109	84
Horaire hivers : du 01/10 au 31/03	21h30 à 6h30	6h30 à 17h30	17h30 à 21h30	24h / 24h
Horaire été : du 01/04 au 30/09	23h à 8h	8h à 19h	19h à 23h	
Redevances de puissance **(*)**	**RPTPH** : 3500 mill/ kW/mois			**RPTU** : 500 mill/ kVA/mois
Surtaxe municipale **SM (*)**	3 mill/kWh			
CRTT en (mill) **(*)**	3500			

(*) : en 2006 1 € = 1.7 DT, en 2015 1 € = 2.2 DT, 1DT = 1000 millimes (mill)

La simulation horaire des équations des deux tarifications permet de choisir la tarification convenable pour chaque régime de fonctionnement d'une station de pompage. Ceci nous permet d'établir les tableaux suivants :

Tableau N°3 : guide de choix entre les tarifications TU et TPH (avec souscription de puissance en pointe) en fonction de la répartition des horaires de pompage

1 cas de souscription de puissance en pointe d’électricité



Nbhf nuit Nbhf Jour	0	1	2	3	4	5	6	7	8	9
0	TU	TU	TU	≈0	≤1	≤2	≤4	≤4	≤4	≤4
1	TU	TU	TU	≤1	≤2	≤3	≤4	≤4	≤4	≤4
2	TU	TU	≈0	≤1	≤2	≤4	≤4	≤4	≤4	≤4
3	TU	TU	≈0	≤2	≤3	≤4	≤4	≤4	≤4	≤4
4	TU	≈0	≤1	≤2	≤3	≤4	≤4	≤4	≤4	≤4
5	TU	≈0	≤1	≤3	≤4	≤4	≤4	≤4	≤4	≤4
6	≈0	≤1	≤2	≤3	≤4	≤4	≤4	≤4	≤4	≤4
7	≈0	≤1	≤3	≤4	≤4	≤4	≤4	≤4	≤4	≤4
8	≤1	≤2	≤3	≤4	≤4	≤4	≤4	≤4	≤4	≤4
9	≤1	≤2	≤4	≤4	≤4	≤4	≤4	≤4	≤4	≤4
10	≤2	≤3	≤4	≤4	≤4	≤4	≤4	≤4	≤4	≤4
11	≤2	≤3	≤4	≤4	≤4	≤4	≤4	≤4	≤4	≤4

NB : Nbhf :

- le nombre d’heures de pompages fictif est égal à la consommation journalière d’énergie (moyenne annuelle) de chaque poste horaire divisée par la puissance souscrite jour.
- (**£ x**) ⇒ Passer en TPH à condition de ne pas dépasser x heures de pompages fictives en pointe STEG
- TU : choisir la tarification TU

Tableau N°4 : guide de choix entre les tarifications TU et TPH (sans souscription de puissance en pointe) en fonction de la répartition des horaires de pompage

2- cas de non souscription de puissance en période de pointe

Nbhf nuit Nbhf Jour	≤0,4	0,4<
≤1	TU	TPH
1<	TPH	TPH

NB : Nbhf :

- le nombre d’heures de pompages fictif est égal à la consommation journalière d’énergie (moyenne annuelle) de chaque poste horaire divisée par la puissance souscrite jour.
- TU : choisir la tarification TU

Condition de souscription d’une puissance en pointe :

Suivant le calcul on peut démontrer que le nombre de dépassement autorisé est au maximum de trois fois par an. Sinon, il est conseillé de souscrire une puissance en pointe.

III.1.2 Principe de révision des contrats d'électricité

Pour optimiser le choix des contrats d'électricité, et programmer la marche des stations au moindre coût nous avons adopté les principes suivants:

- Le choix de la tarification unique (TU) pour les stations de secours ou d'appoints estivales ou celles qui fonctionnent moins de 3 heures par jour en moyenne annuelle.
- le choix de la tarification à postes horaires (TPH) avec souscription de puissance en période de pointe d'électricité pour les stations qui fonctionnent plus de 3 heures par jour en moyenne annuelle, tout en considérant les possibilités de transfert des certaines heures de pompage vers la période de nuit. Le délestage doit alors s'effectuer nécessairement pendant la pointe, et le reste durant la période "Jour".
- le choix de la tarification à postes horaires (TPH) avec non souscription en période de pointe d'électricité si le volume (VDP) moyen distribué durant la période de pointe d'électricité lors de la saison estivale doit être inférieur à 70% du volume de sécurité de pointe d'électricité (Vs).

III.2 OPTIMISATION DU FONCTIONNEMENT

III.2.1 les consignes de fonctionnement économique

Le mode de fonctionnement économique consiste essentiellement à favoriser le pompage durant la période de NUIT. Ce qui correspond aux consignes suivantes :

- La période de délestage doit se terminer en début de la période de NUIT
- La reprise du pompage doit intervenir au début de la période NUIT
- Le délestage doit s'effectuer nécessairement pendant la POINTE, et le reste durant la période "JOUR"
- le niveau d'eau du réservoir ne doit pas descendre au-dessous d'une valeur de sécurité fixée au préalable.
- Le volume distribué durant la période de délestage devra être égal au volume autorisé pour le délestage
- le réservoir doit être plein en fin de la période "NUIT".
- Le délestage doit se faire de manière à ne pas introduire des contraintes hydrauliques (vidange de conduites entre les réservoirs de tête et les réservoirs de distributions en période de délestage, baisse sensible de la pression dans certaines zones,…).
- L'installation d'un système de régulation automatique entre la station de pompage et le réservoir.

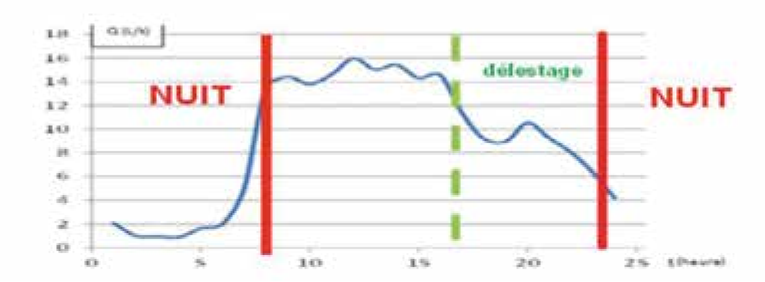


Figure N°2 : Exemple de courbe journalière de la distribution d'eau, avec délimitation de la période de Nuit et de la période de délestage calculée

Ces dispositions devront favoriser le pompage de "Nuit" mais sans, toutefois, porter préjudice au bon fonctionnement des installations et à la continuité du service d'alimentation en eau.

III.2.2 optimisation du cout d’énergie dans un système complexe

Un réseau de production et de distribution d’eau peut être considéré comme un système complexe sur lequel il convient d’intervenir en permanence en fonction des sollicitations des utilisateurs.

Le problème consiste à déterminer les commandes (marche-arrêt des pompes) permettant d’optimiser les coûts d’énergie sachant que des contraintes doivent être respectées ; à savoir :

- Les niveaux dans les réservoirs doivent rester entre des valeurs minimales et un maximales prédéfinies.
- La pression et la qualité d’eau dans le réseau de distribution doivent rester dans les normes.
- Les règles d’optimisation des contrats d’électricité doivent être respectées.
- Les sources d’eau qui ne doivent pas être sollicitées au delà de certaines limites.

De ce fait, l’optimisation du coût d’énergie doit passer essentiellement par l’élaboration d’une commande optimale. Cette dernière nécessite donc l’élaboration de calculs complexes tenant compte de nombreux paramètres : Puissance souscrite, tarification retenue, nombre de démarrage des pompes, consommation des abonnés, niveau des réservoirs d’aspiration, niveau des réservoirs de refoulement et le temps de marche des pompes. Aussi, il est essentiel de disposer d’une bonne estimation de la demande sur la durée de l’optimisation. Cette dernière, nécessite des modèles mathématiques assez puissants (gestion en temps réel).

III.2.3 le contexte justifiant le choix de la technique adoptée

Pour obtenir les meilleurs résultats il est nécessaire de recourir à une optimisation en temps réel et en particulier de déterminer la prévision de la distribution d’eau au cours de la journée par l’emploi de logiciels et un matériel informatique performants. Ce type de moyens n’est pas disponible dans les stations de pompage.

La solution retenue:

- Fixer au préalable les heures des arrêts de délestage de chaque station en tenant compte de la moyenne de la distribution de la saison concernée.
- Ajouter un capteur de niveau bas permettant de forcer le démarrage en période délestage afin d’éviter le vidange du réservoir en dessous d’un niveau critique (NBC)
- Ajouter un capteur de niveau haut (NHC) permettant d’arrêter le pompage suite au niveau(NBC) afin de limiter le pompage en période à cout élevé
- Les mises en route et les arrêts doivent être judicieusement programmés en généralisant dans les stations de pompage les systèmes de régulation (Ligne pilote, radio, etc.) et en introduisant les systèmes d'horloge et d'automates programmables permettant l'effacement en pointe (ou pendant certaines heures du jour) afin de privilégier le pompage de nuit et profiter de la tarification réduite facturée par la STEG (sans pour autant porter préjudice à la sécurité et au bon fonctionnement des installations).

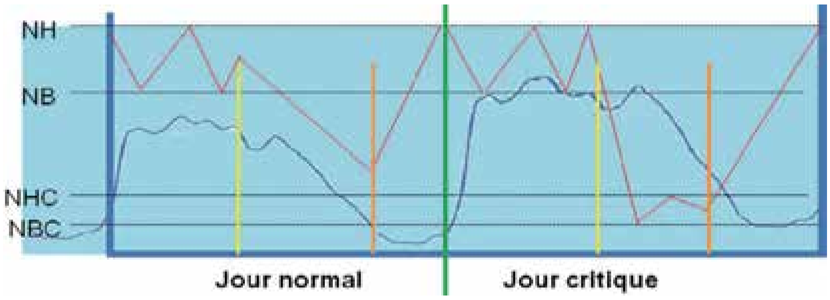


Figure N°3 : Exemple de simulation du fonctionnement tenant compte des conditions citées ci-haut

III.3. COORDINATION AVEC LES PARTIES PRENANTES ET PERENNISATION DE L'ACTION

Les principales étapes se présentent comme suit:

- Collecter toutes les informations sur le complexe de pompage (schéma du réseau, capacité des réservoirs, caractéristiques techniques des équipements de pompage, les courbes de la distribution de chaque réservoir, présence des moyens de régulations du pompage,….)
- discuter avec les différents intervenants (les gardiens pompistes, les maintenanciers, les chefs secteurs, les ingénieurs d'études, et les responsables..) pour identifier les contraintes d'exploitation du système et déterminer les conditions limites d'optimisation,
- réaliser les simulations nécessaires et définir les règles de gestion adéquates
- effectuer des réunions avec les premiers responsables, les staffs techniques et les staffs d'exploitation des 50 districts de la SONEDE pour présenter les études et prendre les décisions et les dispositions nécessaires pour l'application du programme proposé,
- suivre l'exécution du programme (installation des équipements de délestage du pompage, des nouveaux équipements de pompages, de régulation automatique, mise à jour des contrats d'électricité, installation des batteries de condensateurs, ...),
- vérifier les résultats obtenus et effectuer les ajustements nécessaires pour améliorer ou pour corriger les consignes de gestion du pompage,
- améliorer les méthodes de travail et les techniques adoptées à travers les retours d'expériences.

Les étapes présentées ci-haut sont répétées chaque année suivant le modèle PDCA de la Figure N°4, ce qui a permis de réaliser d'importantes économies sur les frais énergétiques durant la période 1999-2014.

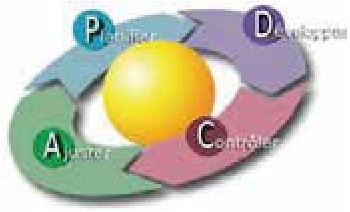


Figure N°4 : Modèle d'amélioration continue PDCA

III.4. RESULTATS OBTENUS

a. Premier indicateur technique: orientation vers le choix de la tarification horaire

Le tableau N°5 montre le transfert progressif des consommations d'énergie de la tarification unique TU vers la tarification à postes horaires, ce qui a permis de contribuer dans la réduction du coût de l'énergie :

Tableau N°5 : modification progressive des contrats d'électricité du TU vers TPH

Année	1998	2003	2006	2014
Pourcentage de consommation d'énergie pour les abonnements à tarification TU	21%	11%	7%	5,5%
Pourcentage de consommation d'énergie pour les abonnements à tarification TPH	79%	89%	93%	94,5%

b. Deuxième indicateur technique : diminution de la consommation d'énergie dans la période de pointe

Le graphique ci-dessous (Figure N°5) montre clairement la diminution de la puissance appelée pendant la période de pointe « à coût élevé ». Ceci est dû aux délestages accomplis sur une partie des équipements.

Cette réduction de puissance appelée a induit :

- le transfert de la consommation d'énergie de la période de pointe vers la période de nuit « faible coût »
- la réduction de la puissance souscrite en pointe

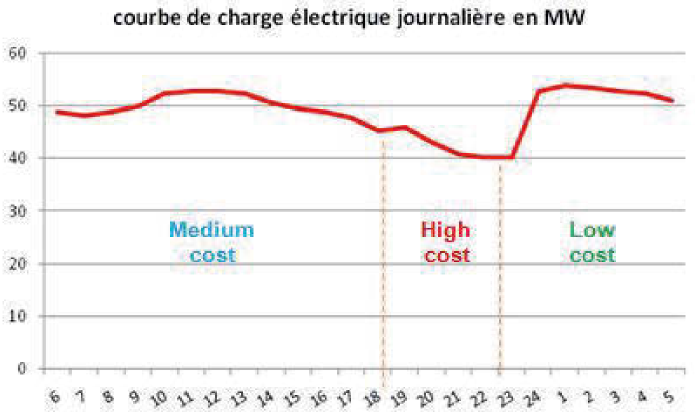


Figure N°5 : Courbe de charge moyenne montrant une réduction volontaire de la puissance appelée dans la période tarifaire à coût élevé

c. Premier indicateur financier : coût du kWh à tarif constant (base 1997)

Pour montrer l'impact des actions entreprises depuis 1998 à 2014, nous avons recalculé les factures sur la base d'un tarif unique (celui de l'année 1997) afin d'éliminer l'effet de l'augmentation des tarifs de l'électricité durant cette période. Le graphique ci-dessous (Figure N°6) montre une diminution progressive du coût du kWh depuis 1998 année du démarrage du programme de maîtrise d'énergie.

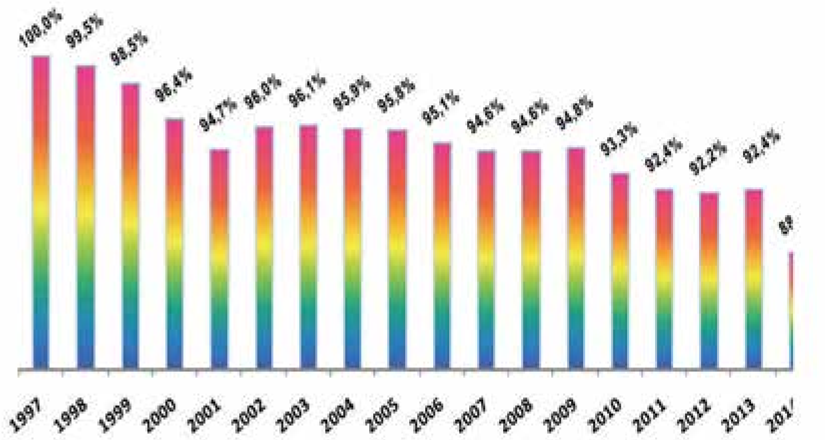


Figure N°6 : diminution du coût du kWh à tarif constant (base 1997 : sans tenir compte de l'évolution du tarif d'électricité)

d. Deuxième indicateur financier : comparaison de l’indice du coût du kWh à la SONEDE par rapport à celui des clients MT de la STEG

Le graphique ci-dessous (Figure N°7), montre que les actions entreprises par la SONEDE ont permis de réduire le coût de l’énergie par rapport à celui des clients MT de la STEG :

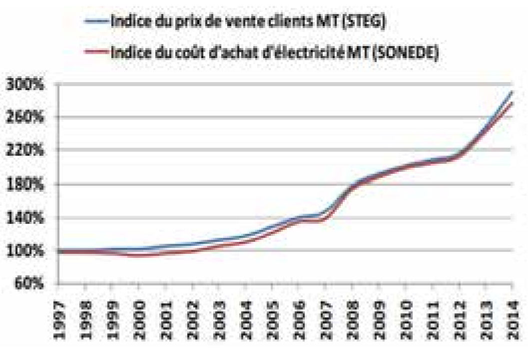


Figure N°7: Indices des prix en monnaie courante : (base 100 = prix de vente STEG MT année 1997).

Figure N°8 : Evolution du prix du gaz naturel (DT /Tep), Sachant que la production d’électricité en Tunisie dépend à 98% du gaz naturel

Il est à signaler que les tarifs de l’électricité ont augmenté depuis l’année 2005 suite à l’évolution du prix international du gaz naturel, comme le montre la figure ci-dessus (Figure N°8), qui représente la source principale de production de l’électricité en Tunisie.

IV. ACTION 2: OPTIMISATION DU COUT D’ENERGIE DANS LES SITES ISOLES ET AUTONOMES

IV.1. Introduction Générale

La tarification de l’énergie électrique fixée par la STEG est basée sur des tranches horaires : «JOUR, POINTE et NUIT ». Le tableau ci-dessous montre la durée de chaque période en fonction de la saison :

Tableau N°6 : délimitation des postes horaires

	MOIS	JOUR	POINTE	NUIT
Période hiver	1er Octobre au 31 Mars	de 6h30 à 17h30	de 17h30 à 21h30	de 21h30 à 6h30
Période été	1er Avril au 30 Septembre	de 8h00 à 19h00	de 19h00 à 23h00	de 23h00 à 8h00
tarif (millimes/Kwh)		149	184	100

Etant donné que le prix de l’électricité est plus cher pendant les périodes de pointe et du jour, il est donc nécessaire de favoriser le pompage en dehors de ces périodes essentiellement la pointe, tout en considérant la capacité de stockage d’eau et les débits des équipements.

De là est venue l’idée de concevoir une carte d’optimisation qui va permettre de réduire le fonctionnement des groupes de pompage durant les périodes à coût énergétiques élevées, et de le maximiser aux périodes les moins chères.

L’objectif de ce travail était l’étude et la réalisation d’une carte électronique à base de microcontrôleur qui permet d’optimiser le fonctionnement des groupes électropompes de la SONEDE en fonction de la tarification horaire de la STEG. La tâche à accomplir se divise en trois volets:

- Elaborer un modèle simplifié de prévision de la distribution d’eau journalière : choisir la meilleure méthode de prévision adaptée à un système embarqué et déterminer un modèle mathématique

(temps de calcul, espace mémoire, opérateurs mathématiques, précision, autonomie de décision….)

- déterminer une stratégie de commande pour gérer et optimiser le délestage du pompage d'eau vers un réservoir en tenant compte de la capacité de ce dernier, de la prévision de la consommation d'eau, et des conditions limites de fonctionnement et de sécurité
- concevoir et réaliser une carte de commande adaptée pour le modèle choisi, essentiellement la vitesse du processeur, les capacités des mémoires, le nombre des entrées analogiques ou numériques indispensables pour le fonctionnement de l'algorithme d'optimisation tels que les débits et le niveau d'eau les entrées et sorties logiques. Ce dispositif doit fournir d'autres options précises comme l'affichage de temps d'arrêt ainsi que la sauvegarde des données saisies à travers de capteurs (tension, courant, température, débits aspiration, débit refoulement…). La carte va permettre de gérer et d'optimiser le fonctionnement des équipements de pompage en tenant compte des postes horaires de tarification. Elle comportera aussi une partie pour l'acquisition en temps réel des données à partir la station de pompage et du réservoir.

L'intérêt de ce système réside aussi dans la simplification de la méthode d'optimisation et la réduction du coût des moyens matériels et logiciels nécessaires pour ce type d'applications.

La procédure d'optimisation proposée ne se limite pas à un simple décalage de la période de pompage, mais permet en plus, de contrôler un volume de régulation afin d'arriver à la période de pointe avec un réservoir plein. Donc mon objectif est de déterminer le temps d'arrêt de la pompe avant la période de nuit, ainsi que le dernier temps de démarrage avant la période de pointe.

Le choix des entrées

Dans ce premier travail nous avons choisi de ne pas utiliser des données météorologiques pour la construction de modèles de prévision de la demande, et ceci pour quatre raisons :

1. Les liens entre des données climatiques et la consommation semblent difficiles à établir car il faut choisir le facteur explicatif adéquat (nombre de jours consécutifs de sécheresse, nébulosité faible, seuil de température...) et nécessitent éventuellement un modèle plus complexe qui sera difficilement implémentable dans le type de carte électronique choisi à performances limitées.
2. L'utilisation de prévisions météorologiques pose le problème des incertitudes du modèle météorologique qu'il faudrait transposer dans le modèle de prévision de la demande, ce qui est délicat à maîtriser.
3. Le modèle qui sera construit devra pouvoir être implanté sur un site isolé où la station doit être gérée en temps réel. Les données d'entrée du modèle devront être facilement accessibles ce qui n'est pas le cas pour des données météorologiques.
4. Les données météorologiques sont implicitement contenues dans les consommations passées. Par exemple, lorsque la prévision de demande se fait au cours d'un épisode climatique chaud et sec, les consommations des heures précédentes traduiront cet épisode par des valeurs élevées. Nous avons choisi d'utiliser plutôt ces consommations passées dites données endogènes que les données climatiques.

Les variables exogènes que nous avons alors recensées pour figurer dans le modèle constitué et qui sont apparues comme significatives sont le mois de l'année, le jour de la semaine, l'heure de la journée et le fait que le jour considéré, corresponde à une période de vacances scolaires. Nous avons besoin alors dans l'optimisation du fonctionnement de connaître la demande sur plusieurs heures consécutives. Idéalement le modèle à bâtir devraient prévoir la demande sur 24 heures ce qui correspond à l'horizon d'optimisation. En pratique, le modèle que nous avons élaboré débutera les calculs de la prévision à 6 heures avec un réservoir plein et continuera jusqu'à 14h pour avoir une prévision fiable de la demande un peu plus tard dans la journée. Les commandes d'optimisation se feront entre 14 heures à 23 heures. Le modèle utilisé et le choix de l'horizon de la prévision sont expliqués dans ce document.

Le premier chapitre sera consacré à l'étude de la variation de la consommation d'eau; quotidiennement et mensuellement sans oublier de mentionner le tarif de consommation d'énergie mis par le STEG.

Le deuxième chapitre sera consacré à l'étude de la procédure d'optimisation et à montrer l'atout de la méthode adoptée tout en décrivant la modélisation mathématique qui m'a permis de simplifier la solution proposée.

IV. 2. Identification du modèle de prévision de la demande en eau adapté pour des sites isolés et autonomes et tenant compte de la disponibilité des données, dans le but de l'implémenter dans un système embarqué

Une prévision est l'interprétation dans le futur d'une série d'observations effectuées à des dates fixes. Une bonne stratégie de commande nécessite l'utilisation de techniques de modélisation de prévisions adaptées pour tenir compte des effets des différents facteurs intervenant dans le système à piloter. L'erreur tolérée de cette prévision doit être minime et relative au domaine de son application. Prenons l'exemple de la prévision de la production d'électricité qui est la plus délicate vu que la production doit être à tout moment égale à la consommation pour maintenir la stabilité du réseau, ce cas est plus sensible que la production d'eau pour laquelle on tolère une erreur faible mais qui peut être compensée soit par une perte de performances ou par l'utilisation d'une partie de la réserve de sécurité du réservoir cette erreur peut être réduite dans les jours qui suivent par l'adaptation du modèle de prévision.

Parmi les techniques de prévision, on peut citer les méthodes extrapolatives qui utilisent les observations quantitatives du passé de la variable pour prédire son futur. Les données de consommation sont enregistrées sur des intervalles de temps réguliers, année, mois, semaine, jour, heure, quart d'heures, minute, etc. Les données enregistrées, filtrées et traitées, seront représentées sous forme de séries chronologiques à travers des graphiques. A partir de ces graphiques on peut déterminer à quel type de tendance celle-ci obéit afin de déterminer la méthode de prévision à appliquer.

Dans notre cas nous avons utilisé la méthode de régression polynomiale d'ordre 2. En effet lorsque l'évolution des valeurs mesurées est à tendance, c'est-à-dire l'allure est croissante ou décroissante. Dans ce cas la prévision n'est autre que le polynôme de régression sur le temps.

Si on note Y la prévision pour la période n, il faut rechercher les ai de sorte que l'équation

$Yn = \sum_{i=0}^{m} (a_i * n^i)$ soit la plus proche du nuage de points.

On peut améliorer la précision de la méthode de régression linéaire si on remarque des fluctuations cycliques sur la tendance en plus du caractère de croissance ou de décroissance.

En tenant compte des fluctuations cycliques, on a à définir des coefficients cycliques par lesquels on multiplie les valeurs prévues par la régression linéaire sur le cycle considéré.

La notion du cycle peut être remplacé par le terme saison et ainsi on définit le coefficient se saisonnalité. Si on note Ci le coefficient cyclique qui se rapporte à l'iéme cycle, alors il est déterminé de la manière suivante :

$$C_i = \frac{\text{Consommation moyenne sur le cycle i}}{\text{Consommation moyenne sur toute la série chronologique}}$$

Les prévisions données par la régression linéaire qui tient compte du coefficient de saisonnalité est définit par : Pn=Ci * Tn

Avec : Tn: équation de la régression linéaire.

IV.3. modélisation de la consommation d'eau d'un site pilote

Nous rappelons que la problématique étudiée concerne le fonctionnement d'une station de pompage qui est étroitement lié à la variation de la consommation d'eau. L'objectif initial était de bâtir un modèle prédisant la demande entre 14h et 23h de chaque jour conformément aux besoins du modèle d'optimisation présenté ci-avant. Cette prévision se fera sur la base des valeurs de consommations d'eau collectées entre 6h et 14h. Il est à noter que l'optimisation est réalisée tout les jours hors les dimanches où l'électricité consommée est facturée avec le tarif nuit (le moins couteux)

Nous allons présenter ici la prévision de la demande de la zone de consommation, dans le but d'améliorer les performances du modèle d'optimisation. Cette prévision se fera au pas de temps de l'heure. Pour construire les modèles de prévision de la demande nous avons utilisé les données d'une zone pilote desservie par le réservoir d'eau « AFH Béja » qui se trouve prés de la ville de Béja située dans le Nord Ouest de la Tunisie.

Nous avons utilisé un échantillon de données de consommation d'eau allant de juillet 2009 à Mars 2011. Ces différentes données sont issues du compteur situé à la sortie du réservoir. La consommation journalière moyenne varie dans cet échantillon de 700 m3 en basse saison à 1500 m3 en pointe. La zone pilote comporte une variabilité horaire et journalière importante, ce qui rend la prévision relativement difficile.

IV.3.1. Traitement des données

Les donnés traitées correspondent à des acquisitions de débit de sortie du réservoir d'eau chaque 2 minutes ce qui correspond à presque 447000 valeurs.

La figure N°9 ci-dessous présente un échantillon des Courbe de modulation de l'année 2010:

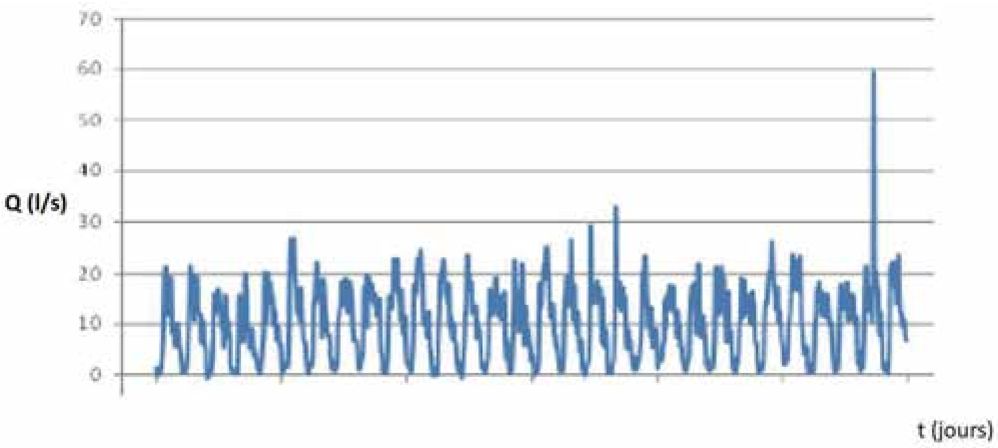


Figure N°9 : Un échantillon des Courbe de modulation de l'année 2010 :
Courbe de modulation du mois de janvier 2010

Dans les tableaux de consommation journalière, nous avons remarqué la présence de valeurs erronées. Pour cette raison, nous avons éliminé à l'aide de règles de validité, les périodes comportant des fuites importantes ou celles présentant des incohérences. En effet la réussite du modèle de prévision dépend essentiellement de l'exactitude des données de base.

IV.3.2. Détermination de la Courbe de distribution horaire journalière moyenne de chaque mois

Etude et interprétation de la courbe mensuelle

Après avoir filtré les données, nous avons déterminé les courbes de modulation journalière moyenne de chaque mois par application de la moyenne arithmétique des courbes journalière de chaque jour du mois.

En effet la consommation d'eau et l'allure de la courbe journalière moyenne varie d'un mois à un autre. Par conséquent, nous avons choisis d'établir des courbes de consommation moyenne mensuelle afin d'affiner le modèle de prévision comme le montre la figure suivante :

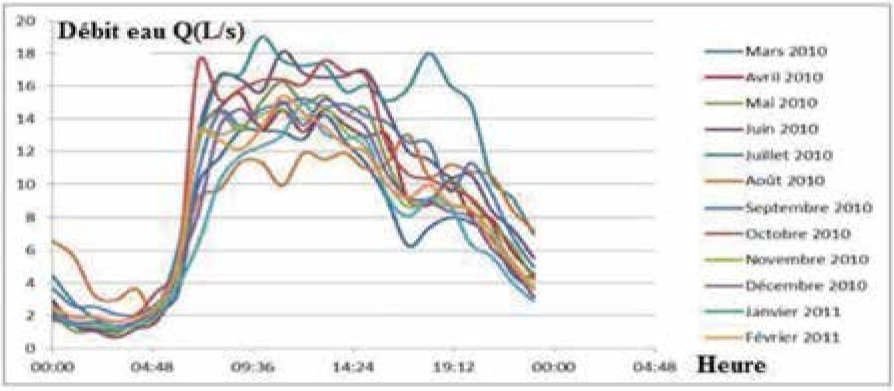
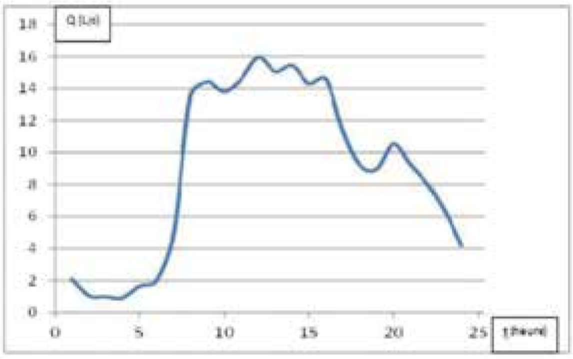


Figure N°10 : Courbes de distribution moyenne de Mars 2010 à Février 2011

Cependant ce type de courbe n'est pas facilement modélisable sous forme d'une équation mathématique. En plus l'algorithme de calcul d'optimisation du fonctionnement de la station de pompage utilise des volumes et non pas des débits ce qui va nécessiter des calculs supplémentaires dans la carte électronique. C'est pourquoi nous avons remplacé la prévision des débits ponctuels par la prévision du volume sur une période bien déterminée.

Les graphiques suivants présentent cette transformation pour le cas du mois de Janvier 2011 :



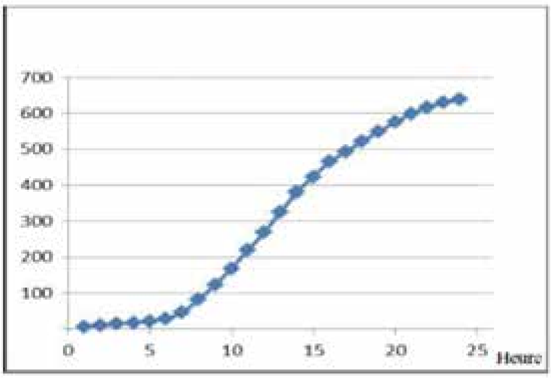


Figure N°11 : courbe journalière moyenne du mois de Janvier 2011

Figure N°12 : Courbe du volume journalier moyen consommé à partir de 0h

Une fois les courbes de volume sont tracées pour les différents mois, nous avons utilisé des fonctions polynomiales pour les modéliser.

Le choix de l’ordre des polynômes a été déterminé par la comparaison du coefficient R2 appelé aussi coefficient de détermination de chaque polynôme. Afin d’éviter la résolution d’une équation d’ordre supérieur à 2 dans l’algorithme de commande, nous avons choisi pour la suite le degré deux pour les équations à implémenter.

IV.3.3. Amélioration du modèle statique

En analysant la courbe de volume journalier moyen consommé (tel l’exemple de la figure N°12), on remarque que la consommation d’eau dans l’intervalle de temps allant de 0h à 6h, est relativement faible par rapport à la consommation journalière totale. De plus cette période est sans intérêt pour l’estimation de la consommation future vu qu’elle ne correspond pas à une activité humaine significative et ne correspond pas à une image climatique du jour vu que c’est la période de nuit. Pour améliorer encore cette démarche nous allons supposer ou imposer d’avoir un réservoir d’eau plein juste à la fin de cette période.

Nous avons déterminé de nouvelles équations (polynôme d’ordre 2) d’origine (5h) et (6h) et nous avons comparé leurs coefficients de détermination R2. En comparant les différentes valeurs pour les deux heures, le choix a été fixé sur 6h comme heure de départ pour le calcul des volumes. De plus nous observons une amélioration du coefficient R^2.

IV.3.4. Mise en place du modèle dynamique à implémenter dans la carte

Une fois, ces équations sont déterminées, nous avons établi un modèle dynamique qui assure la continuité en les équations ci-haut moyennant des coefficients de pondérations linéaires. En effet le principe est de considérer le volume distribué à un instant du jour pour lequel on calcule la prévision est déterminé avec la notion de degré d’appartenance aux équations du mois en cours et du mois précédent et du mois suivant (équivalent au principe de la logique floue).

Le modèle de prévision de la consommation est définit par les équations suivantes :

$$\begin{cases} \textbf{pour } j : \textbf{de } 1 \text{ à } 16 \\ V(m,j,t) = \dfrac{Q(k)réel\ réf}{Q(k)réf} * \left[\dfrac{(14+j)}{30} * V(m,t)réf + \dfrac{(16-j)}{30} * V(m-1,t)réf\right] \\ \textbf{pour } j : \textbf{de } 17 \text{ à } 30 \\ V(m,j,t) = \dfrac{Q(k)réel\ réf}{Q(k)réf} * [\dfrac{(46-j)}{30} * V(m,t)réf + \dfrac{(j-16)}{30} * V(m+1,t)réf] \end{cases}$$

Avec :

l’instant pour lequel on calcule la prévision

j : le jour pour lequel on calcule la prévision

m : le mois pour lequel on calcule la prévision

m-1 : le mois précédent

m+1 : le mois suivant

$V(m,j,t)$: le volume estimé

$V(m,t)réf$: l’équation de référence du mois de la prévision

$V(m-1,t)réf$: l’équation de référence du mois précédent

$V(m+1,t)réf$: l’équation de référence du mois suivant

Q(k)réelréf : le débit mesuré à l'heure de réfrence k qui est initialement k=6h
Q(k)réf: le débit à l'heure de réfrence k qui est initialement k=6h,

Remarque :

Le débit réel est la moyenne des valeurs des enchantions réalisés chaque 2 minutes pendant une période de 20 minutes (-10mn à +10mn autours de l'heure de référence k).

L'heure de référence k est initialement k=6h, si l'erreur par rapport à la valeur estimée est supérieur à 5% alors k et sera remplacé par l'heure ayant ce dépassement de 5%. Aussi le

$$Q(k)r\acute{e}el\ r\acute{e}f \text{ et } Q(k)r\acute{e}f$$

seront remplacées respectivement par le débit réel à la nouvelle heure k et par le débit de référence de la nouvelle heure k.

IV.4. Algorithme de commande et d'optimisation

Comme le montre la figure N°14, la station de pompage dispose de deux pompes (un en marche et un de secours) qui fonctionnent en tout ou rien pour remplir le réservoir d'eau. A l'entrée du réservoir le débit est Qe, ce débit constant est celui de la pompe en fonctionnement, alors qu'en sortie le débit Qs varie selon la consommation des abonnées. Pour pouvoir mesurer le niveau d'eau dans le réservoir, il y a un capteur de niveau ainsi que d'autres capteurs non représentés qui détectent le niveau haut (arrêt de la pompe), bas (démarrage de la pompe) et très bas (ce niveau est atteint essentiellement en cas de casse sur la conduite de distribution ou de refoulement donc la consigne est d'arrêt la pompe).

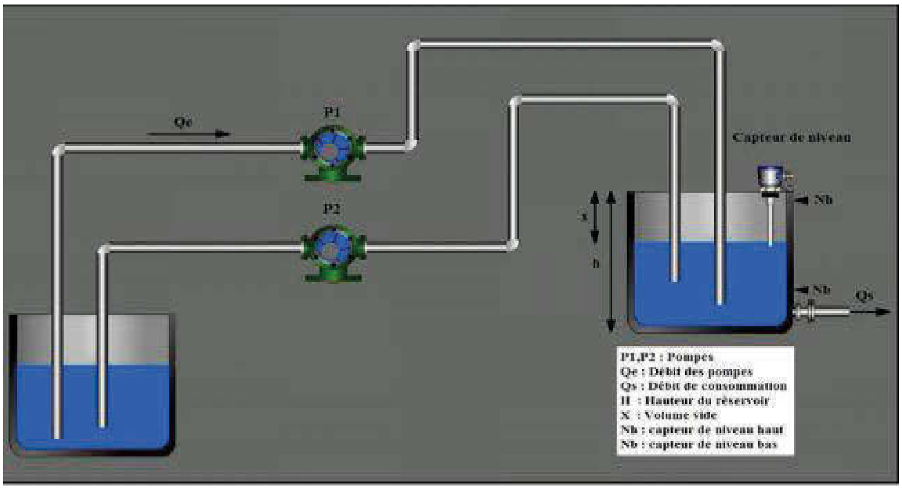


Figure N°14 : schéma de fonctionnement d'une station de pompage

En se référant au tableau des tarifs de pompage, nous allons proposer un mode de fonctionnement qui permet de réduire le coût et d'optimiser le fonctionnement des pompes.

Ce mode de fonctionnement consiste à prendre avantage du bas tarif en faisant fonctionner les pompes durant la période nuit et remplir le réservoir. Le délestage des pompes se fera sur une période à déterminer finissant à 23h pour la période tarifaire d'été et 21h30 pour celle d'hiver. Le début de la période de délestage (heure d'arrêt forcée) peut se situer en période tarifaire de POINTE ou en période tarifaire du JOUR. Sa détermination va dépendre essentiellement du volume de régulation de délestage autorisé par l'exploitant, de la capacité de pompage en période tarifaire de NUIT, et du débit des équipements existants.

Aussi nous avons déterminé l’heure du dernier démarrage forcée permettant d’assurer un réservoir plein à l’heure d’arrêt forcée.

Donc l’algorithme va déterminer deux instants importants :

- heure d’arrêt forcée avant le délestage,
- heure du dernier démarrage forcée permettant d’assurer un réservoir plein à l’heure d’arrêt forcée.

Ces deux instants seront déterminés après le calcul de la prévision de la consommation et en tenant compte du débit réel des pompes. Ils seront recalculés à chaque amélioration de la prévision au cours de la journée.

D’autre part, si le niveau d’eau atteint un niveau bas critique (tbc) à définir par l’exploitant sans que ce soit une casse, il faut que les pompes redémarrent et restent en fonctionnement jusqu’à atteindre un niveau intermédiaire assurant la sécurisation de l’alimentation et la limitation du fonctionnement dans la période à haut tarif.

Modélisation mathématique

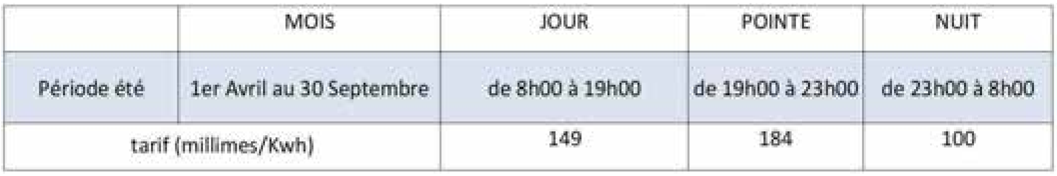
Pour atteindre l’objectif voulu, nous avons déterminé les deux principaux éléments suivants :

- **taf** : le temps d’arrêt forcé de délestage.
- **tdd** : le temps de dernier démarrage.

Calcul du temps d’arrêt forcé (taf)

Dans ce document nous allons présenter uniquement le calcul qui a été fait pour la période de tarification d’été :

Tableau N°7 : délimitation des postes horaires en période d’été



	MOIS	JOUR	POINTE	NUIT
Période été	1er Avril au 30 Septembre	de 8h00 à 19h00	de 19h00 à 23h00	de 23h00 à 8h00
tarif (millimes/Kwh)		149	184	100

Notre but consiste à déterminer un temps d’arrêt délestage forcé « taf » à partir duquel la pompe ne va plus démarrer qu’à 23h.

Pour atteindre cette objective, on doit définir le volume utile délestage « VR » qui n’est que l’intégration du débit sortant au cours du temps.

A partir de ce raisonnement on peut déduire l’équation suivante :

$$\int_{taf}^{23} (Qs(t)) = VR = (Vs(23) - Vs(taf))$$

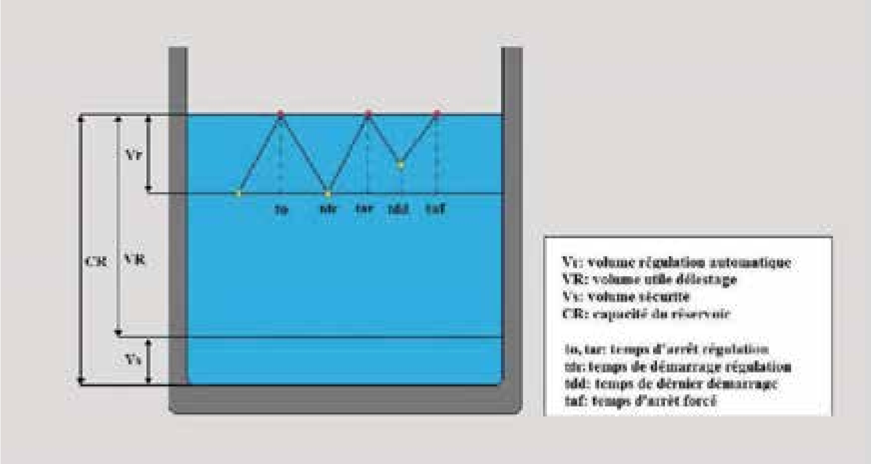


Figure N°15 : Exemple de fonctionnement des pompes dans le volume de régulation

Avec :

t0 : temps d'arrêt de la pompe en mode de régulation automatique et qui correspond aussi à l'instant du calcul initial de tdd

tar : temps du dernier arrêt de la pompe en mode de régulation automatique et qui correspond aussi à l'instant du calcul final de tdd

tdr : temps de démarrage en mode de régulation automatique

taf : le temps d'arrêt forcé de délestage.

tdd : le temps de dernier démarrage.

Vr : volume de régulation automatique

VR : volume utile de délestage

CR : capacité de réservoir

Vs : volume de sécurité

La marche arrêt de la pompe dépend uniquement de la consommation des abonnés et des niveaux « haut » et « bas » de la régulation automatique. L'intégration aléatoire de la commande du temps d'arrêt forcé n'est pas compatible avec ce mode de fonctionnement. En effet le « taf » peut se situer suivant deux cas possible comme indiqué dans la figure suivante (Fig N°16):

- Soit on est en phase de chute de niveau : cas du (Taf1).
- Soit on est en phase de pompage : cas du (Taf2).

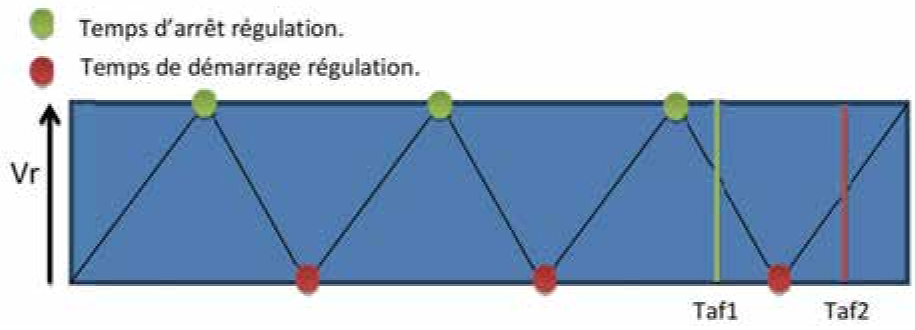


Figure N°16 : deux cas possibles de mauvais Taf

Dans ces deux cas la commande « taf » va intervenir alors que le réservoir n’est pas plein ce qui va réduire le pompage pendant la période « Nuit ».

Nous rappelons que notre but consiste à maximiser le pompage pendant la période « Nuit ». Pour cela, il faut entamer l’instant « taf » avec un réservoir plein.

Le temps du dernier démarrage forcé des pompes « tdd » sera choisi de façon à atteindre cet objectif. (Voir Figure N°16)

Le calcul de « tdd » s’effectue de manière cyclique à partir d’un instant initial « t0 » où le réservoir est à son niveau maximum.

La pompe étant au repos à l’instant « t0 », nous estimons d’abord le temps du prochain démarrage « tdr » selon l’équation suivante :

$$\int_{t0}^{tdr} (Qs(t)) = Vr = (Vs(tdr) - Vs(t0))$$

Par la suite, nous calculons le temps d’arrêt de régulation « tar» selon l’équation (9) :

$$\int_{tdd}^{taf} (Qe - Qs(t)) = Vr = Qe * (tar - tdr) - (Vs(tar) - Vs(tdr))$$

Se calcul se répète à chaque arrêt de la pompe jusqu’à ce que le temps « tar» dépasse le temps d’arrêt forcé « taf» calculé précédemment, alors nous pouvons calculer le temps du dernier démarrage « tdd» selon la formule suivante :

$$\int_{t0}^{tdd} (Qs(t)) = \int_{tdd}^{taf} (Qe - Qs(t))$$

$$Vs(tdd) - Vs(t0) = (Qe * (taf - tdd) - (Vs(taf) - Vs(tdd))$$

Les calculs effectués sont basés sur la résolution des équations polynomiales du second ordre.

V. ACTION 3 : ETUDE DE L'OPPORTUNITE DU PASSAGE DE LA TARIFICATION POMPAGE DE L'EAU A 3 POSTES HORAIRES VERS LA TARIFICATION INDUSTRIELLE A 4 POSTES HORAIRES ET EVALUATION DES RESULTATS OBTENUS:

V.1. contexte général

Le système de tarification à 4 postes horaires a été adopté par la STEG en 2001 en remplacement de celui à 3 postes, vu la modification de la structure de la demande et l'apparition d'une nouvelle pointe d'électricité matinale en période estivale due à l'activité des clients industriels MT et HT et à l'accentuation de l'utilisation de la climatisation comme le montre la figure suivante :

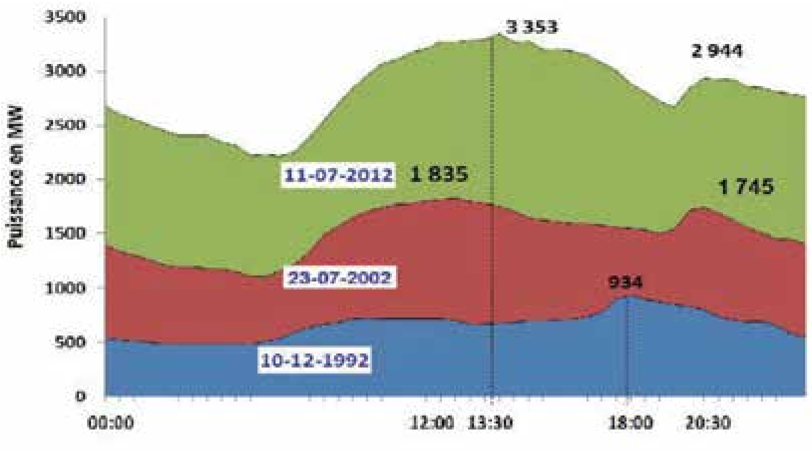


Figure N°17 : Evolution de la courbe de charge nationale (jour le plus chargé)

La SONEDE a estimé en 2001, Suite à la présente étude, que le passage à la tarification à 4 postes sera contraignant de point de vue gestion économique du fonctionnement des équipements et engendrera une augmentation de la facture d'électricité de 5%. Après des négociations, la SONEDE a convenu avec la STEG et le ministère de l'industrie (chargée de l'énergie) de lui accorder une tarification spéciale dénommée la tarification pompage de l'eau à 3 postes.

Cependant cette nouvelle tarification a vu la modification des délimitations horaires et des tarifs de ses postes horaires à partir de l'année 2006 entraînant le regain d'intérêt, comme l'estimait la présente étude, pour son utilisation à la SONEDE. C'est pourquoi cette dernière a convenu avec la STEG et le ministère de l'industrie en 2011 d'adopter la tarification à 4 postes à partir du 1er janvier 2014 pour ses stations. En effet la présente étude a démontrée qu'un gain de 4% (1 Million € par année) peut être escompté suite à ce passage, surtout avec l'amélioration des moyens de contrôle et de gestion des équipements.

La difficulté réside dans l'estimation de la future répartition de la consommation d'énergie sur les 4 postes horaires à partir des données de la facturation à 3 postes horaires.

Il est à remarquer la méthodologie adoptée dans cette étude été la même pour les calculs effectués en 2001 et en 2011. Seuls les tarifs et les délimitations des postes horaires ont changé.

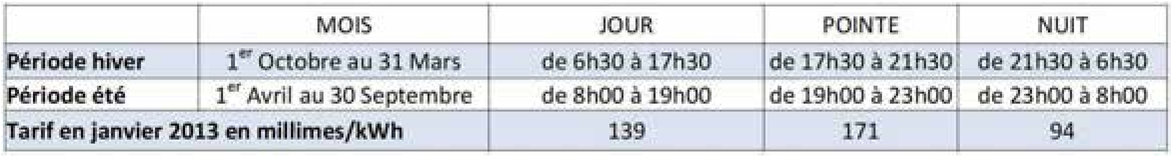
Dans ce chapitre nous allons détailler l'étude amenant la SONEDE à l'adoption de la tarification à 4 postes.

V.2. Rappel sur les deux tarifications horaires applicables pour les abonnements MT

Les tarifications Moyenne Tension à postes horaires sont les suivants pour tous les jours de la semaine à l'exception du Dimanche dont la consommation est facturée uniformément au Tarif «Nuit» :

V.2.1 Tarification à pompage de l’eau à trois postes horaire :

Tableau N°8 : délimitation et tarif du système à trois postes horaires



	MOIS	JOUR	POINTE	NUIT
Période hiver	1^er^ Octobre au 31 Mars	de 6h30 à 17h30	de 17h30 à 21h30	de 21h30 à 6h30
Période été	1^er^ Avril au 30 Septembre	de 8h00 à 19h00	de 19h00 à 23h00	de 23h00 à 8h00
Tarif en janvier 2013 en millimes/kWh		139	171	94

V.2.2 Tarification industrielle à Quatre postes horaire :

Tableau N°9 : délimitation et tarif du système à quatre postes horaires

	MOIS	JOUR	POINTE	SOIR	NUIT
Période hiver	1^er^ Septembre au 31 Mai	de 7h00 à 18h00	de 18h00 à 21h00	-	de 21h00 à 7h00
Période été	1^er^ Juin au 31 Août	de 6h30 à 8h 30 de 13h30 à 19h00	de 8h30 à 13h30	de 19h00 à 22h00	de 22h00 à 6h30
Tarif janvier 2013 en millimes/kWh		123	185	147	94

V.3 Comparaison des deux tarifications horaire

Afin de comparer les prix de revient de l’électricité selon les deux tarifications horaires, nous avons procédé à l’estimation de la future répartition de la consommation d’énergie sur les 4 postes horaires à partir des données de la facturation à 3 postes horaires. Deux méthodes ont été adoptées dans l’estimation des consommations des 4 postes horaires:

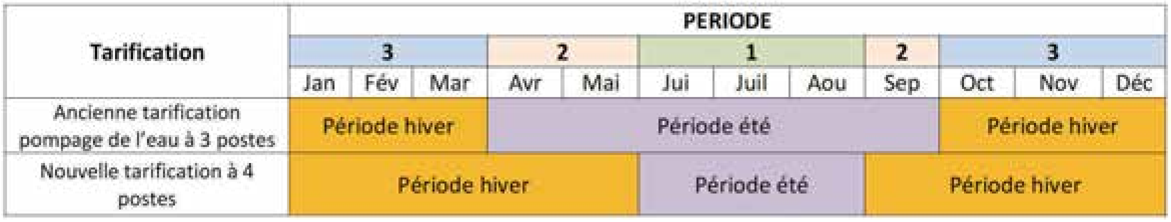
- la première suppose que la puissance appelée est constante pour chaque période tarifaire
- la deuxième utilise des courbes de charges estimées à partir de mesures effectuées sur des

échantillons significatives de stations et en les ajustant par rapport aux consommations facturées par période tarifaire et par poste de tarification (système à 3 postes)

V.3.1 METHODE 1 : calcul sur la base d’une puissance constante par période horaire

Le tableau suivant présente une superposition des périodes tarifaires de chaque tarification :

Tableau N°10 : intersection des périodes tarifaires été et hiver des deux tarifications



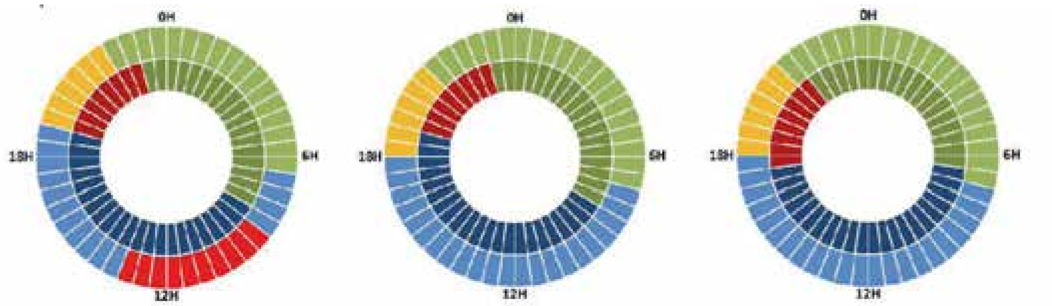
Tarification	**PERIODE**											
	3			**2**		**1**			**2**	**3**		
	Jan	Fév	Mar	Avr	Mai	Jui	Juil	Aou	Sep	Oct	Nov	Déc
Ancienne tarification pompage de l’eau à 3 postes	Période hiver			Période été						Période hiver		
Nouvelle tarification à 4 postes	Période hiver					Période été			Période hiver			

Ceci permet de dégager 3 périodes :

- **la période 1** : concerne le passage de la période été à 3 postes vers la période été à 4 postes et correspondant aux mois de juin, juillet et aout,
- **période 2** : concerne le passage de la période d’hiver à 3 postes vers la période été à 4 postes et correspondant aux mois d’avril, mai et septembre,

- **période 3** : concerne le passage de la période été à 3 postes vers la période été à 4 postes et correspondant aux mois de janvier, février, mars, octobre, novembre et décembre.

La combinaison du tableau N°10 et des tableaux des délimitations horaires des deux tarifications du paragraphe V.2 donne les figures en anneaux suivantes (figures N°18), avec un anneau extérieur correspondant à la tarification à 4 postes et un anneau intérieur correspondant à la tarification à 3 postes. Les anneaux sont divisés en secteurs d'une demi-heure:



période 1 : ancien été vers nouveau été

période 2 : ancien été vers nouveau hiver

période 3 : ancien hiver vers nouveau hiver

Les couleurs des figures précédentes correspondent aux périodes suivantes :

TARIFICATION			
3 postes		4 postes	
🟦	JOUR	🟦	JOUR
🟥	POINTE	🟥	POINTE
🟩	NUIT	🟩	NUIT
		🟨	SOIR

Figures N°18 : différentes possibilités d'intersection des postes horaires des deux tarifications

Equations de transformation de la tarification à 3 postes vers la tarification à 4 postes:

Les figures en anneaux précédentes permettent de dégager le système d'équations suivantes :

Tableau N°11 : équations de transfert d'énergie entre les tarifications à trois et à 4 postes horaires

Période	Mois	Période jour	Période pointe	Période soir	Période nuit
période 3 : ancien hiver vers nouveau hiver	Janvier Février Mars	$\frac{21}{22}Aj+\frac{1}{8}Ap$	$\frac{3}{4}Ap$		$\frac{1}{22}Aj+\frac{1}{8}Ap+An+CDi$
période 2 : ancien été vers nouveau hiver	Avril Mai	$\frac{10}{11}Aj+\frac{1}{9}An$	$\frac{1}{11}Aj+\frac{1}{2}Ap$		$\frac{1}{2}Ap+\frac{8}{9}An+CDi$
période 1 : ancien été vers nouveau été	Juin Juillet Aout	$\frac{6}{11}Aj+\frac{3}{18}An$	$\frac{5}{11}Aj$	$\frac{3}{4}Ap$	$\frac{1}{4}Ap+\frac{15}{18}An+CDi$
période 2 : ancien été vers nouveau hiver	Septembre	$\frac{10}{11}Aj+\frac{1}{9}An$	$\frac{1}{11}Aj+\frac{1}{2}Ap$		$\frac{1}{2}Ap+\frac{8}{9}An+CDi$
période 3 : ancien hiver vers nouveau hiver	Octobre Novembre Décembre	$\frac{21}{22}Aj+\frac{1}{8}Ap$	$\frac{3}{4}Ap$		$\frac{1}{22}Aj+\frac{1}{8}Ap+An+CDi$

Les termes du tableau précédent désignent :

- CDi : consommation des dimanches de chaque mois calculée par l'approximation suivante :

$$CDi=\frac{consommation\ du\ mois}{k}\times l$$

Avec k : nombre de jours du mois et l : nombre de dimanches du mois

- **An** : consommation d'énergie période Nuit de la tarification pompage de l'eau à 3 postes que l'on retranche CDi
- **Aj** : consommation d'énergie période Jour de la tarification pompage de l'eau à 3 postes
- **Ap**: consommation d'énergie période Pointe de la tarification pompage de l'eau à 3 postes
- hors dimanches
- **Nn** : consommation d'énergie période Nuit de la tarification à 4 postes hors dimanches
- **Nj**: consommation d'énergie période Jour de la tarification à 4 postes
- **Np**: consommation d'énergie période Pointe de la tarification à 4 postes
- **Ns**: consommation d'énergie période Soir de la tarification à 4 postes

En appliquant le système d'équations du tableau précédent sur les consommations réelles facturées dans la tarification à 3 postes de la SONEDE nous obtenons des résultats montrant que le prix de revient de l'énergie de la tarification à 4 postes est moins cher que celui de la tarification à 3 postes de 4,16%.

V.3.2 METHODE 2 : calcul sur la base des courbes de charges journalières approximées par saison

La deuxième méthode consiste à déterminer les courbes de charges moyennes de la SONEDE pour les périodes hiver et été.

Les courbes de charges ont été estimées en se basant sur des enregistrements de puissances appelées dans des enchantions de stations de types significatifs (stations de dessalements, forages, surpresseurs, stations de pompages), de gammes de puissances différentes, de régions différentes, et de facteurs d'utilisations différents. Les courbes ont été aussi ajustées par rapport aux consommations facturées par période tarifaire et par poste de tarification (système à 3 postes).

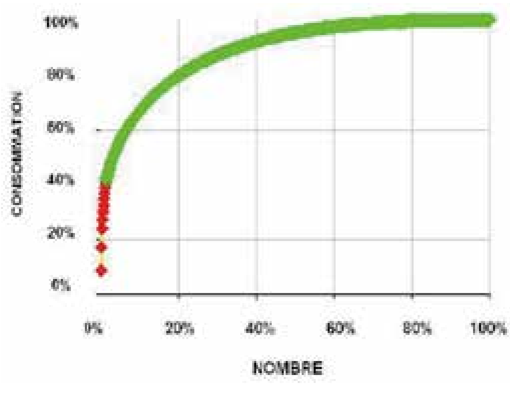


Figure N°19 : pourcentage de la consommation d'énergie suivant le nombre de stations

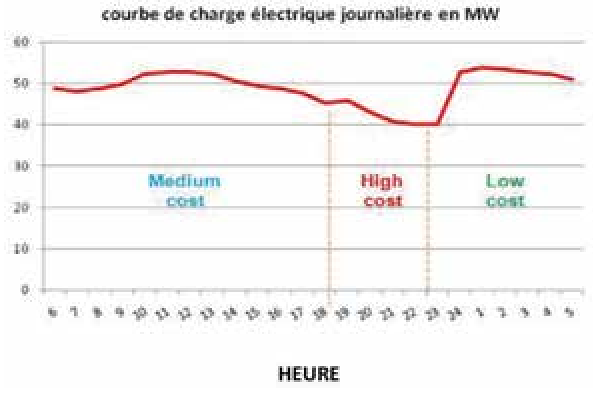


Figure N°20 : Courbe moyenne annuelle

La figure N°19 présente quelques enchantions, en rouge, de stations choisies en fonction de leurs puissances. La figure N°20 présente la courbe moyenne des appels de puissance durant l'année 2011.

En intégrant les courbes déterminées le long des intervalles horaires de chaque poste nous obtenons des résultats montrant que le prix de revient de l'énergie de la tarification à 4 postes est moins cher que celui de la tarification à 3 postes de 4,32%.

V.3.3 Estimation retenu

L'estimation retenue est égale à la moyenne des estimations de la méthode N°1 et de la méthode N°2, ceci donne au définitif un prix de revient de l'énergie pour la tarification à 4 postes, appliquée à la SONEDE, moins cher que celui de la tarification à 3 postes de 4,24%.

V.3.4 Résultat obtenu

En analysant les factures d'électricité de la SONEDE, de l'année 2014, auxquelles a été appliquées la tarification à 4 postes horaires nous observons un gain de (1 Million € par année) ce qui correspond à un écart entre la valeur estimé du gain et celle réalisée de 3%.

CHAPITRE 3 : CONCLUSION GENERALE

La réussite et la durabilité de ces actions durant les 16 dernières années ont été assurées par la coordination, l'assistance technique et le dialogue entre les parties prenantes, surtout par le contact direct à travers des réunions des rencontres des séminaires, des formations périodiques.

Cependant, bien que les actions présentées dans cet article aient permises de réduire les frais énergétiques, celles-ci restent relativement élevées par rapport au chiffre d'affaire de la SONEDE. Ceci s'explique en partie par le faible taux d'augmentation du tarif de l'eau comparé à celui de l'électricité. De plus, il y avait des contraintes pour la promotion des programmes de maîtrise de l'énergie, en effet:

- le cadre réglementaire d'incitation aux actions de maîtrise d'énergie n'était pas suffisamment mature
- l'expertise nationale dans le domaine de maîtrise d'énergie, au niveau du secteur d'eau potable, n' pas pu donner un apport supplémentaire au programme existant de la SONEDE
- la coopération internationale et le programme de partenariat étaient insuffisamment développés
- les technologies d'efficacités énergétiques adaptées au secteur d'eau potable étaient coûteuses et non matures.
- le prix de l'énergie était relativement bas et ne favorisant pas la mise en place de ce type de projets

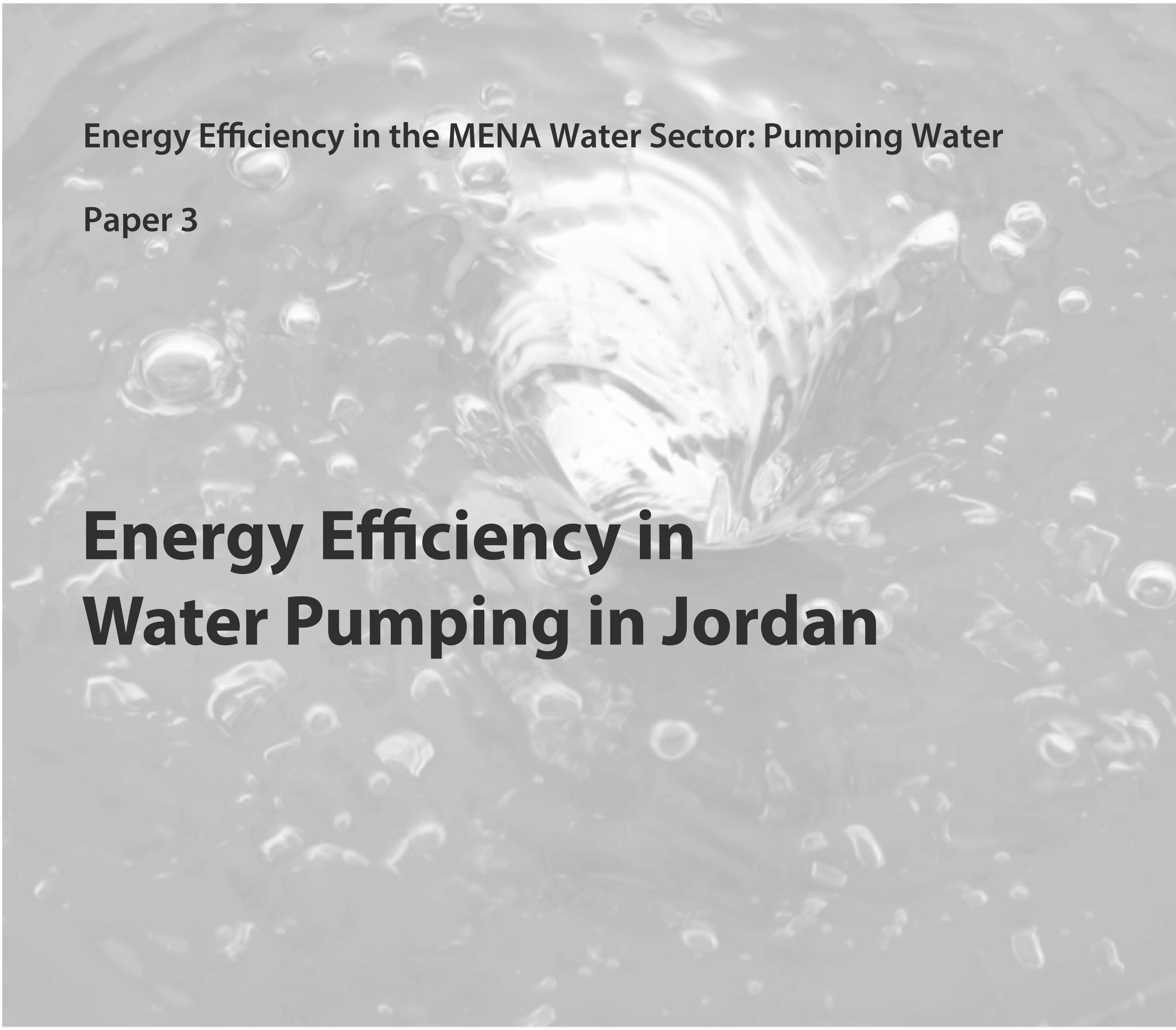
En plus des difficultés précédentes, les projections futures de l'évolution des frais de l'énergie sont inquiétantes, vu l'augmentation rapide et soutenue des prix de l'énergie, et vu la tendance d'augmentation de consommation d'énergie, suite à la croissance de l'activité économique et de lapopulation ainsi que l'obligation d'améliorer le taux de desserte de l'eau potable(dans le milieu rural) nécessitant l'extension du réseau de pompage et de distribution et le raccordement des zones difficilement accessibles.

En effet, la SONEDE est obligée à recourir à des solution d'alimentation et de production d'eau de plus en plus énergivores afin de préserver l'équilibre entre l'offre et la demande en eau dans le futur. Les projets futurs concerneront principalement la mobilisation de toutes les ressources disponibles, le renforcement des transferts de l'eau du Nord vers le Sud, et le recours à des ressources non conventionnelles tels que le dessalement des eaux saumâtres et des eaux de mer.

Face à cette situation et ces perspectives induisant des coûts énergétiques importants et qui pèsent de plus en plus sur le prix de revient de l'eau et à des prix de l'énergie durablement élevés et volatiles la SONEDE a mis en place, en parallèle aux efforts d'économie d'eau, une stratégie énergétique. A cet effet un plan de maîtrise d'énergie pour la période 2012-2030 visant à :

- limiter la consommation spécifique (Wh/m3) à 85% de sa valeur probable dans un scenario d’évolution normale à l’horizon 2030,
- intégrer les énergies renouvelables à concurrence de 30% de la consommation totale d’énergie en 2030 (objectif du gouvernement tunisien),
- optimiser davantage le pompage de l’eau en tenant compte des coûts des postes tarifaires de l’électricité, avec un objectif de réduire le prix d’achat du kWh de 10% à l’horizon 2018 (base tarif constant de l’année 2012),
- réduire la consommation de carburants de 20% à l’horizon 2016,
- mettre en place avant 2017 un système de management de l’énergie conformément à la norme ISO 50001.

Pour contribuer à garantir la pérennité du programme de maîtrise d’énergie à la SONEDE, une équipe de travail, composée de jeunes ingénieurs multidisciplinaires et motivés, a été constituée au niveau central et régional. Elle assiste périodiquement à des formations de haut niveau dans le domaine de la maîtrise de l’énergie assurées surtout par l’ANME, la STEG et la GIZ.



Energy Efficiency in the MENA Water Sector: Pumping Water

Paper 3

Energy Efficiency in Water Pumping in Jordan

Written by:
Daniel Busche and Bassam Hayek, Water Portfolio - Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) Amman – Jordan

ACWUA
Arab Countries Water Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Executive Summary

Energy Efficiency in Water Pumping in Jordan

by Daniel Busche and Bassam Hayek

The German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) started in 2008 the International Climate Initiative (ICI) to support reducing greenhouse gas emissions. "Improvement of Energy Efficiency (IEE)" of Water Authority of Jordan (WAJ) is a first project under the ICI; it is implemented by the Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) with WAJ and the Performance Monitoring Unit.

Sustainable energy supply is a challenge in Jordan. Water pumping consumes 14% of electricity supply. High pumping inefficiency results in high costs and increased CO_2 emissions. Therefore, an eco-efficient and sustainable model for water pumping is crucial.

A step-wise approach was followed in assessing and culturing energy efficiency practices. After an initial audit in middle governorates showing promising energy saving potentials, a county wide assessment was done covering major pumping stations. Pumps performance and their electro-mechanical aspects were investigated. Water flow, pressure and electricity consumption were measured, as was the system performance. Eco-efficiency benefits were estimated assuming the use of improved technology and enhanced operation and maintenance. Technical measures were developed as well as institutional concepts and respective contracts to support implementing the measures sustainably; such as via energy service performance contracting models with the private sector investing in and operating the pumps, and sharing benefits. Pilot projects were implemented; the first was in Baqourieh pumping station in Al Salt in 2010 and the most recent is the project in Wala/Lib station in Madaba in 2014.

The assessment revealed that the annual energy saving potential from all the investigated pumping facilities (10 well fields and 15 pumping stations) would reach to 42’100 MWh (33.5% reduction), equivalent to 3.3 million Euro (based on 2013 electricity tariff). The saved power will result in reducing CO_2 emissions by 30,637 t/y. Around 1/3 of the savings can be obtained from 10 well-field pumping stations, while 2/3 of savings from other 15 network pumping stations.

The pilot in energy efficiency in Baqourieh was accomplished by WAJ and in partnership with Wilo, a German pumps manufacturer. The activity resulted in an average of 33.5% reduction in specific energy consumption; saving 1.5 GWh and 1100t CO_2 annually. The Wala / Lib pumping station project involves WAJ / Miyahuna (water utility) and an Energy Service Company (comprising an engineering consultant (Engicon) and Wilo) who is taking the responsibility of operating the stations for 5 years. The investment in the pilot project is 726’426 EUR (GIZ contribution: 24%) including 8 new high quality pumps to improve the specific energy consumption from 1.02 to 0.90 (kWh/m^3) in Wala and from 1.1 to 0.82 (kWh/m^3) in Lib. At an average of 9 Mm^3/y of pumped water and electricity tariff (0.078 EUR/kWh, in 2013), the shared annual savings would reach to (280’800) EUR/y, thus the project simple payback period is 2.6 years. The expected reduction in CO_2 emissions is 2’500 t CO_2 /y.

The outcomes demonstrate a triple win case. The savings from improved energy efficiency are shared; WAJ via the water utilities can obtain new infrastructure for water pumping together with optimized operation for a long term (due to reductions in operational costs and down time); and reduced carbon footprint of the water supply sector can be ensured.

The sustainability of energy efficiency projects in the water sector can be assured by having high quality equipment and adequate operation and maintenance. Private sector partnership via performance based contracts is crucial.

1. Background

Jordan suffers from scarce water resources and conventional energy resources. The country's demand for fresh water exceeds 1.4 billion m^3 while the available resources are around 1 billion m^3. Water is mainly supplied by pumping from ground water sources (60%), developed surface water bodies (30%) and reclaimed water (10%). Pumping stations are established for abstraction from well-fields, water conveyance and supply networks. Water pumping in Jordan is energy intensive due to the topography of urban areas and the depth and distance of water sources. For example ground water abstraction occurs from rather deep wells mostly more than 100 m below ground level. Water is conveyed (in major supply lines) for relatively high elevations, such as from 300 m below sea level to nearly 900 m above sea level (for the water sources from the Jordan Valley), while in other cases the distance of transport can reach 100 km and 300 km as in the case of Azraq supply to Amman line and from Disi to Amman respectively.

Jordan depends on imported energy, mainly oil and gas, to generate electric power. The water sector is among the large electricity consumers, see Figure 1. In 2013, the water sector consumed 2,076 GWh (14% of total power generated) [1]. More than half of this amount was used in pumping drinking water [2].

Water and energy nexus (or energy for water) is thus of particular importance to Jordan. The aspect has become increasingly pronounced with the volatility of fossil energy prices internationally. Electricity tariff in Jordan has been increased as the government opted to remove the subsidy gradually in order to sustain the supply of power to the economic sectors. The electricity tariff for water utilities was changed consequently as given in Table 1, where the price will double by 2017. The cost of energy for water has thus become a critical factor in providing water services.

Water supply is the responsibility of the Water Authority of Jordan (WAJ). In recent years WAJ adopted a strategy of commercializing water services, for this state-owned companies such as Miyahuna (serving mainly Amman), Aqaba Water Company in the south and Yarmouk Water Company in the north have been established. Due to the scarce water resources and the increased demand for water for the various users, the prime priority for WAJ has been to supply water to the users. Water supply has become costly due to the raise in electricity prices and intensive use of energy in pumping as a result of relatively high pressure head as well as compromised pumping efficiency. The latter is mainly due to operating old oversized pumps and insufficient pumps maintenance and repair processes. On the other hand, since electric power in Jordan is generated using fossil fuel, the excessive use of power in water pumping consequently results in increased CO_2 gas emission from the service.

Historically, public-private partnerships in managing public services such as water supply have been a challenge, mostly due to lack of financial sustainability as a result of subsidized prices of environmental resources (water and energy). In such a situation and as long as not all costs are reflected in the cost structure of water supply, it will be hard to develop a business case and therefore find a economically viable entry-point for the private-sector. Despite this fact, the concept of energy services companies has started in Jordan a decade ago in an attempt to improve the eco-efficiency of enterprises such as industrial facilities, but it was faced by hardships. These were mainly due to conflicts that arose due to the lack of adequate measurements to prove the savings. Thus the application of the concept has been somehow hibernating since 2008.

To improve the eco-efficiency of water supply services, WAJ and GIZ started in 2008 on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) the implementation of "Improvement of Energy Efficiency (IEE)" of Water Authority of Jordan (WAJ). The project aimed in general to improve the efficiency of water pumping and reduce green-house gas emissions. As a result of the pressing problem of energy for water, the IEE project has been launched with the following objectives:

- To reduce specific electricity consumption and green-house gas emissions.
- To assess situation for electricity use and identify savings potential in selected pumping stations and well-fields.
- To have energy contracting based operation models in pumping stations perceived as an attractive business field.

2. Approach

A step-wise approach was required to implement the project. The approach involved understanding the context, developing reliable data (facts and figures), identifying priorities, developing the concept and building awareness on private-public partnership and piloting energy saving practices in water pumping.

The work on developing energy efficient practices in the sector was supported by an EE Task Force formed at WAJ. This was crucial to develop mutual understanding of the concept as well as to co-develop the plans of work. The IEE project was structured in two phases: In the first phase, an energy audit was conducted for the major consumers of electricity in the three governorates of Balqa, Madaba and Zarqa. This energy audit consisted of pump performance measurements and electro-mechanical investigations. Therefore water flow, pressure and electricity consumption were measured, as was the system performance. Based on the derived factual efficiency, energy savings potential were calculated assuming the use of improved technology and better operations, and then the required investments were estimated. As a result of the promising findings of the audit, a country wide assessment including major pumping stations was then undertaken.

Based on this, technical measures for reducing the consumption were developed. In addition, institutional concepts and respective contracts were drafted in order to support the sustainable implementation of the measures, e.g. via direct procurement with maintenance contracts, Micro-BOT or energy contracting models involving the private sector.

In the second phase, the measures and methods derived in the prior phase were to be implemented. The focus has been to use private sector operational expertise and private finance as far as possible. This would mean that beside direct procurement and improved operation of pumps, the investments in and the operation of pumping stations might be outsourced by WAJ to the private entity for a specific duration. To demonstrate the approach, two pilot activities were implemented to lay the basis for a future country- wide upscaling.

3. Activities and Achieved Results

Initial energy audits in selected pumping stations in middle governorates

The results of the energy audit for major pumping stations in middle governorate showed energy saving potentials ranging from 4%-65%, the potential savings were estimated at 21.4 million kWh per year (Table 2). [3]

Energy assessments in the water supply sector

As a result of the initial audit, a detailed assessment of major pumping stations in Jordan was launched. A country-wide preliminary assessment was conducted from which a shortlist of high priority pumping stations was indentified for detailed assessment. The detailed assessment showed high potentials in various key well-field and network pumping stations in Jordan (Table 3 and 4). The savings potentials were estimated at 3.3 million Euro per year (based on 2013 electricity tariff). The power saving from well-field pumping stations amounted to 13,588 MWh/yr corresponding to 9,877 tons of CO2 reduction, while the power saving from the measures in network pumping stations can reach 28,512 MWh/year corresponding to 20,760 tons of CO2 reduction. Thus a total power savings of 42’100 MWh (33.5% reduction) will result from the energy efficiency measures reducing CO2 emissions by 30,637 ton/yr. [2]

Developing public – private partnership and energy performance contracting model

In order to have a sustainable improvement, the procurement of new pumps alone will not be sufficient. Therefore, a focus on life cycle cost (LCC) for the procurement as well as a change in the organisational processes was required. The IEE project promoted a comprehensive optimisation process, which has been introduced to support WAJ in the full cycle of pumping station operations within so-called “Energy Performance Contracting” (EPC) models.

EPC stands for a contract between an energy service company (ESCo) and WAJ aiming at the reduction of WAJ energy costs for water pumping. The ESCo provides the funding for the retrofitting of the pumping equipment, designs and installs the equipment, and takes over operation, maintenance and repair processes for a defined period. The remuneration of the ESCo for its services depends on the reduction of specific energy consumption (kWh/m3 pumped) during the contract period, as the cost savings are shared between WAJ (or the water utility) and the ESCo, which creates strong incentives for the ESCo to realize the predicted energy savings. [4]

Pilot in Baqourieh

The implementation of the measures via EPC increases energy efficiency and reduces operating costs with no up-front cost and limited risk for the utility. EPC is known widely in Europe, less so in the Middle East and even less in the Middle East water sectors. Since pumping stations are a key element in Jordan’s technical water supply infrastructure and vital for the provision of reliable services, there were socio-political barriers to overcome and decision-makers to convince. Therefore, it was important to establish a test case, as a first example demonstrating the implementation of an Energy Contracting model for a pumping station in Jordan. It was decided that such a test case should minimise the risk for WAJ and the private sector, hence this pilot project was realized with the support of the IEE project via a development partnership with the private sector (develoPPP). Therefore, the approach was jointly financed by GIZ and a German pump manufacturer as the ESCo (Wilo). In order to achieve the targeted performance improvements, the ESCo was given the authority and responsibility to implement the necessary changes. The private partner was required under the agreement to develop an energy saving concept considering all aspects of importance from technology to pumping station operations including specifications for the required pumps and other equipment like automation devices for remote control and training of seconded staff. This pilot project has been running since November 2009. The results of the improved technology linked with better operations have exceeded the original estimations. The specific energy consumption has been reduced from 1.73 kWh/m^3 to 1.15 kWh/m3, i.e. a reduction by 33%. This resulted in saving in one year of operation (during 2010/2011) about 1.5 GWh (which cost was around 65,000 Euro when the tariff used to be subsidized to 0.043 Euro/kWh) and a reduction of about 1100 ton of CO$_2$ emissions. [5]

Piloting in Wala / Lib

As a result of the technical and financial success of the pilot in Baqourieh pumping station, WAJ was eager to execute a pilot activity where a complete EPC model is practiced and thus to provide a model for future application in various pumping stations in Jordan.

The pumping stations in Wala and Lib close to Madaba have been identified as pilot sites since they have one supply source (Heedan well-field) and controllable distribution system that has recently been rehabilitated to reduce water losses. The new pumps are energy efficient and with the above conditions their impact can be well demonstrated and monitored.

With support of IEE project, a private consortium – comprising the Jordanian consultancy Engicon and the German pump manufacturer Wilo – formed an energy service company (ESCo), which financed the retrofitting of the pumping stations. Each of the pumping stations has been equipped with four highly efficient pumps (replacing five old ones). The new pumps can be equipped with variable speed drives allowing adapting to new pumping requirements (expansion or reduction in water demand) and yet maintaining efficiency. A proper monitoring and control system has been put in place to follow up the operation and pumps' efficiency. In addition, along the water pipeline 15 damaged air relief valves have been renewed to ensure smooth operation and avoid damages from trapped air.

The investment of 725,000 EUR is being covered by the private consortium with financial support of GIZ. The investment will be refinanced from energy savings. The savings are estimated at an average of 280,000 EUR /y (or 20% saving) and are shared with the water utility Miyahuna on a performance-based contract; Miyahuna will pay 75% of the accrued savings to the ESCo for five years. The ESCo is expected to recover its direct investment between year 2 and 3, based on its performance. Thereafter, payments of Miyahuna will be as direct profit for the ESCo. After five years of operation, the assets will be transferred to Miyahuna.

The main direct benefits of this pilot activity are

- Reduced energy consumption: 3.6 GWh/yr
- Reduced energy cost: 280,000 EUR/yr
- Reduced emissions: 2500 tCO2/yr

4. Lessons Learnt and Recommendations

Performance Based Contracting (PBC) has been piloted successfully to finance energy saving projects in Jordan's water sector through developing private public participation. From this experience it can be concluded that PBC provides a sound platform for improving the performance of services, the water sector is one example while the experience could also be applicable to other sectors. Certainly, mutual trust, transparency and close cooperation between the public and private sector is essential for the success of operation.

The success in the operation of the new pumps in securing savings, reaffirms not only the need for having energy efficient pumps but also proper pumping management including sound maintenance, monitoring and data management. These will enable adjusting the operation of the pumps and keep them at their optimum performance.

It is strongly recommended to follow up the success of these practices and disseminate the model to other pumping stations and to the wastewater sector. Specific financing lines have been set up to pave the way for further upscaling.

5. Impact and Sustainability

The IEE project and the pilots in pumping stations developed local knowledge in implementing performance based contracting and intensified private sector involvement in the water sector.

The executed pilot activities ensured having efficient pumping adapted to hydraulic conditions, the activities also resulted in raising the know-how of operators in this respect and in energy efficient pump technologies.

The use of advanced technology pumps requiring much less maintenance than the former systems resulted in reduced costs of operation and more stable water supply. Thus improved the eco-efficiency of the service, where better service is delivered at much less costs and environmental resources.

The new pumps of relatively low noise levels improved also work conditions at the stations.

Roll out in Jordan such as by applying the concept of PBC in other pump stations is promising. There are at least 10 well-fields and 15 network pumping stations in Jordan where similar approach can be implemented; thus would result in annual savings of:

- 42.1 GWh energy saving
- 3.3 million EUR cost saving
- 30’600 tCO2 emissions

Results of the IEE project have been picked up by WAJ. At present, feasibility studies are being prepared to roll out the approach to other pumping stations.

References

[1 "Ministry of Energy and Mineral Resources - Annual Report," Amman - Jordan , 2013.]

[2 GIZ/KFW/WAJ, "Energy Assessments in the Jordanian Water Supply Systems".]

[3 D. Rothenberger and A. Mokbel, "Energy Efficiency in Water Pumping: Cost Recovery at] Water and Wastewater UZliZes," in Arab Water Week, Amman, 2010.

[4 GIZ/WAJ, "Assessment of Pump Efficiency, Pump OperaZon and Energy Saving PotenZal,"] GIZ, Amman, 2009.

[5 GIZ, Energy Efficiency in Baqourieh Pumping Sta:on, Case Study, 2011.]

Acknowledgement

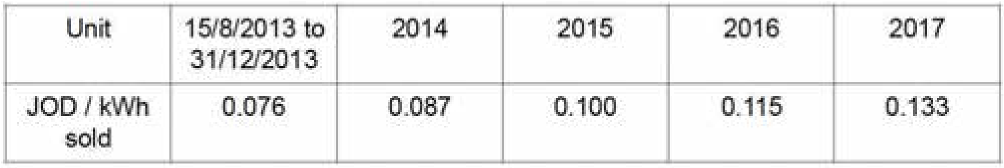
The IEE project has been implemented in the context of the International Climate Initiative. Since 2008, the International Climate Initiative of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has been financing climate and biodiversity projects in developing and newly industrializing countries, as well as in countries in transition. The International Climate Initiative is a key element of Germany's climate financing and the funding commitments in the framework of the Convention on Biological Diversity. The Initiative places clear emphasis on climate change mitigation, adaption to the impacts of climate change and the protection of biological diversity. These efforts provide various co-benefits, particularly the improvement of living conditions in partner countries.

The energy assessments of the water supply systems were conducted with co-financing by GIZ and Kreditanstalt für Wiederaufbau (KfW) as per a financing agreement with WAJ.

The authors appreciate the efforts of the team of workers on the IEE project from WAJ and GIZ. The authors extend their appreciation to former GIZ contributors to the project namely Mr Dieter Rothenberger, Mr Ronald Hagger, Ms Elke Zimmermann. In addition, the efforts of GIZ technical advisors including Mr Juergen Loos and Fayez Al Attrash are highly recognized.

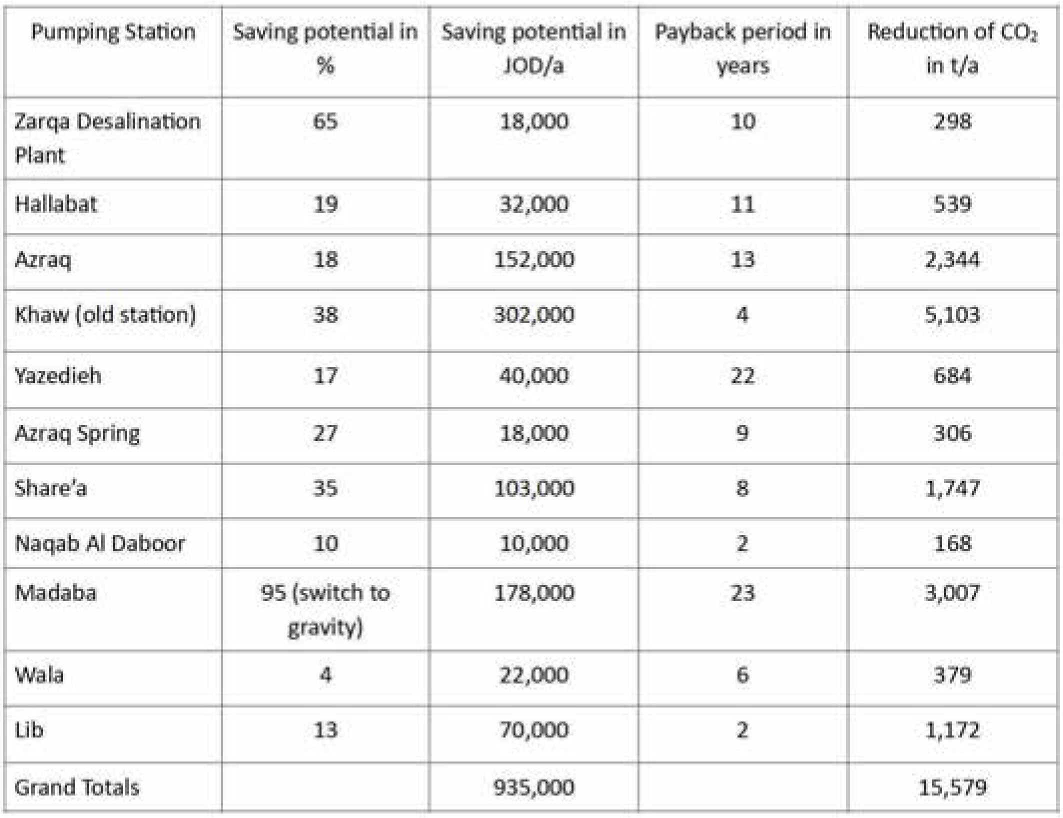
Annex

Table 1: Electric energy tariff for water pumping plants and sewage treatment plants owned by Water Authority all over the Kingdom, [source official GazeBe No. 5162 dated 17/6/2012]



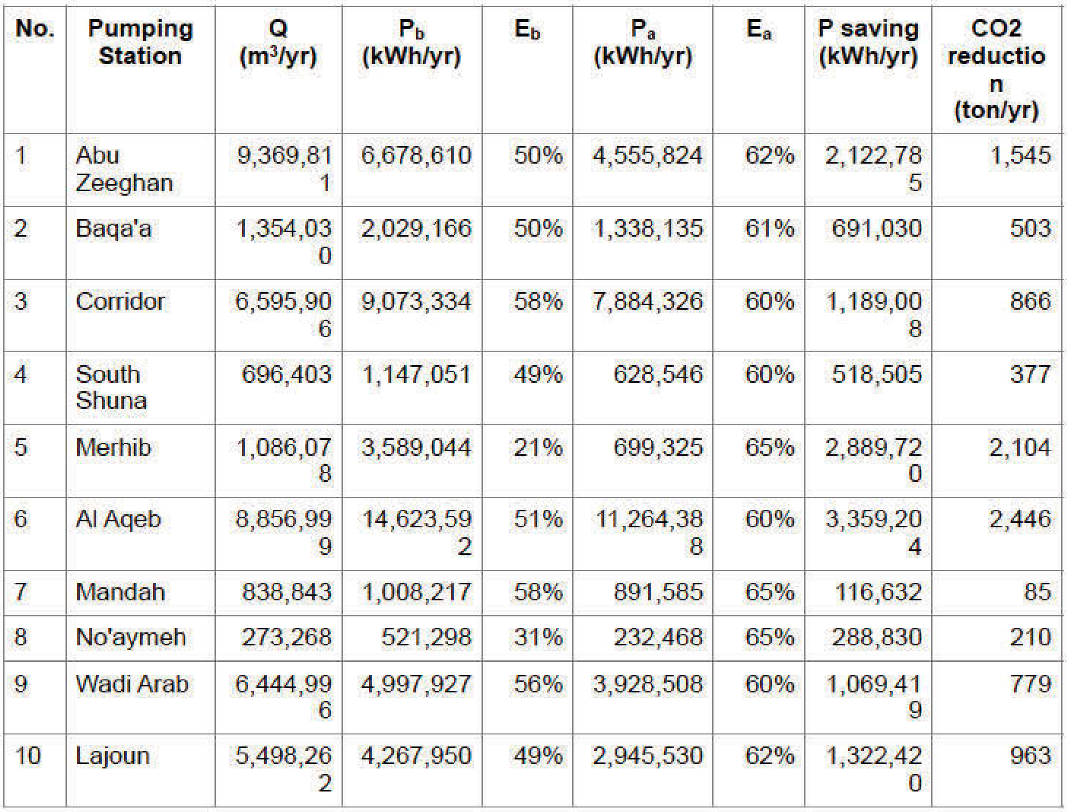
Unit	15/8/2013 to 31/12/2013	2014	2015	2016	2017
JOD / kWh sold	0.076	0.087	0.100	0.115	0.133

Table 2: Results of the energy audit in middle governorates



Pumping Station	Saving potential in %	Saving potential in JOD/a	Payback period in years	Reduction of CO_2 in t/a
Zarqa Desalination Plant	65	18,000	10	298
Hallabat	19	32,000	11	539
Azraq	18	152,000	13	2,344
Khaw (old station)	38	302,000	4	5,103
Yazedieh	17	40,000	22	684
Azraq Spring	27	18,000	9	306
Share'a	35	103,000	8	1,747
Naqab Al Daboor	10	10,000	2	168
Madaba	95 (switch to gravity)	178,000	23	3,007
Wala	4	22,000	6	379
Lib	13	70,000	2	1,172
Grand Totals		935,000		15,579

Table 3: Results of detailed assessment for the selected well-field pumping stations



No.	Pumping Station	Q (m^3/yr)	P_b (kWh/yr)	E_b	P_a (kWh/yr)	E_a	P saving (kWh/yr)	CO2 reduction (ton/yr)
1	Abu Zeeghan	9,369,811	6,678,610	50%	4,555,824	62%	2,122,785	1,545
2	Baqa'a	1,354,030	2,029,166	50%	1,338,135	61%	691,030	503
3	Corridor	6,595,906	9,073,334	58%	7,884,326	60%	1,189,008	866
4	South Shuna	696,403	1,147,051	49%	628,546	60%	518,505	377
5	Merhib	1,086,078	3,589,044	21%	699,325	65%	2,889,720	2,104
6	Al Aqeb	8,856,999	14,623,592	51%	11,264,388	60%	3,359,204	2,446
7	Mandah	838,843	1,008,217	58%	891,585	65%	116,632	85
8	No'aymeh	273,268	521,298	31%	232,468	65%	288,830	210
9	Wadi Arab	6,444,996	4,997,927	56%	3,928,508	60%	1,069,419	779
10	Lajoun	5,498,262	4,267,950	49%	2,945,530	62%	1,322,420	963

Table 4: Results of detailed assessment for the selected network pumping stations

No.	Pumping Station	H (m)	Q (m^3/yr)	E_b	SEC$_b$ (Wh/m^3/m)	P_a (kWh/yr)	E_a	SECa (Wh/m^3/m)	P saving (kWh/yr)	CO2 reduction (ton/yr)
1	Muntazah PS	76	30,484,800	36%	7.7	8,317,429	76%	3.6	9,465,371	6,891
2	Wadi Eseer Pool	126	3,810,600	59%	4.7	1,942,795	68%	4.0	298,399	217
3	Kharabsheh PS	52	17,520,000	55%	4.9	3,352,795	74%	3.7	1,679,150	1,222
4	Tamween	66	1,490,451	29%	9.5	422,243	63%	4.3	569,788	415
5a	Wadi Arab	241	6,570,000	45%	6.1	6,065,594	71%	3.8	3,681,000	2,680
5b	WA PS0 new loc.	173	6,570,000	32%	8.6	4,388,765	70%	3.9	5,357,829	3,900
6	Wadi Arab	220	24,528,000	58%	4.7	20,423,607	72%	3.8	4,918,968	3,581
7	Hofa	244/138	2,884,251	60%	4.5	2,702,785	70%	3.89/4.05	442,142	322
8a	Sumaya	120 to 361	5,252,520	45%		3,185,760	68%		952,545	693
8b	Sumaya reinforced	75 to 205	5,252,520	45%		2,841,348	68%		1,296,957	944
9	Al Ghwair	195	3,285,000	58%	4.7	2,485,367	70%	3.9	547,736	399
10	Safi	152	985,500	48%	5.7	650,674	63%	4.3	205,380	150
11	Qasr	78	1,148,160	30%	8.9	208,401	61%	4.4	210,877	154
12	Hasa	155	2,365,200	35%	7.9	1,435,111	70%	3.9	1,451,534	1,057
13	Hasa	193	2,365,200	32%	8.4	1,785,510	70%	3.9	2,062,797	1,502
14	Hasa	155	2,365,200	36%	7.5	1,435,111	70%	3.9	1,308,351	952
15	Zibdeh	150	1,138,800	32%	8.5	734,610	63%	4.3	717,950	523

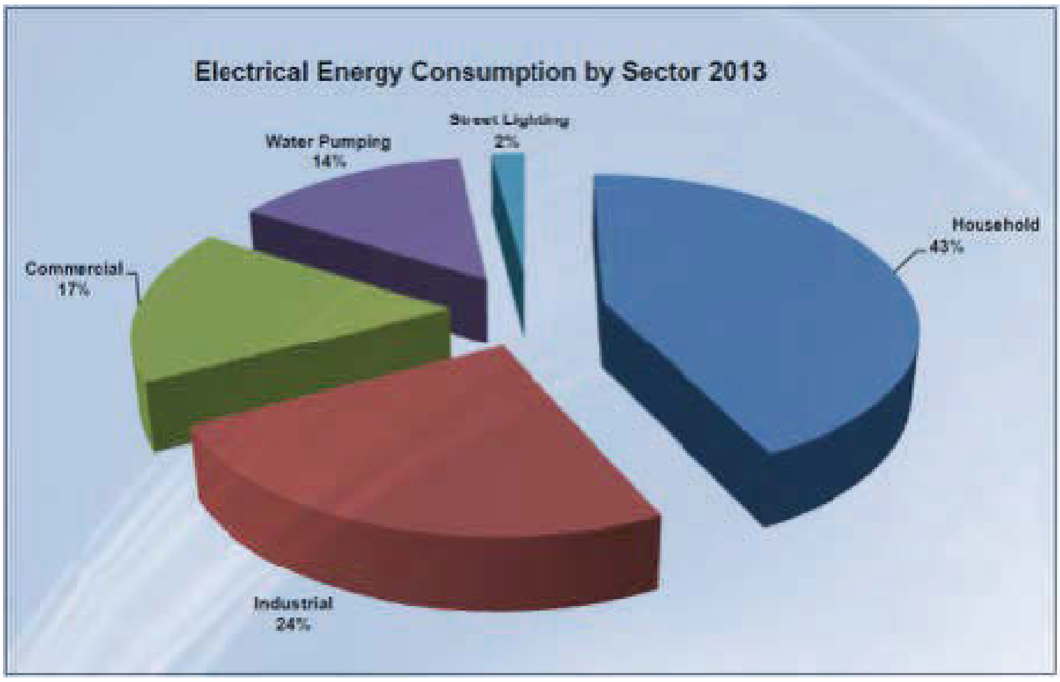
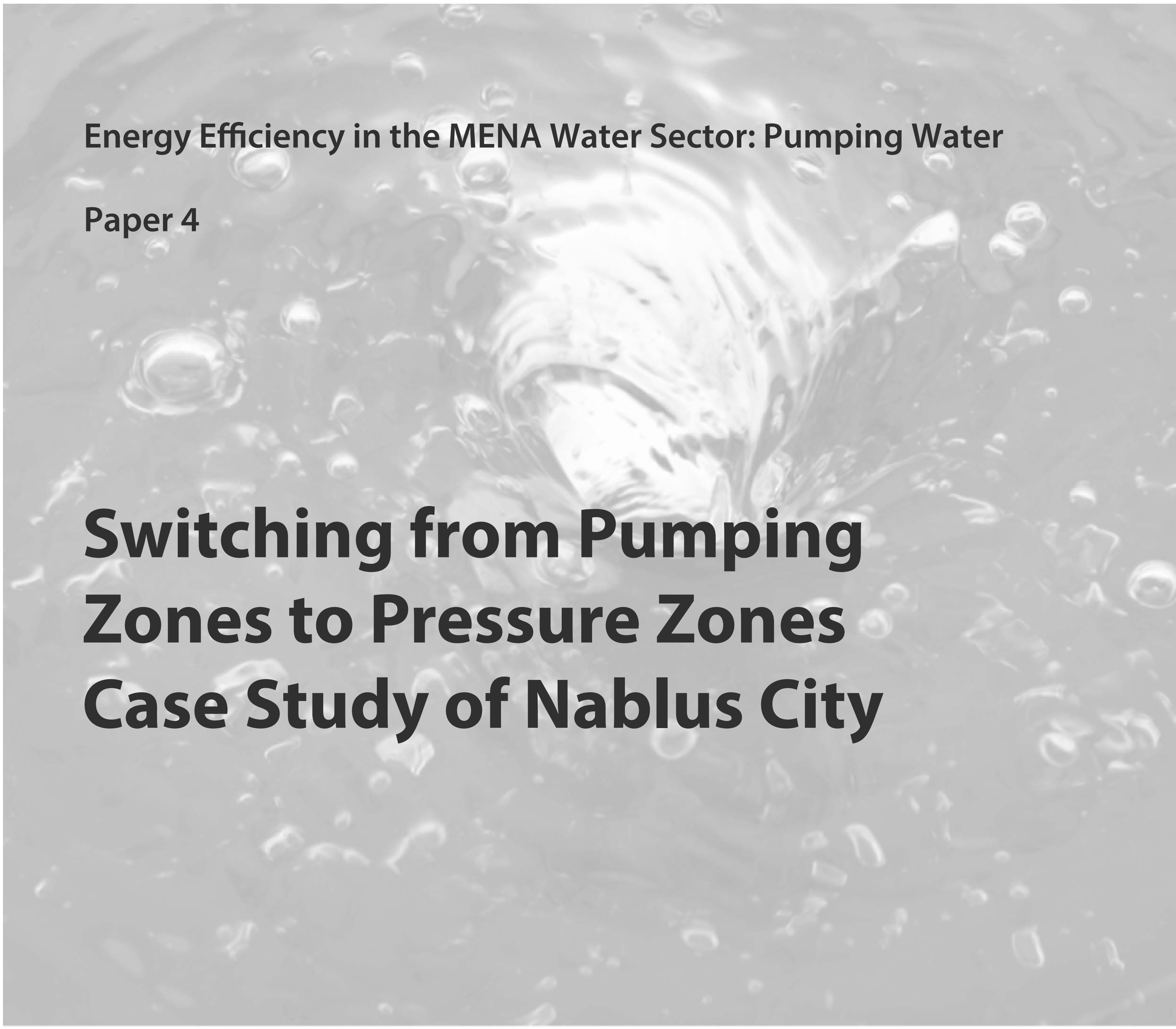


Figure 1: Electricity consumption by sector, total generation = 14564 GWh, source Ministry of Energy & Mineral Resources annual report, 2013

Nomenclature

a	denotes situation after the measure
b	denotes situation before the measure
BOT	Build, operate and transfer E Efficiency
EE	Energy efficiency
G	Giga
H	Pressure head (m)
IEE	Improvement of energy efficiency JOD Jordanian dinar
M	Mega
P	Electric power
Q	Flow rate (m3/yr)
SEC	Specific electricity consumption (kWh/m3/m) Wh Watt hour
Y	year



Energy Efficiency in the MENA Water Sector: Pumping Water

Paper 4

Switching from Pumping Zones to Pressure Zones Case Study of Nablus City

Written by:
Salah Shaikha and Dr. Amal Hudhud, Palestine - Nablus, December 2014

ACWUA
Arab Countries Water Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Abstract

Switching from Pumping Zones to Pressure Zones, Case study of Nablus City

by Eng. Salah Shaikha and Dr. Amal Hudhud

Previous Situation

The natural mountainous topography of Nablus city (see attached photo at the end of the report) is one of the main challenges in operating water system. More than 400 m was the difference in level between some water resources and distribution points (see attached photo at the end of the report). The pumping pressure reached up to 25 bars in some pumping stations, this lead to high operating and maintenance cost.

40% of water operating cost was energy, frequent failure in water distribution components (pipes, pumps, domestic water meters and fittings) happened due to high operating pressure.

Also the same pump was used to distribute water a on rotational basis to different distribution Pumping Zones that have various elevations. Therefore, the pump could not operate at optimum point. In addition to that, the previous situation had many problems which reduced the efficiency of operating water distribution system in the city.

Current situation

Water Loss Reduction project funded by Kreditanstalt für Wiederaufbau (KFW) with 20 Million € budget, this project was started in 2007 and completed in 2011. The main aim of the project was to reduce the Non Revenue Water (NRW) from 40% to 25% and to reduce the energy consumption.

Through water loss reduction the water distribution network and related facilities have been rehabilitated and restructured. The project included physical implementation comprised of laying new water pipes and house connections, installation of 28 pressure zones, as well as the rehabilitation and construction of relevant reservoirs and pumping `& booster stations.

Major parts of the systems were put in operation at the beginning of 2012, however works are still ongoing and challenges have to be faced.

Although splittng of water distribution pumping zones into pressure zones required large investment because it needed additional pumping stations, reservoirs and transmission lines. It became more economical in operation since energy consumption had been reduced by 35 % compared to the past.

The main fruits of implementing the project are (but not limited to) the following:

The energy consumption was reduced from 0.93 KWH per cubic meter to 0.59 KWH.

The project resulted in reduction of physical damage of the distribution system components, even at the customer's side behind the water meter.

Facilitating the computation of water balance and managing NRW Considerable reduction in customer complains.

As well, physical water losses in zoned networks are reduced as a result of a lower pressure in pipes and especially in indoor installations.

However, the commercial losses are still high due to over-aged domestic water meters which the municipality is intending to start to replace accordingly in the near future.

OUTLINE

1. Problem Analysis.
2. Methodology/restructure strategy.
3. Energy saving.
4. Challenges and Obstacles.
5. Accompanying Measures.
6. Actions to be implemented.
7. Learning lessons.

ABBREVIATIONS:

PZ:	pressure zone.
WLRP:	Water Loss Reduction Program.
KFW:	Kreditanstalt Fur̈ WiederauOau / German Bank for Development.
MPCV:	Modulating Pumping Control Valve.
WSSD:	Water Supply & Sanitation Department.
NM:	Nablus Municipality.
VFD:	Variable Frequency Drive.
DMA:	District Metering Area.
SCADA:	Supervisory Control and Data Acquisition.
OA:	Operational Assistance.
DI:	Ductile Iron.
PE:	Polyethylene.
NRW:	Non Revenue Water.
ILI:	Infrastructure Leakage Index.
GPRS :	Gather Packet Radio Service

Abstract

Previous Situation

The natural mountainous topography of Nablus city (see attached photo at the end of the report) is one of the main challenges in operating water system. More than 400 m was the difference in level between some water resources and distribution points (see attached photo at the end of the report). The pumping pressure reached up to 25 bars in some pumping stations, this lead to high operating and maintenance cost.

40% of water operating cost was energy, frequent failure in water distribution components (pipes, pumps, domestic water meters and fittngs) happened due to high operating pressure.

Also the same pump was used to distribute water a on rotational basis to different distribution Pumping Zones that have various elevations. Therefore, the pump could not operate at optimum point. In addition to that, the previous situation had many problems which reduced the efficiency of operating water distribution system in the city.

Current situation

Water Loss Reduction project funded by Kreditanstalt fur̈ Wiederaufbau (KFW) with 20 Million € budget, this project was started in 2007 and completed in 2011. The main aim of the project was to reduce the Non Revenue Water (NRW) from 40% to 25% and to reduce the energy consumption.

Through water loss reduction the water distribution network and related facilities have been rehabilitated and restructured. The project included physical implementation comprised of laying new water pipes and house connections, installation of 28 pressure zones, as well as the rehabilitation and construction of relevant reservoirs and pumping & booster stations.

Major parts of the systems were put in operation at the beginning of 2012, however works are still ongoing and challenges have to be faced.

Although splittng of water distribution pumping zones into pressure zones required large investment because it needed additional pumping stations, reservoirs and transmission lines. It became more economical in operation since energy consumption had been reduced by 35 % compared to the past.

The main fruits of implementing the project are (but not limited to) the following:

- The energy consumption was reduced from 0.93 KWH per cubic meter to 0.59 KWH.
- The project resulted in reduction of physical damage of the distribution system components, even at the customer's side behind the water meter.
- Facilitating the computation of water balance and managing NRW
- Considerable reduction in customer complains.
- As well, physical water losses in zoned networks are reduced as a result of a lower pressure in pipes and especially in indoor installations.
- However, the commercial losses are **still** high due to over-aged domestic water meters which the municipality is intending to start to replace accordingly in the near future.

1. Problem Analysis

Introduction

The Nablus area has significant general and local variations in topography, necessitating clear differentiation of the supply to individual areas. A great part of the city area, except the old centre of Nablus, has recently faced rapid development of a primarily residential nature. To cope with the increased demand before Water Loss Reduction Program (WLRP), the pipe network had been extended on an ad-hoc basis, without sufficient attention being paid to designing for topography, friction losses, storage capacity, leakage control, pressure control and efficiency of operations as result of lack of primary facilities (pump stations, reservoirs and adequate network).

Distribution System status before implementing WLRP

Presently, storage facilities of the water supply system comprise 10 reservoirs with an overall useful capacity of 14,700 m^3. Their individual capacity reservoir ranges between 150 and 5,000 m^3.

Since 1932, the distribution network has been continuously expanded to the present with total length of about 290 km of transmission lines (diameter of 2” to 12”). This figure does not include the pipes with diameters less than 2” where the house connections are falling in. The pipe material of the networks at that time consisted mainly of steel, ductile iron, cast iron (some 500 m only) for the diameters more than 3” and of galvanized steel and polypropylene exclusively for the smaller pipes.

With over 37,000 house connections, the entire town population is connected to the water supply system (connection rate 100%). The distribution system is composed of several water supply zones. Some individual supply zones were interconnected. A continuous water supply is ensured only in the old part of town and areas connected along the transmission mains from the external sources. The modern quarters were divided into over 10 water pumping zones that were supplied with water mostly twice a week for several hours. By this operation mode, the municipality intended to distribute the available water equally and to limit the times of excessive pressures in the network and consequently the technical water losses. Before WLRP, there were 10 pumping stations distributed in different areas of the city.

Deficiencies in the distribution system before the WLRP

The water supply system was designed mostly without exact calculations but rather based on estimates and historical figures.

1. Due to the high differences in altitude within the city, insufficient definition of pressure zones and several sub-service areas being supplied by direct pumping without balancing reservoirs, water pressures can reach excessive levels in some parts of the network. This was one of the main reasons for high physical water losses and more than ten pipe breaks daily, mostly occurred in the house connections.
2. Most of the old pipes had been laid without proper sand bedding. In particular pipes of smaller diameter were laid very close to the surface or even on the ground. Thus, the increasing traffic also led to pipe bursts and other damages.
3. The undersized distribution lines (in particular in the outskirts of Nablus) caused high head losses and the customers in the areas of higher ground levels were supplied insufficiently.
4. The intermittent supply produced long idle periods of water in pipelines and house reservoirs and, as a result negative pressure, which possibly caused sewage to enter the drinking water

network, and which led in individual cases to a contamination of drinking water. In addition to that the intermittent supply allowed the air to fill the pipes during the shut off time, and that affected the accuracy of water meter readings.

5. The intermittent supply regime in combination with overrated pumping facilities (usually one pump supplies areas located at substantially different altitudes, thus creating excessive pressure in the system and at the house connections. Having in mind that fittings (small diameters for private consumers) are usually not of the very best quality, the over pressure created was often reason for pipes bursts.

2. Methodology/ restructure strategy

The objective WLRP that have been funded by KFW was the rehabilitation and restructuring of the water distribution system of Nablus city in order to reduce technical water losses and increase energy and operating efficiency.

The German Government through KFW has allocated EURO 17.1 million as a grant for the implementation of Water Loss Reduction Nablus Project. The Executing Agency Nablus Municipality (NM) contribution was EURO 1.71 million. The implementation of the physical measures was concluded by the end of 2011 and major parts were put into operation at beginning of the year 2012

The program is based on a long term planning concept until the year 2025 and on a hydraulic analysis study submitted in 2005.

The establishment of restructured areas (Pressure Zones), including construction of water transmission, storage facilities and new pumping facilities (Pump Stations) as well replacement of existing ones which cannot meet the restructuring philosophy. Reinforcements of primary and secondary mains and the installation of flow measurement facilities at reservoirs and pumping stations are also included. Each individual area of the restructured whole system will be termed further as “Pressure Zone” (PZ).

The redesign idea of the water supply system under WLRP program proposes to establish 28 separate pressure zones. Each zone shall be fed with water by a separate supply source, either by

- Direct pumping,
- Direct pumping through the zone into a balancing reservoir,
- Gravity supply.

Restructuring the water system enables:

1. To avoid high pressure and thus minimize pipe breaks and water losses.
2. To better monitor the water inflow and outflow (water balance).
3. To reduce energy consumption.

The scope of work included the following pipelines:

1. 66km of distribution mains DN90 and DN11O PE and DN15O to DN400 Dl.
2. 15.6 km of transmission mains DN200 to DN350.
3. 2,590 Nos. house connections.

4. Structural, Mechanical and Electrical works which included the works in 17 locations (10 existing and 7 new) which implied the construction of new reservoirs and pumping stations.

3. Energy saving

Concerning the electricity costs for pumping, those for pumping inside the city (excluding the wells), have been separated from those pertaining to the wells. The former is reduced by the project. From 0.93 kWh per m^3 before the WLRP of water distributed (according to Hydraulic Analysis Study of the Nablus Water Supply Report in 2010 carried by the German Consultant Lahmeyer/SETEC/ACE) to 0.59 kWh per m^3 after WLRP.

To evaluate the effect of WLR on energy consumption, data analysis was carried out for energy consumption for the pumping stations for the years 2011, 2012 and 2013. The result is shown in figure (1), it is obvious that the energy consumption goes down to average annual value of 0.59 kWh per m^3 in 2013. That contributes to 36% reduction in energy consumption. The value of energy consumption goes beyond the target value (0.77 kWh pet m^3) that was settled by the consultant as a target to be achieved after the project implementation.

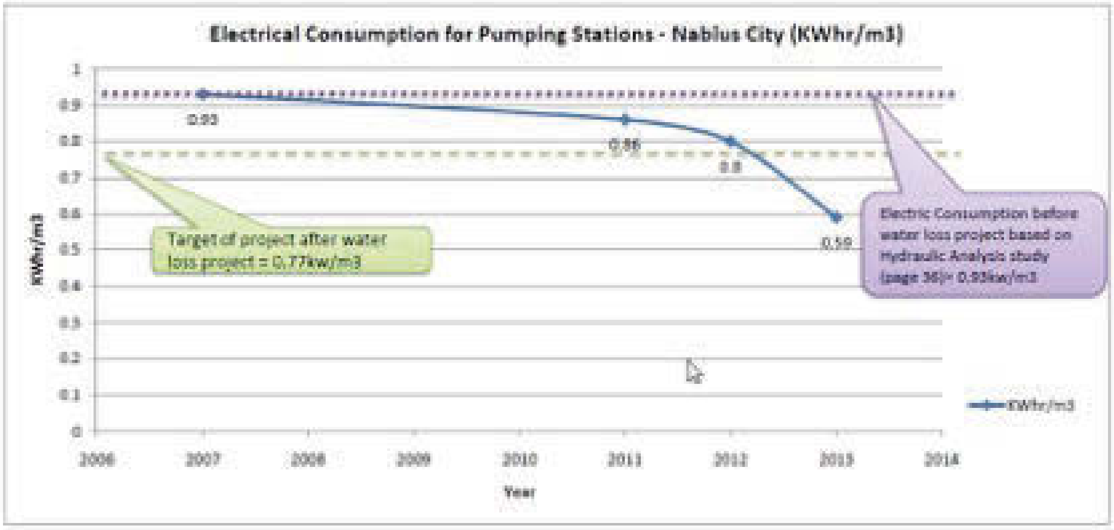


Figure (1) : average annual energy consumption 2011-2013.

4. Challenges and Obstacles

During the Water Loss Reduction project, the pressure zones were not isolated completely and also the old network was not separated totally from the new one. An additional fund from KFW is used by Water Supply and Sanitation Department fWSSD) at Nablus Municipality (NM); to complete the isolation of the pressure zones, to complete the monitoring system of network indicators and to install a SCADA system as a short term actions in the way to implement NRW strategic plan.

The main challenge is that the new installed pumping sets (two or three pumps) and their pump control have been designed assuming 24h supply/service, while presently, several pressure zones are supplied intermittently due to the deficit in water supply in relation to the demand. The current kind of operation leads to the fact that in some cases the pumps are operated outside their operating range and thus some of them get damaged. This holds especially for the time of filling the empty pressure zones. Furthermore it seems that some pump groups are not capable to deliver sufficient pressure to reach high elevated customers. This is because some of the pressure zones have been extended above their designed pressure zone boundaries. To solve the problem, first of all the operational conditions for each pump group and pressure zone have to be defined and analyzed in greater detail. This means:

1. The Pressure zones have to be physically separated in order to create constant operational conditions.
2. Operational data of each pump group needs to be collected and evaluated
3. Pressure loggers have to be temporarily installed within the pressure zones in order to monitor pressure during a pumping cycle.
4. Possible functions of the Modulating Pump Control Valve (MPCV) have to be investigated and checked in case of variable speed pumping.
5. If applicable, a hydraulic model has to be set up for each pressure zone. The model has to reflect the storage capacities of the roof top tanks to allow a realistic simulation of the system. When possible the hydraulic model needs to be calibrated.
6. Each pressure zone has to be verified, if operational conditions meet the individual characteristics of the installed pumps. Especially it has to be checked, whether the design head of the pumps is sufficient to supply the customers at upper elevations.

5. Accompanying measures

Water distribution network and related facilities have been rehabilitated and restructured. Physical implementation which comprised of installing new water pipes and house connections, installation of 28 pressure zones, as well as the rehabilitation of relevant reservoirs, pumping and booster stations, those works were concluded in 2011. Major parts of the systems were put in operation at the beginning of 2012, however works are still ongoing and challenges have to be faced.

After WLRP was put into operation still the water losses was high, accordingly KFW decided to investigate the reasons behind that by implementing Operational Assistance (OA) project, the objective of this project was to optimize the general management of efficient operation and maintenance of the water supply facilities. This especially concerns the pressure and water loss management in 28 pressure zones and future District Metering Areas (DMA5), as well as the sustainable and efficient operation of more than 80 pumps and their related reservoirs. Part of the assignment is to develop necessary operational strategies and concepts as well as to identify and to implement adequate training activities.

Overall the measures shall contribute to the main objectives of WLR program which are:

1. Reduction of water losses from presently 40 % to 25 %.
2. Reduction of energy costs by the development of a pumping concept and optimization of pump efficiency.
3. Increased availability of water resources to be able to supply 7 days/week instead of 2-3 days/week after finishing the construction of new transmission line of a new drilled well in Nablus west.

The following points shows the measures that are already finished and the others that are still ongoing:

Implemented measures

1. Determination the boundary of pressure zones and solve the problems of zone overlapping
2. Providing the WSSD-NM with the technical basis for collecting the data needed by installing measurement devices (pressure & flow) at each relevant point of the network in order to get an optimal information about the water production and the water consumption not only for the whole network, but also for each distribution zone and even for smaller units within the big distribution zone. Magnetic water meters will be installed at production points and distribution station inlets, at main stations outlet and at reservoirs.

Measures under implementation

1. Finalizing the separation of pressure zones in the water supply network of Nablus by :replacement and new construction of pipes including house connections, disconnect the pipe from old system and removing the valves (Mostly done).
2. Although there was a Tele-control system depending on Gather Packet Radio Service (GPRS) communication, which implies hand shaking between the sending pumping stations and receiving reservoirs, a SCADA system with a central control room is being installed for water supply system of Nablus, including data evaluation tools, to monitor the flow and pressure in order to detect leakage (bursts) and monitor the chlorination system and control pumping station, the SCADA will be capable to make many computations like water balance and operational efficiency (will be under operation in February 2015).
3. Education and training: including training on the customization of the SCADA-system, training needs on pump operation and maintenance and training in predictive and preventive maintenance (ongoing).

6. Action to be implemented

After the analysis, an appropriated operational concept need to be developed. The main object of the concept shall be to operate the installed pumps in a way that damages and break downs are avoided. On a short notice there are the following scenarios:

1) Switch to a constant supply as soon as possible. This would mean that the systems are pressurized 24h and that the pumps could be operated according to their design by a pressure depending frequency control (new transmission line from the new drill well are under construction).
2) Stay with intermittent supply but reducing the intervals between pumping. This would prevent a complete emptying of the installed roof top tanks and thus reduce the time needed for filling the zones.
3) In cases where the lifting head of the installed pumps is not sufficient and adjustment of the impeller or the installation of additional booster pumps with higher head might be an option.

- Concerning the quality of repair the following challenges have to be faced:

Material management need to be improved. In general spare parts, pipes and fittings have to be on stock for all installed materials and dimensions. A big problem is that the new Ductile Iron (DI) for pipes and fittings installed under WLRP are not available on the local market. Strategies have to be found, how to purchase the required materials in a reliable way. Furthermore quality standards have to be improved. Skills of staff need to be improved. Especially the technicians and operators need to be trained on the correct handling of new pipe materials like DI and PE. Furthermore additional training on leak detection is required. Documentation of repair needs to be improved. All information collected during repair measures should be captured and used for updating of network documentation and failure statistics. To realize this necessary processes between workers in the field and GIS unit have to be defined. Necessary equipment and tools need to be purchased. For efficient and good quality repair additional tools, equipment and transport are required. Organization of preparatory works needs to be improved.

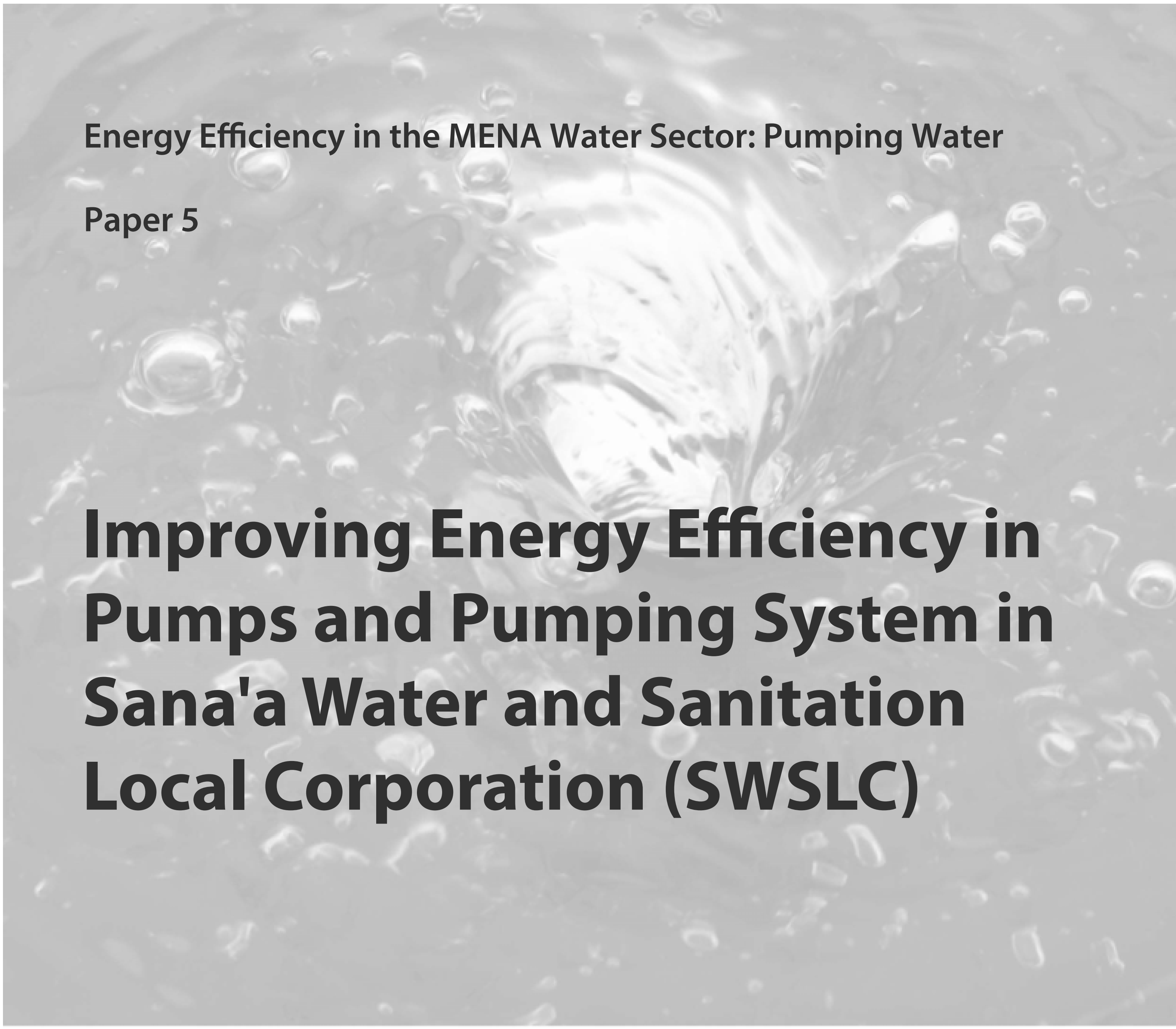
To improve reliability and quality of the water balance the following challenges have to be faced:

1) Improvement of customer water meter management. Customer water meters need regular replacement or calibration. Common mechanical water meters every six years. This means that the sixth part of all meters has to be calibrated or replaced during one year.
2) Quality of customer water meter needs to be improved and adapted to the operating conditions (intermittent supply, water quality, volumes to be measured). Quality standards should be introduced. Practice of meter installation and house installation needs to be improved and standardized.
3) Introduction of the infrastructure leakage index (ILI). The performance indicators which are presently in used (absolute water losses, water losses in %) don’t reflect the condition and the pressure of the networks. The infrastructure leakage index is a good addition to the applied water loss monitoring and will help to better compare the performance of the several pressure zones.

7. Learning lessons

1) Lacking in data base was the main obstacles in separating the pressure zones. Although there were drawings for the newly installed networks (since 2005), there was no documentation for the old distribution network systems including house connections. So it was very difficult to know the location of the pipes and fittings during the separation process of zones. Still there is no documentation for the maintenance works carried out by WSSD-NM staff.
2) It is important to insure that the old pipes are completely disconnected before backfilling and asphalting the trenches and before operating the new systems.
3) As the water supply system in Nablus has special circumstances (limited water resources, intermittent supply, roof tanks, topography ....), it is recommended to work with local or regional consultants that have experience in the aforementioned operating conditions.
4) Never use Variable frequency Drive (VFD) and Modulating Pump Control Valve (MPCV) at the same time, there was a contradiction in function by using these two system together.
5) It is very efficient to use VFD in pressure zones for both energy saving and water loss reduction.

Photo shows the natural mountainous topography of Nablus City



Energy Efficiency in the MENA Water Sector: Pumping Water

Paper 5

Improving Energy Efficiency in Pumps and Pumping System in Sana'a Water and Sanitation Local Corporation (SWSLC)

Written by:
Fuad Saleh Saleh Al-Awzari

ACWUA
Arab Countries Water
Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

TABLE OF CONTENTS

Abbreviations

MTBF	Mean Time Between Failure
SWSLC	Sana'a Water and Sanitation Local Corporation VSD Variable Speed Drive
SWL	Static Water Level
DD	Drawdown
PWL	Pumping Water Level
SD	setting Depth
TSD	Total Setting Depth
TDH	Total dynamic head
NPSH	Net Positive Suction Head
BEP	Best Efficiency Point
GIS	Geographical Information System
NWSA	National Water Supply Authority
JICA	Japan International Cooperation
MASL	Meter Above Sea Level
HEM	High Electric Motor
PIIS	Performance Indicators Information System USD United State Dollar
YR	Yemeni Real

Executive Summary

Improving Energy Efficiency in Pumps and Pumping System in Sana'a Water and Sanitation Local Corporation (SWSLC)

Eng. Fuad Saleh Al-Awzari

This paper is concerned with "Improving Energy Efficiency in Pumps and Pumping System in Sana'a Water and Sanitation Local Corporation (SWSLC)".SWSLC is responsible for the delivery of water and sanitation services to the capital Sana'a. High consumption of energy consumed by the pumps is one of the major problems facing the SWSLC. Two kinds of centrifugal pumps are used in this utility, horizontal split and submersible pumps. Horizontal split pumps are used in four main pumping stations and submersible pumps are used for extraction of groundwater from wells. The large consumption of energy is consumed by sub- mersible pumps. The study aims at evaluating the energy of 81 submersible pumps-sets which are operating by SWSLC. The solution of this problem will be through the assumption of two scenarios. The first scenario is the potential saving option due to pumps-sets re- placement. The second scenario by using the modification in pumping system through these methods: throttle valve control, bypass control, modifying impeller diameter and variable speed drive (VSD).

The study reveals that, the average overall efficiency of all existing submersible pumps and the specific energy are 43% and 2.05 kwh/m^3 respectively.By applying the first scenario above to replace the existing pumps- sets to the new pumps with optimal efficiencies 61% - 63%.The specific energy will reduce to 1.27 kwh/m^3, which means a reduction of the annual energy cost from 6,192,301 USD to 4,360,212 USD. In other words, the annual savings in energy consumed by the submersible pumps will be1,832,089 USD with maintaining the same quantities of water to the same head. In short, 29.59% of the total cost of energy consumed by the submersible pumps can be saved annually. In addition, the feasibility study of this scenario indicates that, the costs required to implement this option is 2,600,000 USD while the annual savings in energy costs would be 1,832,089 USD, which means that the payback period of recovery of capital cost will occur after 1.42.This savings in energy costs will impact on improving the performance of the SWSLC and general health of the community. Hence, improving energy efficiency will lead to improving of general health because the customers are obliged to use private wells due to the lack of water production by SWSLC wells during the maintenance times. As a result of this, certain health problems occur, such as impossibility of purification of private wells. In addition, the percentage of citizens who obtain the service will increase substantially, which will spontaneously improve their general health.

About the second scenario, applying the adjusting on pumping system by using these methods; throttle control valve, bypass control valve and modifying impeller diameter are completely useless in all of the fields. While using VSD to improve pump efficiency will be avail- able only in Musaik and Asser fields, because the demand is changing during the day, while using VSD will be useless in Western and Eastern fields.

CHAPTER 1: INTRODUCTION

1.1 Background of the study

“A penny saved is a penny earned“ Benjamin Franklin. Generally Energy is one of the main contributors in water supply price. Improving energy efficiency should be paid attention with the rapid increment of energy production. Pumps and Pumping systems consume about 20% of the total energy which are produced in the world, and around 50% of this energy can be saved up (Giribone, et al., 2006).High energy and maintenance costs are considered one of the main problems that are facing the SWSLC (Alhindi 2013) .Some saving energy studies indicate that pumping system has a big value to save energy. Selecting optimal pumping system is the most important key to reduce operation cost (Ladouani and Nemdil 2004). Choosing a high efficiency pump is not enough to save energy. Achieving maximum energy efficiency needs the selection of a pump-set with high efficiency to work on a good design of pumping system (Kaya 2008). In order to achieve full energy efficiency, system designers and engineers need to understand specific system operating conditions to size a centrifugal pump correctly (U.S. Department of Energy 2008).Many articles address that selecting pump to work at best efficiency point is not only saving energy cost, but it will also provides additional advantages such as: saving maintenance costs for bearings, wear rings, bushes, couplings and seals. Moreover, the risk of cavitation will be reduced. Furthermore, the vibration risk will be minimized. Figure1.1 below shows that operating pump away from best efficiency point will cause problems. When pump operates far from its best efficiency point, it will lower the Mean Time Between Failure (MTBF). So, saving energy will provides the potential to reduce maintenance and decrease time costs. In this figure it can be seen that the curve in grey represents: Mean Time between Failures as a function of operating flow around Best Efficiency Point(BEP). And the curve in blue represents: Failure modes related to operation out of BEP (Violain 2013).

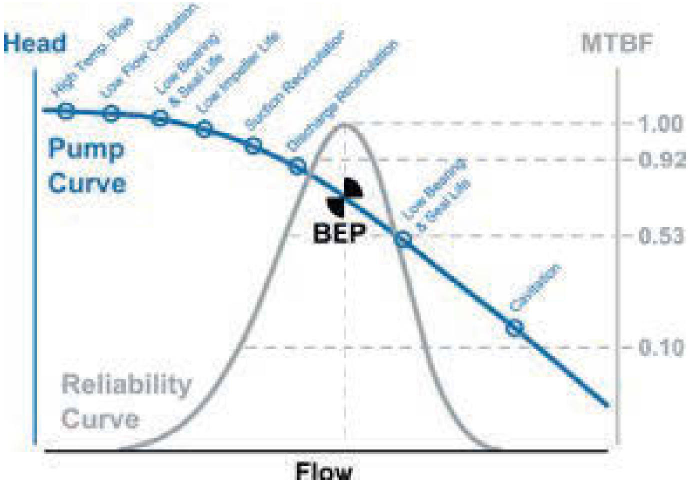


Figure 1. 1. Pump curve sensitivity for centrifugal pump reliability (Violain 2013)

1.2. Pump operating point and best efficiency point

It is important to notice what and where is the operating (duty) point of the pump. Operating point is the rate of flow at specific head. It is determined by the intersection of the system curve and the pump curve. At this point, the pump head equals the system head (Volk 2005). So, It is important to choose the duty point of pump to be in the best efficiency. Figure 1.2 shows the duty point of pump is away from the best efficiency point of pump. As a result, some unnecessarily energy consumption will occur (World pump 2010).

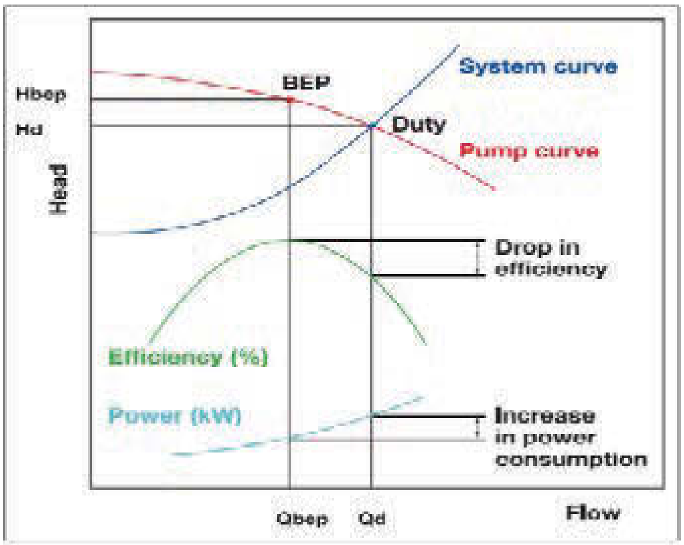


Figure 1.2. Describes the intersection of duty point and BEP (World pump2010)

The mistake of adding more capacity to the pump – to be in safe in future – is made by some engineers. Unfortunately, this over sizing will increase energy and maintenance cost more than choosing the proper size of pump. Besides, excess flow will damage the components of the system, such as: wearing and tearing valves, increasing piping stress and noise will exist (U.S. Department of Energy 2008). Sometimes when designing pumping system, owners are concerned about capital cost, so they decide to choose the lowest prices. But, they didn't notice that the overall efficiency in the system has a better cost reduction.

1.3 Choosing pumps based on initial cost instead of LCC

Achieving optimum pumping system from economic point of view and life cost cycle (LCC) must be taken into consideration during choosing the components of pumping system. In life cycle cost analysis of pump, the initial cost will be less than 15%, while energy and maintenance cost are between 50-95% of the total cost, as shown in figure 1.3 according to JBA study.

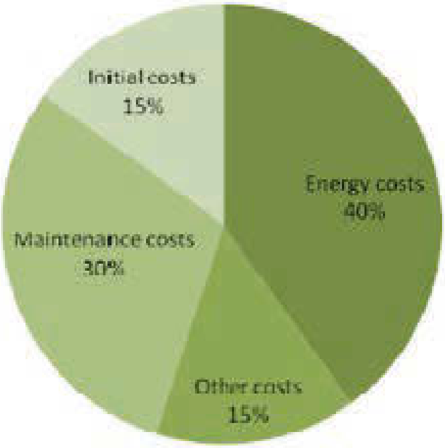


Figure 1.3. Typical proportions in the life cycle cost analysis of a well-maintained medium sized industrial pump (JBA energy)

1.4 Extra benefits of improving energy efficiency of pumps

Evans 2005) addresses more benefits of improving energy efficiency besides saving cost, such as: increase productivity, reduce production costs, reduce environmental compliance costs, and reduce waste disposal costs. In addition, it improves production quality, capacity utilization, reliability and worker safety.

1.5 Main benefits of improvement of energy efficiency in health

Water is the most important requirement for life. Supplying clean water to the whole city is not easy, because the budget of applying new projects is costly. Moreover, the energy cost in SWSLC consumes big percentage of the total revenues. Thus, finding a new way to improve the energy efficiency is essential. Hence, improving energy efficiency will lead to improving of general health because the customers are obliged to use private wells due to the lack of water production by SWSLC wells during the maintenance times. As a result of this, certain health problems occur, such as impossibility of purification of private wells. Also, the percentage of citizens who obtain the service will increase substantially, which will spontaneously improve their general health.

1.6 Problem statement at SWSLC (high power consumption)

High expenses of energy are considered one of the main problems that are facing SWSLC. The following table 1.1 shows the total revenues, as well as the electricity expenses in the SWSLC and the proportion of energy expenses to total revenues based on the budget status report in SWSLC for 2013 (Financial administration 2013). It can be seen that the percentage of energy expenses to total revenues is a big value which approximately equals 35 %.

Table 1.1. The total revenues and energy expenses in the SWSLC of three month July, August, September and the summary from January to September 2013 (Financial administration 2013)

Account type	July	August	September	January to September
Total revenues (YR)	366,907,993	349,965,068	386,293,058	3,911,397,750
Energy expenses (YR)	120,122,929	145,765,295	156,184,918	1,387,500,000
Energy/revenues	0.327392511	0.4165138	0.404317175	0.354732525

In addition to that, there are common problems that are related to the high energy consumption such as: increasing maintenance cost of pumps as result of operating the pumps away from their best efficiencies points, decreasing the total revenues of SWSLC due to reduction of production. Add to that increasing the number of customer's complaints according to not providing them with adequate water.

CHAPTER 2: STUDY AREA AND METHODOLOGY

2.1 Scope of work

The study entitled "Improving Energy Efficiency in Pumps and Pumping Systems in SWSLC" is undertaken to collect detailed information about all drinking wells that are employed in SWSLC – such as details about submersible pumps, wells, pumping system (capacity, type, make, age, rating of submersible motor, flow, energy consumption, total dynamic system and type of pumping to networks directly or to reservoirs). The study provides overview of energy consumption, water flow, overall efficiency and specific energy of all running submersible pumps in SWSLC.

The study included a 72 of working pumps out of 81 pumps, where the rest of pumps were out of service due to maintenance works. The possibility of achieving energy saving has been studied by using the replacement of the existing pumps with optimal pumps which have high efficiencies. Here are the various methodological procedures which were used to achieve the current study.

2.2 Study area

The study discusses the possibility of reducing energy cost of all submersible pumps in SWSLC with maintaining the same productivity of water at the same head. The following figure 1.4 describes the locations of wells in four fields. The wells are located as following: 19 wells in the Western field, 21 wells in the Eastern field,24 wells in the Musaik field and 17 wells in the Asser field (SWSLC 2013). So, the study area is consist of four studies areas as will discuss later.

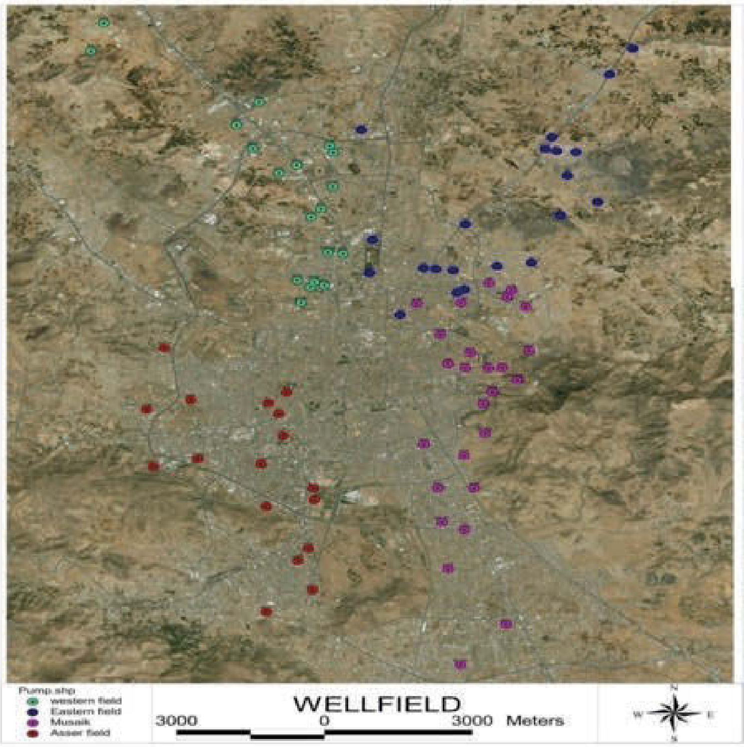


Figure 1.4. Groundwater wells belong to SWSLC in four fields (SWSLC 2013)

2.3 Methodology

2.3.1 Gathering data

The data of each well was collected from SWSLC as follows: specifications of wells, total depth, and diameter of well and riser pipes, specification of bowels – submersible motors and type of pumping. There was a problem in getting accurate information of the static water lev- els and drawdown in some wells. So, data of static level and drawdown on 2008 were obtained from the water resource and production administrations. So, estimating static level was taken by using data in 2008 with adding the annual decline in drawdown between 7-8 meters in each well as the reports of the geological studies at Sana'a basin. The annual energy cost in SWSLC has been collected. In addition to that, data of power index (PI) from PIIS in 2011 and 2012 have been collected. Furthermore, collecting data from the depart- ment of statistics and planning. There was a difficulty to find the maintenance cost of submersibles pumps-sets only. Usually the data from the quantities of water produce should have been analyzed in comparison with the original performance curves that are supplied by the pump producer. But in most of the cases, no data could be found in the central work shop in SWSLC.

2.3.2 Measurements

The measurement was applied only on the 72 working pumps out of 81 pumps, for the rest of pumps were out of service. The power consumption has been measured for an hour by using the electricity meter also the flow rate has been measured for the same time by using water meter as shown in figure 1.5.

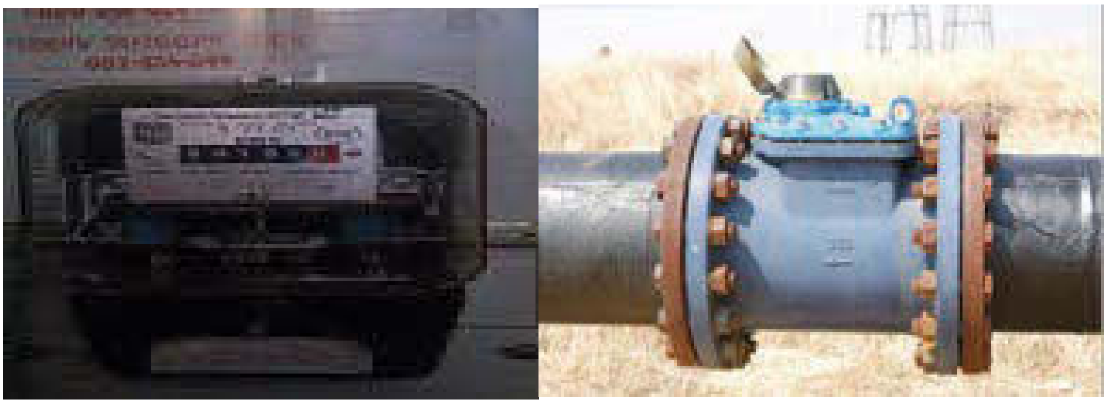


Figure 1.5. Type of water mater and energy meter in SWSLC

2.3.3 Calculations

All of the calculations have been done using Microsoft Office Excel sheets. To calculate the overall efficiency of the pumps-sets, procedures must be done as following:

i. Friction losses and total dynamic head must be calculated. The calculation of the friction losses and total dynamic head for the all of the wells in each field is shown in Appendix 2, 3, 6, 7, 10, 11, 14 and 15

ii. After that, the equation no. 1 was used to calculate the overall efficiency. The existing overall efficiency has been calculated as followings; the power consumption and flow were measured for an hour which equals

……………………………1

Where
Hydraulic power [kW]
Required power on the pump's axis [kW]
Efficiency of the pump

iii. Calculation of the potential energy saving
Potential energy savings can be determined by using the difference between actual system operating efficiency (ηa) and the design (or optimal) operating efficiency (ηo) The following equation no. 2. is used to determine the potential energy savings (U.S. Department of energy 2005)

……………………………2.

Where
Savings = energy savings, in kilowatt-hours (kWh) per year
= input electrical energy, in kilowatts (kW)
t = annual operating hours
= actual system efficiency, calculated from field measurements
= optimal system efficiency.

2.3.4 Second scenario (Adjusting pump performance)

Finding the pump to match the request demand is not always possible. Therefore, few methods are used to achieve the requested demand(Grundfos Industry 2004). The most common methods of adjusting pump performance are:

1- Throttle control
2- Bypass control
3- Modifying impeller diameter
4- Variable Speed Drive (VSD)

An attention must be paid during adjusting the pump performance to achieve the requested performance such as; changing on the volume flow and head, affecting on the efficiency and changing in power demand. Therefore, the priority is to operate the pumps at their best efficiency.

CHAPTER 3: RESULTS AND DISCUSSION

The chief concern of this chapter is to present analysis of the data and the related statistical procedures with a view to obtain a clear picture about the objectives of the study, with the purpose of is, evaluating the existing efficiencies of 72 submersible pumps that are currently operated by SWSLC, and in addition, looking into the potential saving options due to replac- ing pumps which have low efficiencies with high efficient pumps. The results were prepared due to each field separately as following.

3.1 Western field results

The flowing figure 3.1 describes the location of wells which located in Western field.

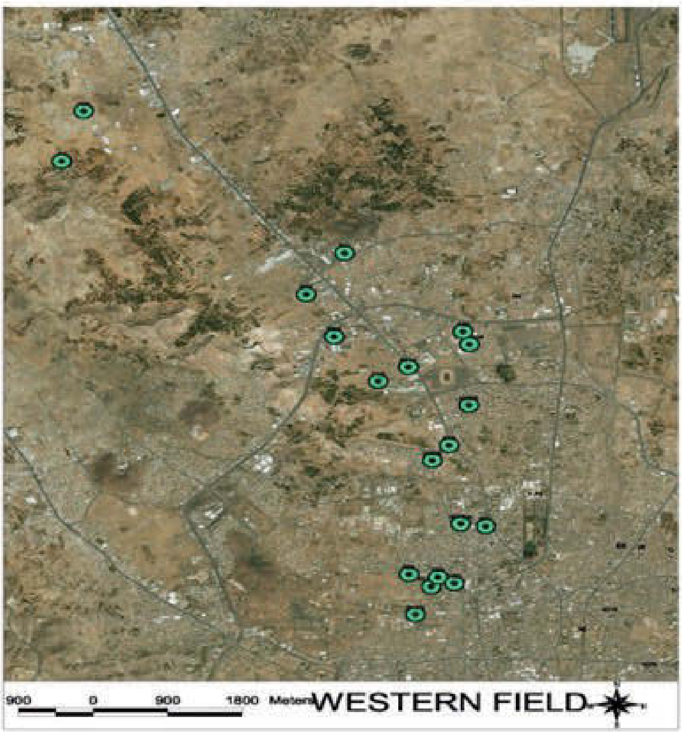


Figure 3.1. Western field wells (SWSLC 2013)

3.1.1 Overall of existing pumps efficiencies – Eastern fields

The overall efficiency is the relationship between the amounts of water produced to the amount of energy consumed.

The fiction losses and total dynamic head have been calculated as shown in the tables in Appendix 2&3.

Table 3.1. Calculation of the overall pumps-sets efficiencies – Western field

No	Well Name	Flow (m3/h)	Total Dynamic Head (m)	Measured Power (kwh)	Overall efficiency
1	ST1	51.04	223.23	68	0.45
2	ST5	14.42	285.32	72	0.16
3	ST6	28.43	243.09	72	0.26
4	ST11	45.73	299.25	76	0.49
5	P10	55.28	229.04	82	0.42
6	p18	30.49	259.30	77	0.28
7	p20	8.99	182.03	49	0.09
8	p22	16.94	310.10	71	0.20
9	p24	19.41	241.56	31	0.42
10	p26	50.52	310.08	80	0.53
11	Nwsa	44.35	252.67	53	0.58
12	D.h	45.00	309.37	81	0.47
13	P23R	32.46	380.53	57	0.59
14	P25R	21.60	273.60	48	0.33
15	P19R	25.33	244.45	58	0.29
16	P28	44.34	315.33	69	0.55
17	P27R	24.61	321.44	44	0.49
The average of overall efficiency					0.39

It can be seen from results in the table 3.1 above, the average efficiency of all current pumps-sets that are operating in Western field is 39%. The overall efficiencies of the pumps that are operating in this field take the range from 0.09% to 59 %. Most of pumps and motors in this field are repaired more than one time during their life span and according to refurbish or maintenance, pumps-sets efficiencies decreases. Furthermore, the results illustrate that the working pumps in following wells ST5, ST6, P18, P2, P22, and P25 Rare operating at low efficiencies. In general, there is a need to know the categories of efficiencies of pumps-sets at this field. Hence, the percentage of pumps that are operating in low, medium and high efficiencies should be identified. Consequently, the categories are clarified as can be seen in figure 3.2 below which indicates that, 41.18% of the total pumps are operating in efficiency below 40% and 35.29% of the total pumps are operating in efficiency between 40%-50%, while the proportion of the pumps that are operating in the efficiency greater than 50% is 23.53%.

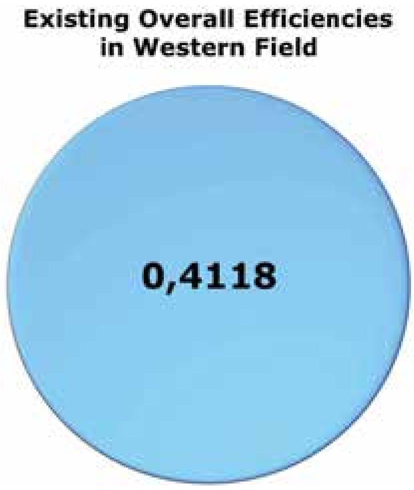


Figure 3.2. Categories of the Western field wells efficiencies

3.1.2 The specific energy of existing and new pumps-sets – Western field

The goal of an energy assessment is to compare the actual specific energy and to compare it to new optimal specific energy. So, the specific energy(Es) (kwh/m^3) is useful to evaluate the energy consumption before and after replacement pumps sets. In addition to that, when comparing between the different pumps. Moreover, when the need of improving the pumping system by comparing between different solutions of modifications in pumping systems. So it will be assuming the replacement existing pumps with optimal pumps to operate efficiently. The efficiencies of optimal pumps will take a range between 61% and 63% as shown in appendix 1 and this choice will be applied to all pumps in all fields. The evaluation the energy consumption, the specific energy between existing and new pumps sets in this field have been calculated as shown in table in the Appendix 4. Even though, figure 3.3 below illustrates the specific energy of existing and optimal pumps in Western field. Through this figure it can be seen that, the following wells; ST5, ST6, P18, P20, P22, P25R and P19R have a great opportunity to reduce energy consumption. So, SWSLC has to give these pumps the highest priority for replacement.

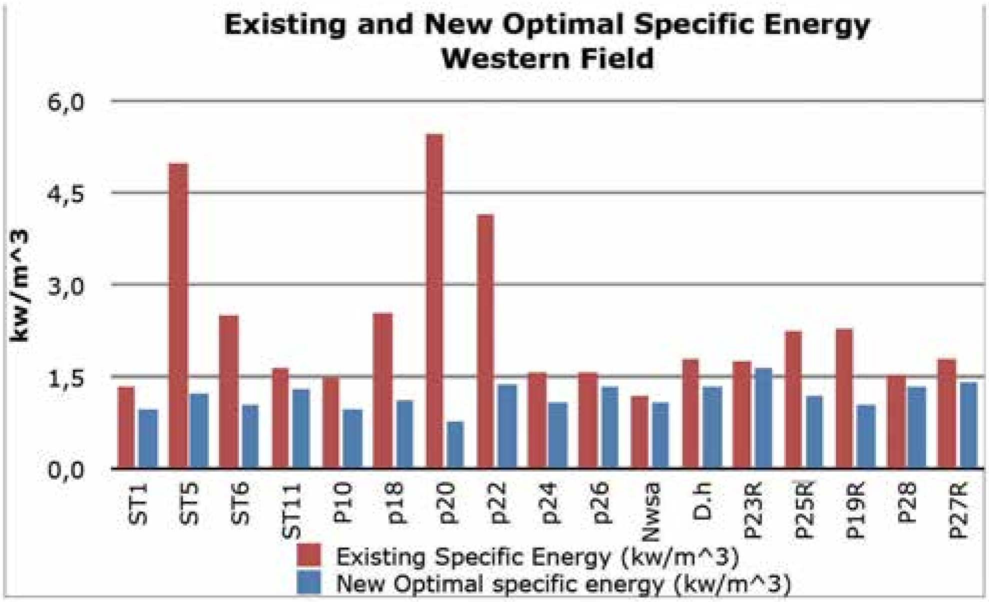


Figure 3.3. Comparison between existing and new optimal specific energy-Western field

3.1.3 Western field energy assessment

Water extraction from the deep wells is energy intensive in all SWSLC fields. For assessment of the energy consumption in this field, the averages of the specific energy of existing pumps and optimal pumps have been calculated. The following figure 3.4 describes the rate of specific energy used to produce a cubic meter of water in case of the existing pumps and new pumps in Western field .It can be seen from the figure, the production of a cubic meter of water consumes 2.35 kWh, while it is possible to produce it by 1.2 kWh only.

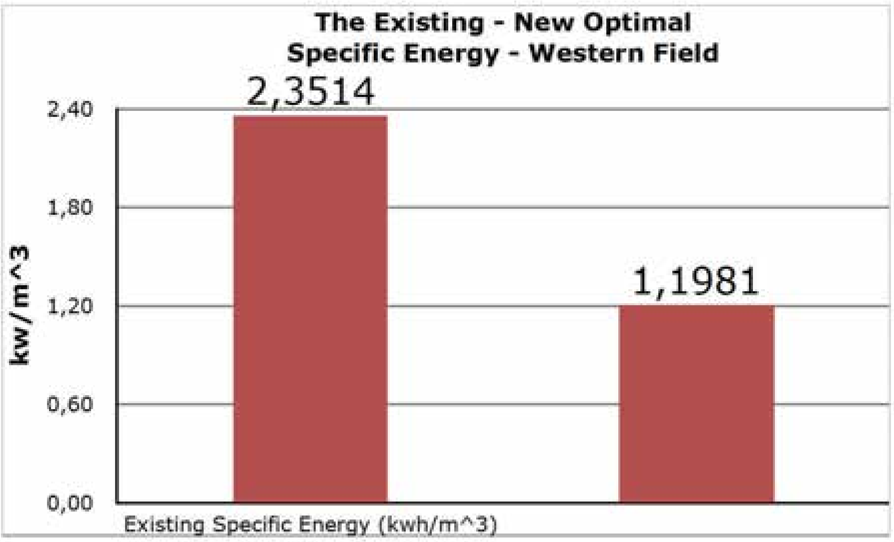


Figure 3. 4. The average of the existing and the new optimal specific energy – Western field.

3.1.4 Potential saving in energy cost – Western field

The feasibility study of replacement the existing pumps with optimal pumps in Western field have been calculated as shown in table in the appendix 5. The annual saving in energy cost in each well in Western field has been calculated by using the difference between actual efficiencies and optimal efficiencies of pumps. The average working hours of the pumps during the year is 8000 hours according to the analysis of the past several years. As has been mentioned in the methodology section, the new optimal efficiencies were selected according to the table in Appendix 1. The prices of pumps-sets were considered according to the tenders of pumps in the procurement and stores administration in the SWSLC for the last three years. From the analysis of the results in figure 3.5 below, the annual energy cost that, which are supposed to pay by current pumps is 1,417,212 USD while the annual cost of energy with optimal pumps will reduce to 878,596.11 USD. This means that the annual savings in the energy cost will be538,616 USD. So, the reduction in energy consumption will have an immediate effect on the financial performance. So, energy efficiency can be enhanced by replacing the current pumps sets with optimal pumps-sets.

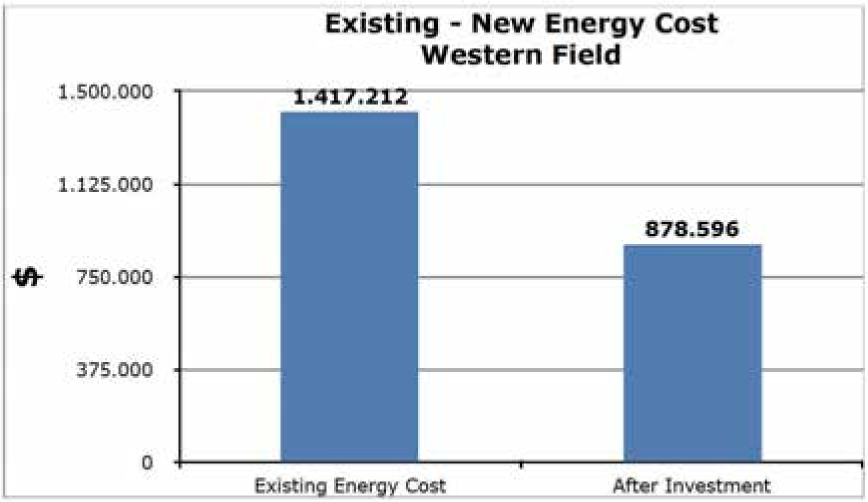


Figure 3.5. The existing – new optimal energy cost at Western field

3.2 Eastern field results

The flowing figure 3.6 describes the location of wells which located in Eastern field.

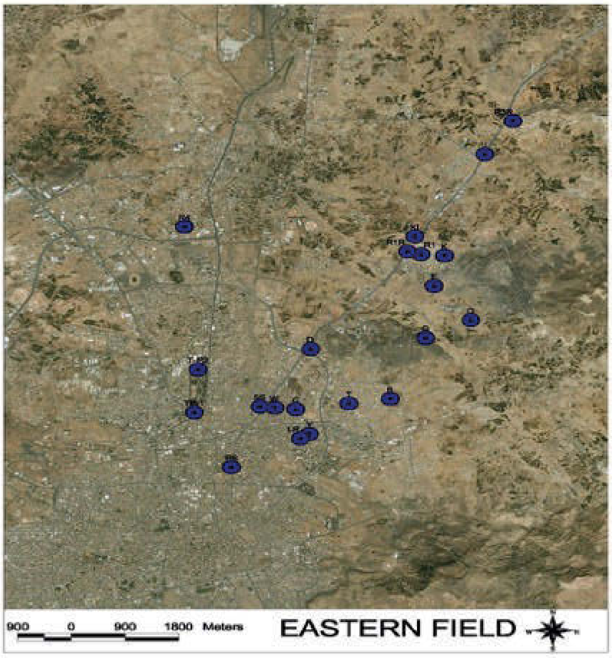
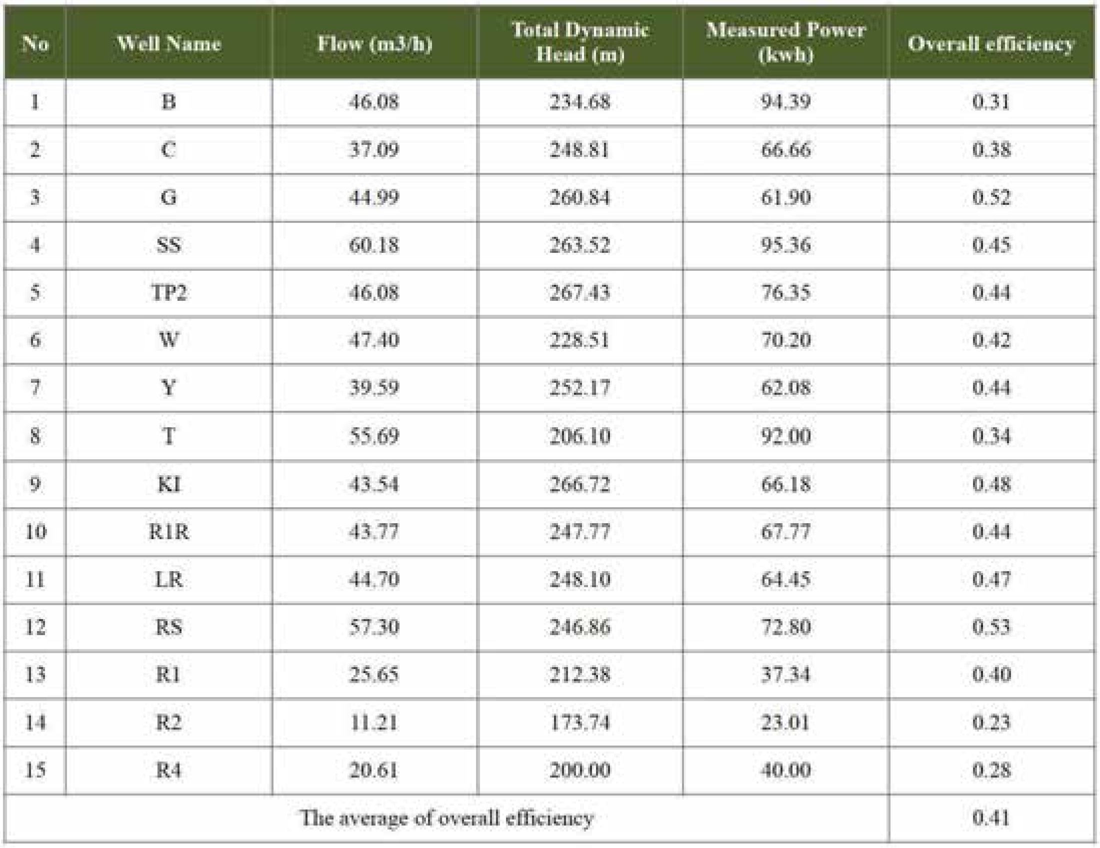


Figure 3.6. Eastern field wells (SWSLC 2013)

3.2.1 Overall of existing pumps efficiencies – Eastern fields

The similarity, Been using the same method that was applied in the calculations of the previous field, power consumption and flow of wells in the Eastern field have been measured for an hour by using the electricity meter and water meter. The fiction losses and total dynamic head have been calculated as shown in the tables in Appendix 6&7.The calculation of existing efficiencies of submersible pumps-sets in Eastern field as shown in the following table 3.2

Table 3. 2. Calculation of the overall pumps-sets efficiencies – Eastern field



No	Well Name	Flow (m3/h)	Total Dynamic Head (m)	Measured Power (kwh)	Overall efficiency
1	B	46.08	234.68	94.39	0.31
2	C	37.09	248.81	66.66	0.38
3	G	44.99	260.84	61.90	0.52
4	SS	60.18	263.52	95.36	0.45
5	TP2	46.08	267.43	76.35	0.44
6	W	47.40	228.51	70.20	0.42
7	Y	39.59	252.17	62.08	0.44
8	T	55.69	206.10	92.00	0.34
9	KI	43.54	266.72	66.18	0.48
10	R1R	43.77	247.77	67.77	0.44
11	LR	44.70	248.10	64.45	0.47
12	RS	57.30	246.86	72.80	0.53
13	R1	25.65	212.38	37.34	0.40
14	R2	11.21	173.74	23.01	0.23
15	R4	20.61	200.00	40.00	0.28
The average of overall efficiency					0.41

The table above indicates the average efficiency of all existing pumps-sets is 41%.The overall efficiencies of the pumps that are operating in the field take the range from 23% to 53%. The results illustrate that pumps-set in wells: B, C, T, R2 and R4 are operating at low efficiencies. The total number of pump sets lying in different range of operating efficiencies as following figure 3.7 which describes the categories of pumps efficiencies in Eastern field as follows: 40% of the total submersible pumps are operating in efficiencies below 40% and 46.67% of the total pumps are operating in efficiencies between 40%-50%, while the proportion of the pumps that are operating in the efficiencies greater than 50% is 13.13%

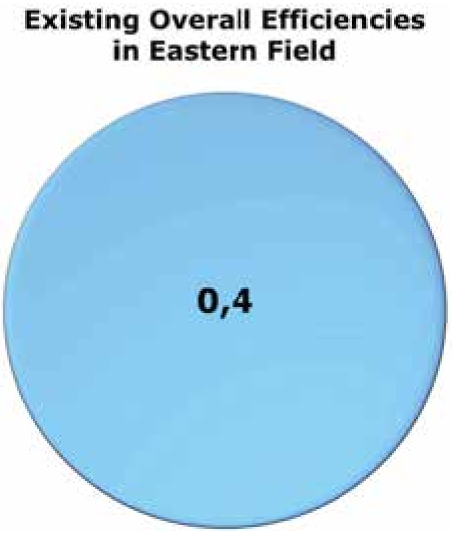


Figure 3.7. Categories of the Eastern field wells efficiencies

3.2.2 The specific energy of existing and new pumps sets – Eastern field

Similarly, the same method which was applied in Western field is used to calculate the specific energy Es (kwh/m^3) in Eastern field as shown in Appendix8. Although, the following figure 3.8 illustrates the specific energy of existing and optimal pumps in Eastern field. It can be seen that the following wells; B, C, R2 and R4 have a great opportunity to reduce energy consumption. So, SWSLC has to give these pumps the highest priority for replacement.

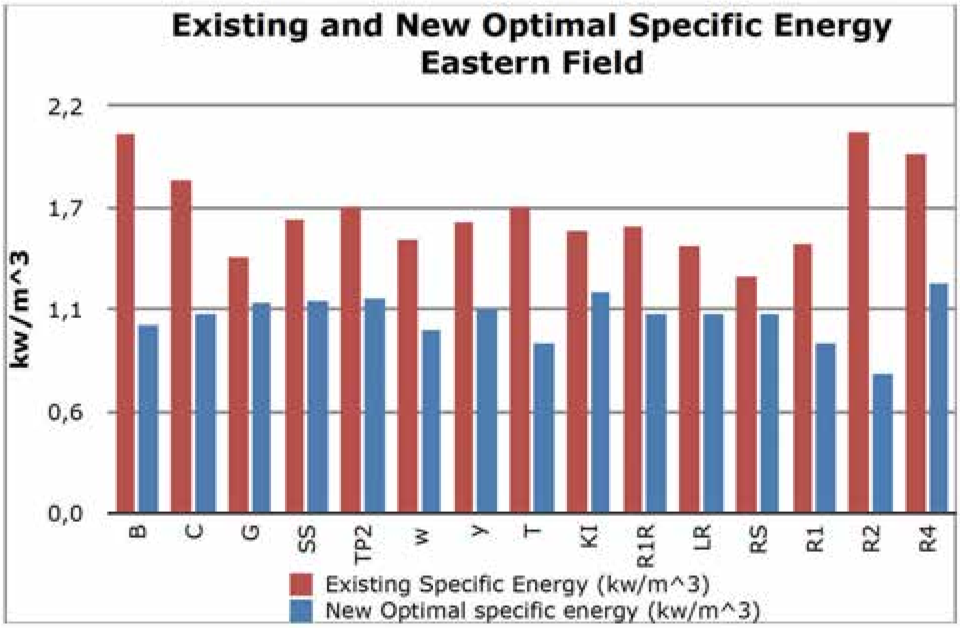


Figure 3.8. Comparison between existing and new optimal specific energy – Eastern field

3.2.3 Eastern field Energy assessment

There is a need to know the energy consumption of producing one cubic meter of water in the event of the current pumps and pumps optimal. The following figure 3.9 shows the rate of specific energy used to produce a cubic meter of water in case of the existing and new pumps in Eastern field. The average of the existing specific energy is 1.63 kwh/m^3 while in case of optimal pumps, the average of specific energy will reduce to 1.06 kwh/m^3.

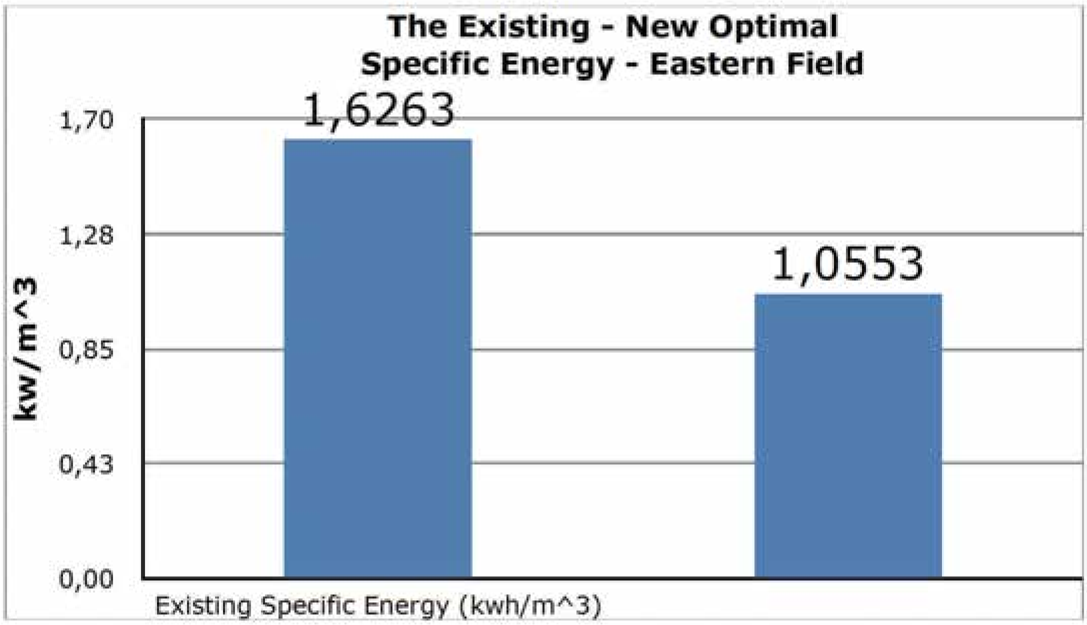


Figure 3.9. The average of the existing and the new optimal specific energy – Eastern field.

3.2.4 Potential saving in energy cost – Eastern field

Figure 3.10 below shows the possibility of reduction in annual energy costs in Eastern field. Potential energy savings have been calculated by using the difference between actual efficiencies and the optimal efficiencies in Eastern field as shown in table in Appendix 9. A summary of potential savings resulting from these improvements is provided in figure 4.8 below, the annual cost of the energy used in this field at the current efficiencies is1,289,937 USD while it can be reduced by optimal pumps to 867,524 USD. As a result, the benefit of replacement the existing pumps by optimal pumps is saving 422,413 USD every year.

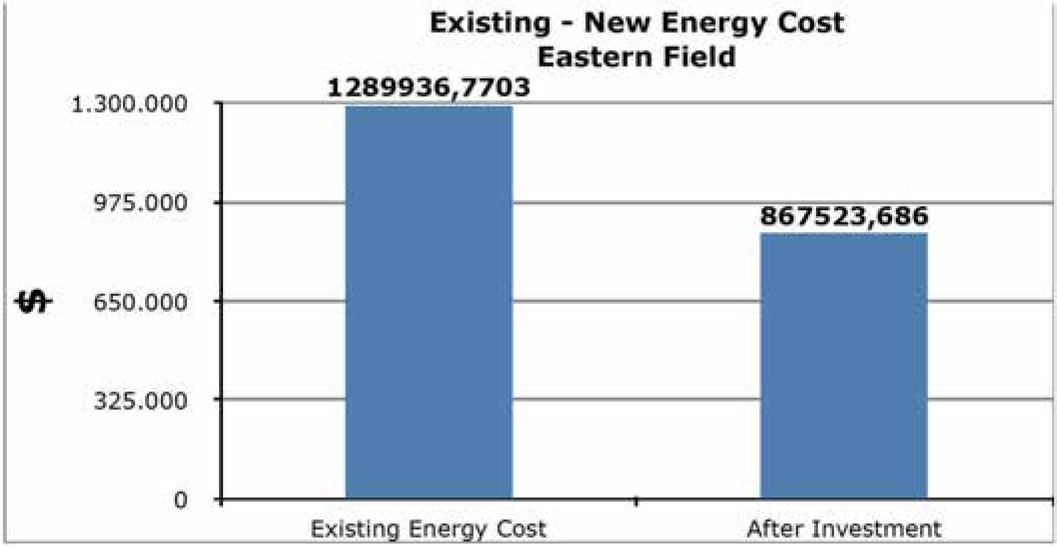


Figure 3.10. The existing – new optimal energy cost at Eastern field

3.3 Musaik field results

The flowing figure 3.11 describes the location of wells which located in Musaik field.

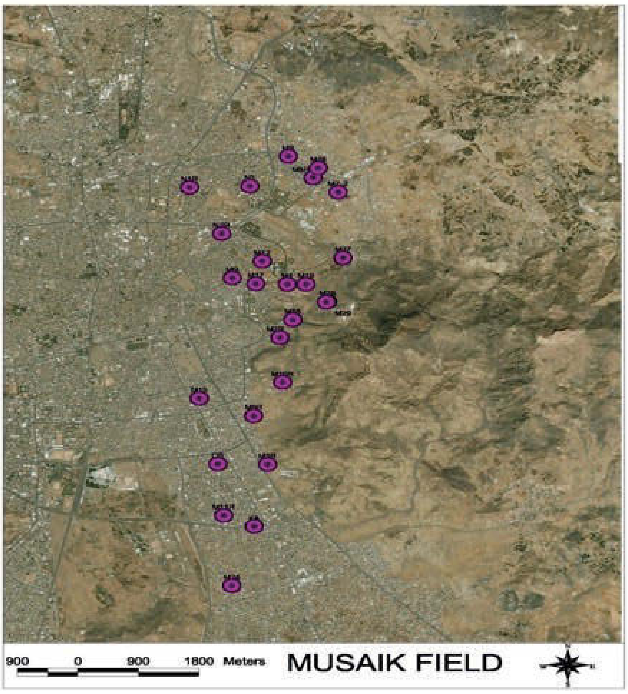


Figure 3.11. Musaik field wells (SWSLC 2013)

3.3.1 Overall of existing pumps efficiencies –Musaik field

Similar to the calculation in the previous fields, power consumption and flow have been measured for an hour by using the electricity meter and water. The friction losses and the total dynamic head have been calculated as shown in the tables in Appendix 10&11.The following table 3.3 shows the calculation of existing efficiencies of pumps-sets in Musaik field wells.

Table 3. 3. Calculation of the overall pumps-sets efficiencies – Musaik field

No	Well Name	Flow (m3/h)	Total Dynamic Head (m)	Measured Power (kwh)	Overall efficiency
1	M1	34.07	356.35	66	0.50
2	KA	60.16	311.41	95	0.54
3	M10R	32.09	339.46	71	0.42
4	M12	42.24	405.06	80	0.58
5	M14	11.81	309.00	51	0.19
6	M16	17.53	249.21	35	0.34
7	M17	46.80	400.84	87	0.59
8	M19	41.07	349.12	66	0.59
9	M19-A	48.96	297.43	70	0.57
10	M24	42.09	296.59	86	0.39
11	O.S	42.36	330.94	118	0.32
12	N2R	41.64	290.48	71	0.47
13	N3	39.70	307.46	62	0.54
14	M9R	41.91	332.90	72	0.53
15	MZ-2	48.87	304.64	84	0.49
16	MS	13.88	240.76	24	0.38
17	M11R	25.10	309.10	46	0.46
18	N1R	38.23	270.02	55	0.51
19	M5R	43.20	298.74	60	0.58
20	N4	22.95	325.68	34	0.59
21	M3R	35.31	349.21	87	0.39
22	M7R	56.23	340.98	84	0.62
23	HZ-1	20.01	372.41	41	0.49
24	M2R	16.44	337.47	49	0.31
The average of overall efficiency					0.47

It can be seen from the table above, the average efficiency of all existing pumps-sets that are operating in this field is 47%.The overall efficiencies of the pumps that are operating in the field take the rang from 19 % to 62 %. Furthermore, the results illustrate that pumps in wells: M14, M16, M24, O.S, M23R, HZ-1and M2R are operating at low efficiencies. In general, there is a need to know the categories of efficiencies of pumps-sets at this field. Figure 3.12 indicates that 29.17% of total submersible pumps of Musaik wells are operating in the effciencies below 40%. Moreover 20.83% of total pumps are operating in the efficiencies between 40%-50% and 50% are operating at efficiencies more than 50%.So, in Musaik field the percentage of pumps that are operating in efficiencies more than 50% are greater than the pumps efficiencies in the Western and Eastern fields.

Figure 3.12. Categories of the Musaik field wells efficiencies

3.3.2 The specific energy of existing and new pumps sets –Musaik field

Similarly, the same method was used to calculate the specific energy Es(kwh/m^3) in Musaik field as shown in Appendix 12. The following figure 3.13 illustrates the specific energy of existing and optimal pumps in Musaik field. In addition, the result indicates that pumps in the following wells: M14, M24, O.S, M3R ,HZ-1 and M2R have a great opportunity to reduce energy consumption. So, SWSLC should give these pumps the highest priority for replacement in this field.

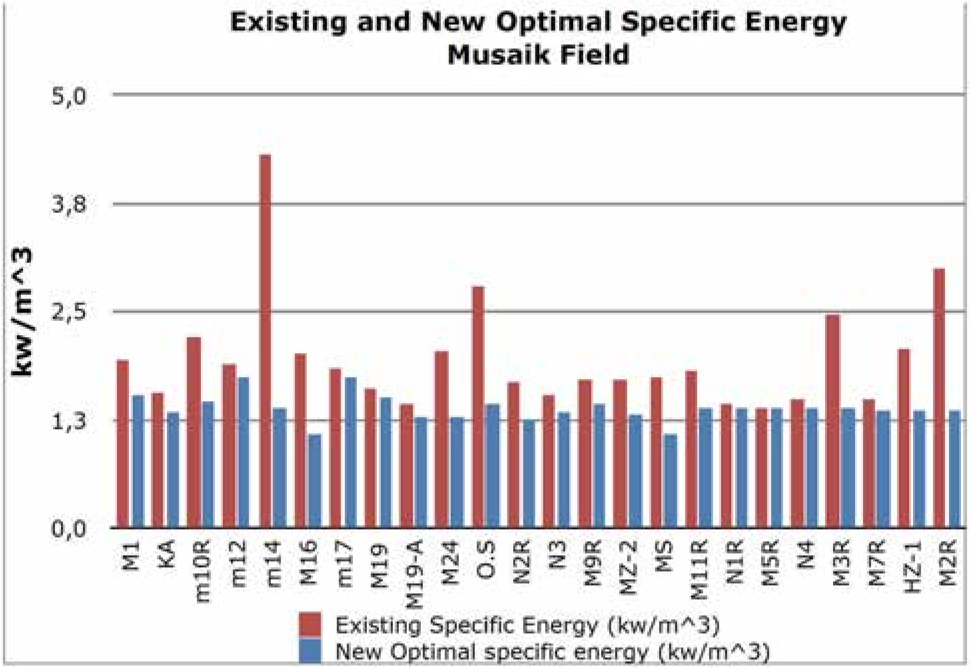


Figure 3.13 Comparison between existing and new optimal specific energy

3.3.3 Musaik field energy assessment

There is a need to know the energy required to produce one cubic meter of water in the event of the current pumps and pumps optimal. The following figure 3.14 illustrates that, the rate of specific energy used to produce a cubic meter of water in case of the existing and new pumps in Musaik field So, the average of the existing specific energy is 1.97 kwh/m3 while, the average of the specific energy will reduce to 1.38 kwh/m^3 in case of the optimal pumps.

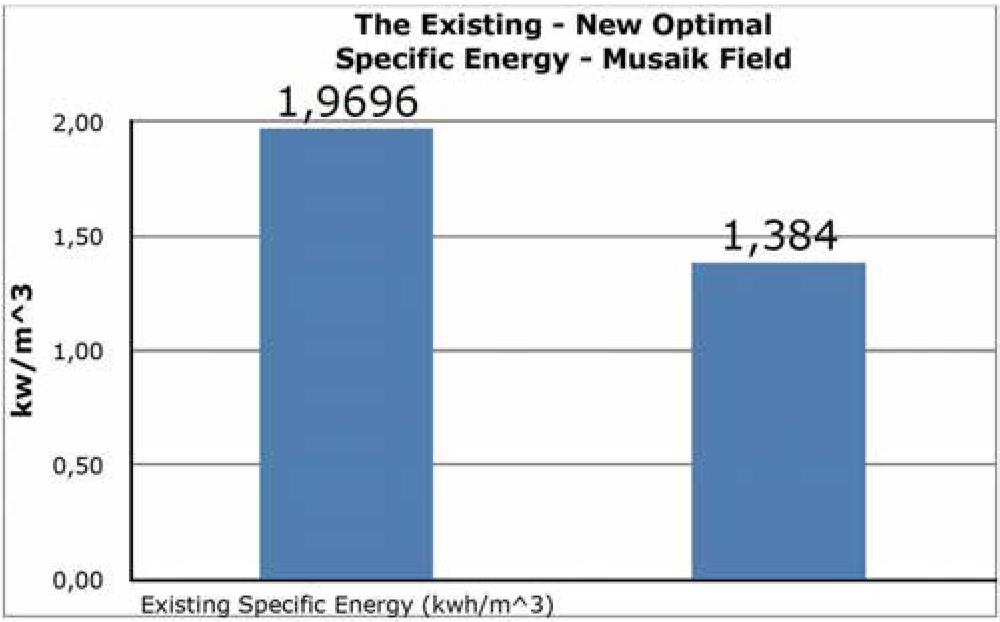


Figure 3.14 The average of the existing and the new optimal specific energy – Musaik field

3.3.4 Potential saving in energy cost-Musaik field

The feasibility study of replacement the existing pumps with optimal pumps in Musaik field have been calculated likewise the same method which was applied in pervious fields. Potential energy savings have been calculated by using the difference between actual efficiencies and the optimal efficiencies in Musaik field as shown in table in Appendix 13. To summarize the results in the table in Appendix, using the following figure 3.15 below which displays the annual reduction in energy cost in Musiak field.

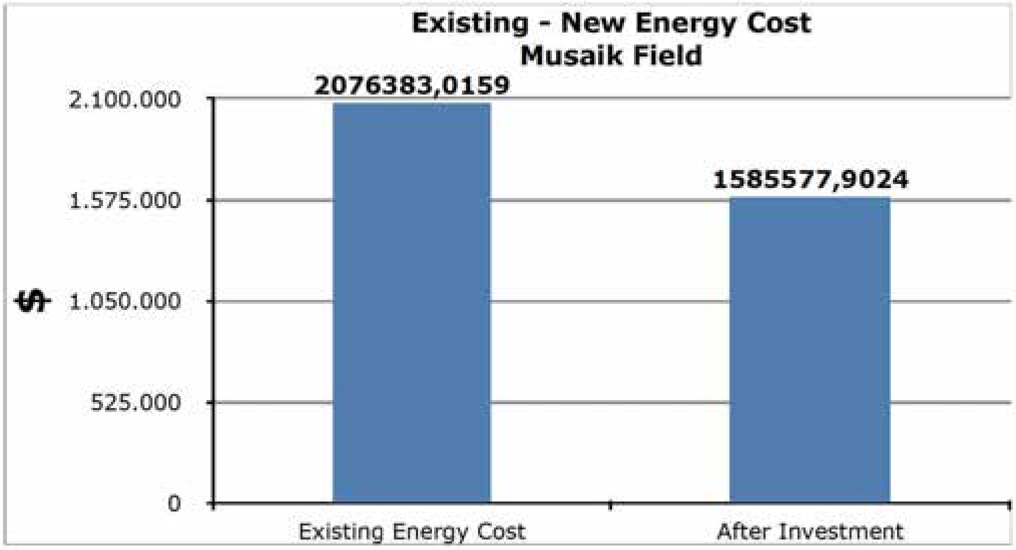


Figure 3.15 The existing – new optimal energy cost at Musaik field

From the analysis of the results in the figure 3.15 above, the annual cost of the energy used in Musaik field at the current efficiencies is 2,076,383 USD while the annual cost of energy with optimal pumps will reduce to1,585,578 USD. This means the savings in the energy cost will be 490,805 USD every year.

3.4 Asser field results

The flowing figure 3.16 describes the location of wells which located in Asser field.

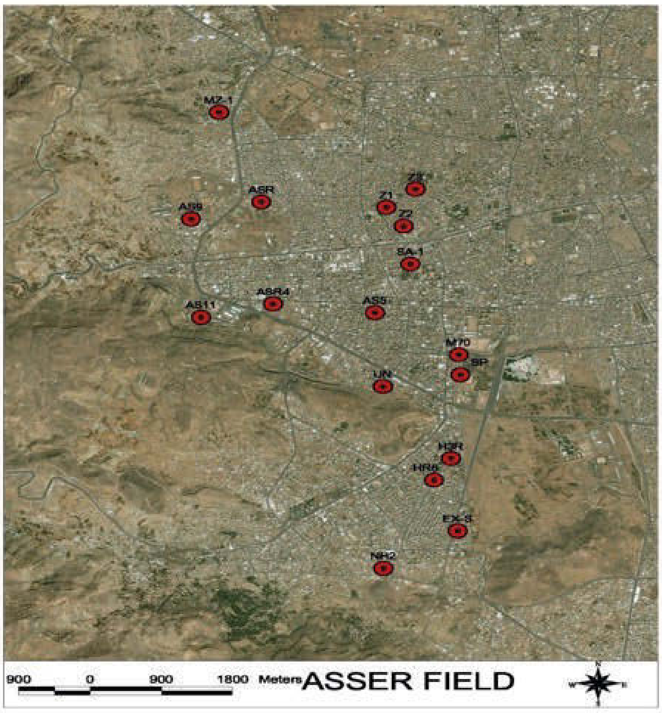


Figure 3.16. Asser field wells (SWSLC 2013)

3.4.1 Overall existing of existing pumps efficiencies –Asser field

As previously method used in three fields before, the power consumption and the flow of wells in the Asser field have been measured for an hour. The friction losses and the total dynamic head have been calculated as shown in the tables in Appendix 14&15.The calculations of the efficiencies of all existing pumps have been done as shown in the following table 3.4.

Table 3. 4. Calculation of the overall pumps-sets efficiencies – Asser field

No	Well Name	Flow (m3/h)	Total Dynamic Head (m)	Measured Power (kwh)	Overall efficiency
1	M70	15.95	390.53	40	0.43
2	SP	47.22	303.01	73	0.54
3	H3R	12.84	273.10	34	0.28
4	EX-S	45.05	355.52	85	0.52
5	H6R	44.64	359.50	94	0.46
6	H8R	57.56	330.38	84	0.61
7	SA-1	41.52	296.76	79	0.43
8	AS9	12.21	380.96	35	0.37
9	AS11	17.64	317.59	81	0.19
10	UN	11.93	318.34	43	0.24
11	ASR4	28.45	283.20	63	0.35
12	MZ-1	43.85	360.52	74	0.58
13	Z-2	58.77	321.32	86	0.60
14	ASR-1	59.23	315.31	84	0.60
15	Z-3	33.00	301.78	44	0.61
16	AS13	26.49	351.35	83	0.31
The average of overall efficiency					0.44

It can be seen from the table above, the average efficiency of all existing pumps-sets is 44%.The overall efficiencies of the pumps that are operating in the field take the rang from 19% to 61%. Also, the results indicate that the pumps in wells; M70, H3R, AS9, AS11, UN, ASR4 and AS13 are operating at low efficiencies. It's important to identify the categories of pumps efficiencies that are operating in this field. The following figure 3.17 indicates that 37.50% of total pumps are operating in efficiencies below 40% and 18.75% of pumps are operating in efficiencies between 40%-50%, while 43.75% of pumps are operating at efficiencies more than 50% in Asser field The proportion of the pumps operating above efficiency greater than 50% is greater than the ratio of the pumps in Western and Eastern fields but it's not bigger than the ratio in the Musaik field.

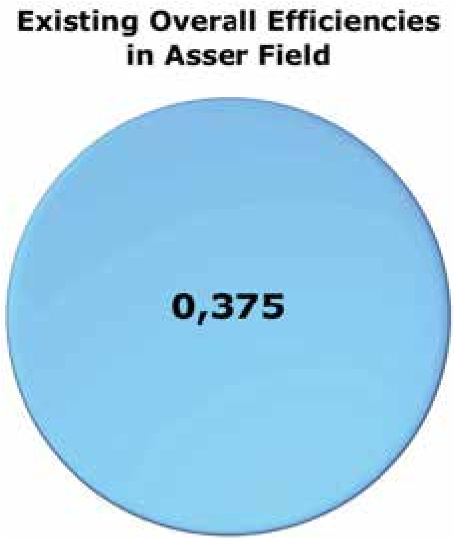


Figure 3.17 Categories of the Asser field wells efficiencies

3.4.2 The specific energy of existing and new pumps sets –Asser field

Similarly, the same method which was applied in pervious fields is used to calculate the specific energy Es(kwh/m^3) in Asser field as shown in table in the Appendix14.The following figure 3.18 describes the specific energy of existing and optimal pumps in Asser field. It can be seen that the following wells;M70, H3R, AS9, AS11, UN, ASR4 and AS13 have a great potential and big opportunities to reduce the energy consumption. So, SWSLC has to give these pumps the highest priority for replacement in this field.

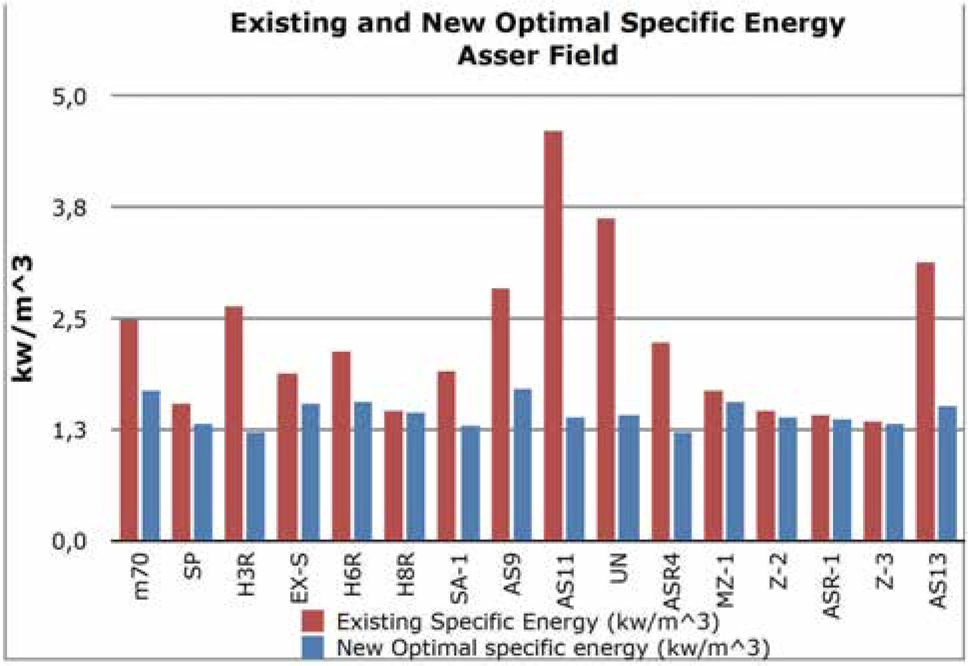


Figure 3.18 Comparison between existing and new optimal specific energy

3.4.3 Asser field energy assessment

There is a need to know the energy required to produce one cubic meter of water in the event of the current pumps and pumps optimal. The following figure 3.19 illustrates the rate of specific energy used to produce a cubic meter of water in case of the existing and optimal pumps in Asser field. The average of the existing specific energy is 2.27 kwh/m^3, while in case of the new pumps; the average of the specific energy will reduce to 1.43 kwh/m^3.

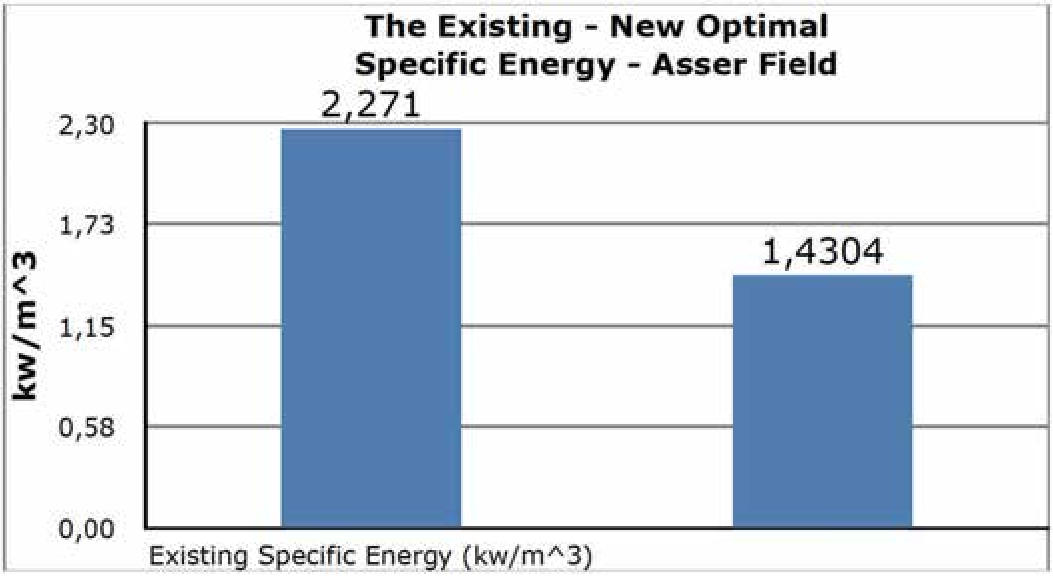


Figure 3. 19 The average of the existing and the new optimal specific energy – Asser field

3.4.4 Potential saving in energy cost – Asser field

As previously method used in three fields before. Table in the Appendix 17 indicates the annual saving and payback period of each well in Asser field. Potential energy savings have been calculated by using the difference between actual efficiencies and the optimal efficiencies in Asser field. To summarize the results in the table in Appendix, using the following figure 3.20 below that displays the existing and new energy cost in Asser field.

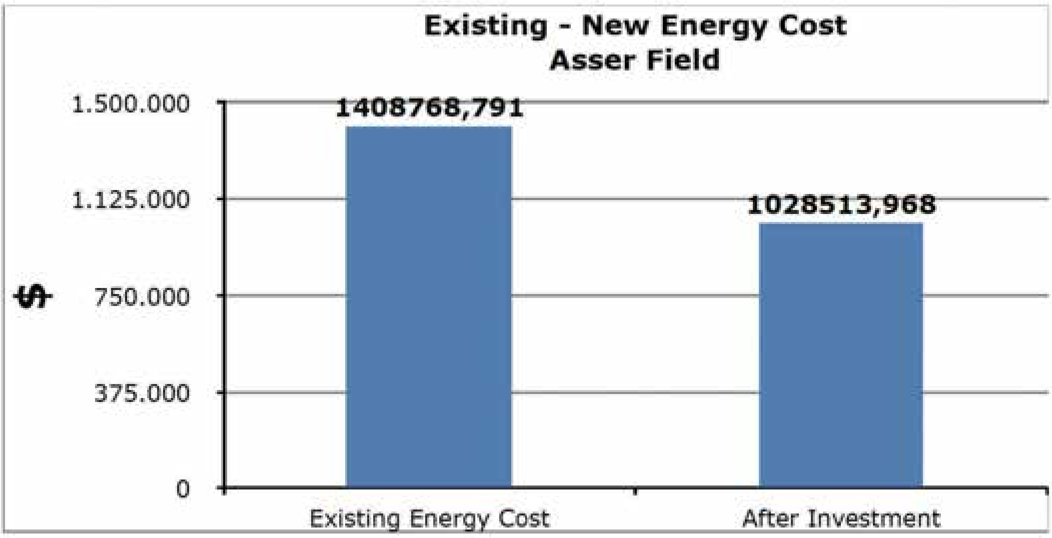


Figure 3. 20. The existing – new optimal energy cost at Asser field

It can be seen from the figure above, the annual cost of energy with existing efficiencies at Asser field is 1,408,769 USD while the annual cost of energy with optimal pumps will reduce to 1,028,514 USD. So, the benefit of replacement the existing pumps with optimal pumps is saving 380,255 USD every year.

3.5 SWSLC fields results

3.5.1 Existing efficiency and specific energy at SWSLC fields

There is a need to know the average amount of energy required to produce a cubic meter of water in all fields in case of current pumps and optimal pumps. The following figure 3.21 summarizes the difference between the specific energy of production one cubic meter of water under the current efficiencies, as well as the specific energy of production one cubic meter of water in the event of use optimal pumps as discussed in earlier chapters in all SWSLC fields.

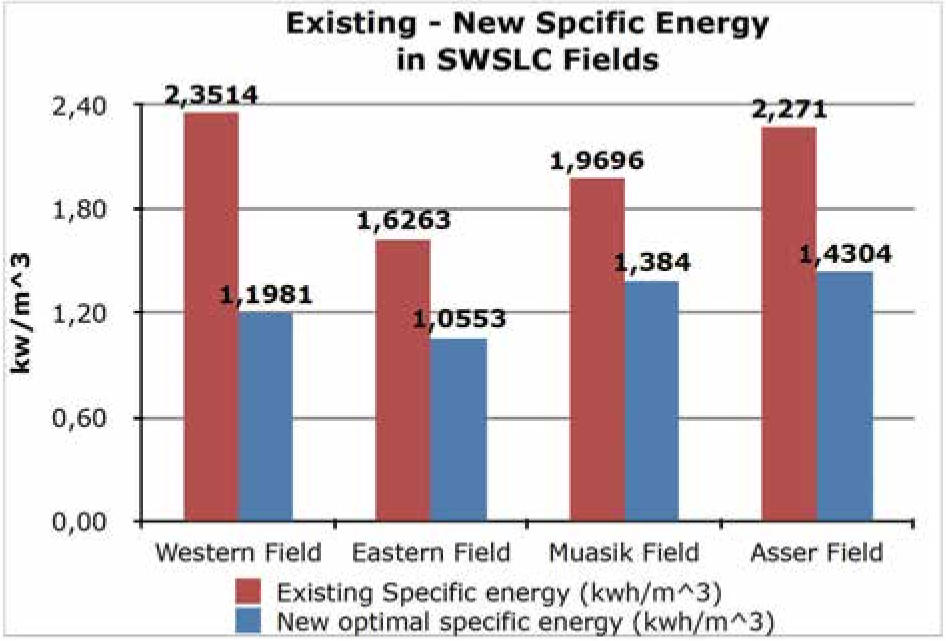


Figure 3.21. The average of the existing and the new optimal specific energy – SWSLC fields

The following table 3.5 summarizes the average efficiencies of the all pumps in each field. The results in table indicate that the average overall efficiency of all existing pumps that are operating in SWSLC fields is 43%. Add to that, there is a possibility of reducing the amount of energy needed for production cubic meters of water from 2.05 kwh/m^3 to 1.27 kwh/m^3 at all SWSLC fields.

Table 3. 5. Existing efficiency and existing – new specific energy at SWSLC fields

No	Field name	Existing efficiency	Existing specific energy (kwh/m^3)	New optimal specific energy (kwh/m^3)
1	Western Field	0.39	2.35	1.20
2	Eastern Field	0.41	1.63	1.06
3	Muasik Field	0.47	1.97	1.38
4	Asser Field	0.44	2.27	1.43
	Average	0.43	2.05	1.27

3.5.2 Summary of results at SWSLC fields

Figure 3.22 below shows the existing energy cost, new optimal energy cost, the opportunity of annual saving and the payback periods of all fields in SWSLC. It is found that, the total annual cost of energy consumed by the current pump is 6,192,301 USD, while the annual energy cost with optimal pumps will be 4,360,212 USD. So, the annual saving of the energy cost will be 1,832,089 USD without reducing the quantities of water to the same head. SWSLC sometimes don't be aware of the electrical energy utility bill and that easy changes in operations can guide to important savings in energy cost. While, water system management and operations team members are often ignore the energy costs. So, SWSLC should provide incentives to staff who are responsible to minimize energy usage.

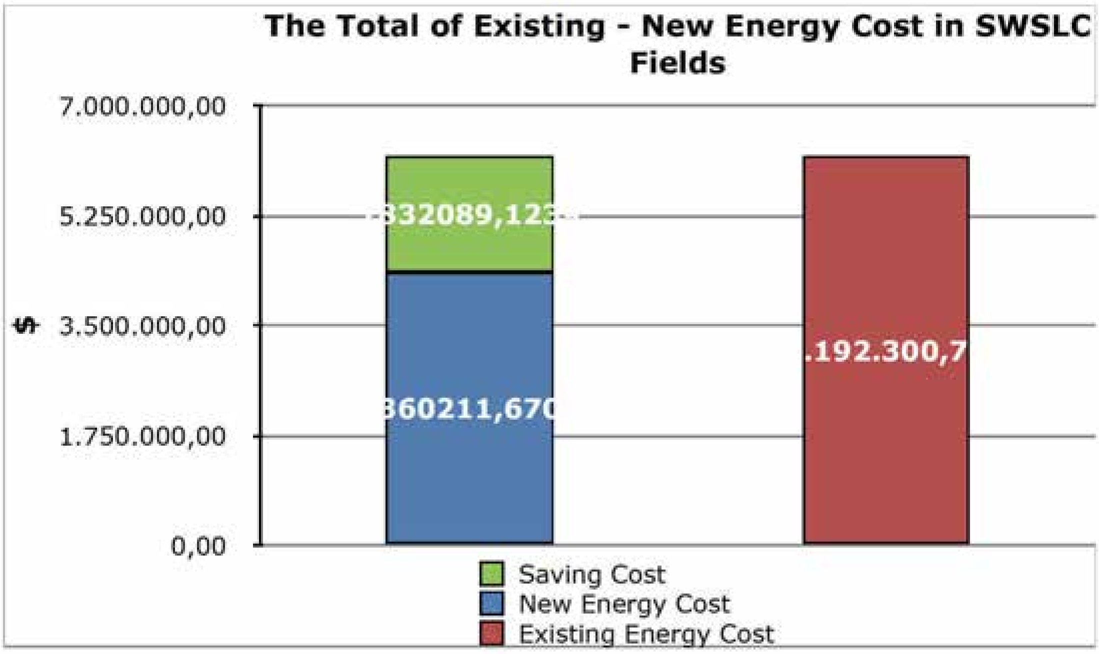


Figure 3. 22 . The existing – new energy cost and the opportunity of saving energy cost in SWSLC

SWSLC should understands all of the concepts and considerations for the following things during pumping system: improving energy efficiency, increasing productivity, reducing operating costs which reflect on increasing the total profits. It can be seen from the figure 3.23 below, the opportunity of annual saving in energy cost is 29.59% out of the annual existing energy cost that are used by submersible pumps.

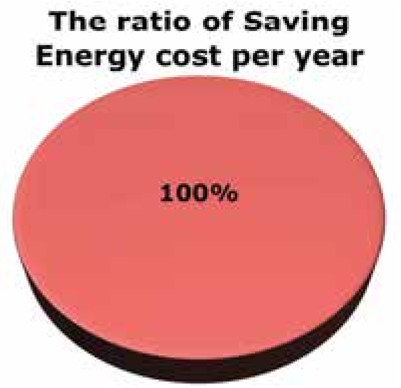


Figure 3. 23. The ratio of the energy cost reduction at SWSLC fields

3.5.3 Feasibility study

3.5.3.1 Payback period calculations

By studying the economic feasibility study as shown in the table 3.6 below, the total cost of all new investments to replace all existing submersible pumps is 2,600,000 USD, while the annual saving in energy cost will be 1,832,089 USD. Therefore, the payback period will occur after 1.42 year. One common decisive factor is the time of payback period to recover the capital cost of optimal pumps with an annual energy saving cost in the table below 3.6 and 3.7, Western field has the highest energy saving cost, while Asser field has the lowest energy saving cost. So, Western field has to be given the top priority for investigation regarding the current situation of pumps efficiencies, energy saving potentials and payback period.

Table 3.6. The Existing, new optimal energy cost and payback period at SWSLC fields

No	**Field Name**	**Existing energy cost/y($)**	**New energy cost/y ($)**	**Investment cost($)**	**Saving cost/ y($)**	**Payback Period (y)**
1	Western Field	1,417,212	878,596	560,000	538,616	1.04
2	Eastern Field	1,289,937	867,524	505,000	422,413	1.20
3	Muasik Field	2,076,383	1,585,578	900,000	490,805	1.83
4	Asser Field	1,408,769	1,028,514	635,000	380,255	1.67
	Total	6,192,301	4,360,212	2,600,000	1,832,089	1.42

3.5.3.2 Return of investments calculations

The return of the investment cost on saving energy after this time.

$$ROI = \frac{\text{Total Energy Savings (For Life of Project)} - \text{Estimated Project Cost}}{\text{Estimated Project Cost}} \; x \; \frac{100}{\text{Project Life}}$$

ROI = Total Energy Savings (For Life of Project) – Estimated Project Cost x 100 Estimated Project Cost Project Life

Table 3.7. The Existing, new optimal energy cost and payback period at SWSLC fields

Year	Investment cost($) ($)	Saving cost/y($) ($)	ROI ($)
1	2,600,000	1,832,089	-767,911
2	0	1,832,089	1,064,178
3	0	1,832,089	2,896,267
4	360,000	1,832,089	4,368,356
5	0	1,832,089	6,200,445
6	0	1,832,089	8,032,534
7	0	1,832,089	9,864,623

39.9% = 100 / 7× 2,600,000)/2,600,000]7 - year

3.6 Discussion

The average efficiencies and the specific energy of all submersible pumps-sets in the SWSLC is 43% and 2.05 kwh/m^3 respectively. Figure 3.23 shows that 29.59% out of the annual energy cost that is used by submersible pumps in SWSLC fields can be saved every year. This means SWSLC can produce the same quantities of water to the same heads with annual saving 1,832,089USD because, the more efficient pumps used, the lower energy consumed to achieve the same work. Table 3.6 states that increasing the efficiencies of the submersible pumps-sets to the range between 61% to 63% will reduce the specific energy from 2.05 kwh/m^3 to 1.27 kwh/m^3. Consequently, SWSLC must select the pumps to work at their best efficiencies as well as to select appropriate motors to work in proper loads. t is found from the figure 3.23 pumping system in SWSLC has a big rate to save energy in each fields. The results in table 3.6 showed the feasibility of the study, whereas the total cost of investments to replace all existing submersible pumps is 2,600,000 USD, while the annual saving in energy cost will be 1,832,089 USD.Therefore, the payback period will happen later than 1.42 year. So, after this time,1,832,089 USD will be save every year .

In order to achieve full energy efficiency, SWSLC engineers must take care of the conditions of pumping systems to be able to choose the correct pumps. The reasons behind the low efficiencies of pumps-sets are: pumps are operating away from their best efficiencies points (BEP), pumps' efficiencies were decreased due to over aged status, and motors that are operating in wells are standard motors, where the efficiencies of the standard motors are less than the premium or energy – efficient motors. In addition to that, installing big capacities of motors to be work at low loads will lead to reduce motors efficiencies in some wells.

There are also a major reason causes low efficiencies of existing pumps which happened during the analysis of the tenders in the SWSLC, the people who are responsible for analyzing the tenders are concerned about the capital cost. So, they decide to choose the lowest prices of pumps, however they didn’t notice that the overall efficiency of pump has a better cost reduction. In addition to that, there are some factors affecting on increasing energy cost such as; lack of sufficient experience to choose the appropriate pumps and other components in pumping systems. Moreover, static level and production of wells are changing, while SWSLC still using the same pumps. Also, working under pressure due to the lack of alternative pumps to be ready to install in the event the pumps stopped due to faults. In addition, most of pumps and motors in SWSLC are repaired more than one time during their life span and according to refurbish or maintain the pumps-sets efficiencies will decrease.

About the second scenario, applying the adjusting on pumping system by using these methods throttle control valve, bypass control valve and modifying impeller diameter are completely useless in all of the fields. While using variable speed drive (VSD) to improve pumps efficiencies will be available only in Musaik and Asser fields, because the demand of water and head are changing during the day. On the other hand using (VSD) will be useless in Western and Eastern fields, because the fields' wells are pumping water to the main reservoirs, so there is no changing in water demand or head in these wells.

CHAPTER 4:
CONCLUSIONS AND ECOMMENDATIONS

4.1 Conclusions

In SWSLC, most of the submersible pumps-sets are operating at low efficiencies, due to choosing improper pumps, changing in water tables, reducing of wells efficiencies and irregular maintenances etc, which could affect in the overall efficiencies of the pumps-sets. The study showed that, the overall of existing pumps-sets efficiencies at all WSLC fields is 43%. And,increasing the efficiency to the range of (61%-63%) will decrease the specific en- ergy from 2.05 kwh/m^3 to 1.27 kwh/m^3. Based on the results of this study, the total existing energy cost is 6,192,301 USD per year, and the new optimal energy cost will be 4,360,212 USD per year. Hence, the opportunity of saving energy cost will be 1,832,089 USD every year with pumping the same quantities of water to the same heads. All in all, 29.59% of the total existing energy cost can be saved up yearly. The feasibility study indicates that the total cost of all investments is 2,600,000 USD and the payback period will occur after 1.42 year. After this period1,832,08USD will be saved every year. Considered the service life of pumps-sets units over a 20 year as manufacturers specification, the initial cost typically represents small value of the total cost in SWSLC. With proper operation of pumps-sets, it is possible to keep away from some unnecessary energy cost.

Nevertheless, there is little connection between actual energy efficiencies and state of pumps. So, SWSLC should start to implement projects of renewing or replacing the existing pumps. However, the renewal of the old pumps are expensive in most cases.

4.2 Energy efficiency and additional advantages

SWSLC decisions must be based not only on the concepts of profitability, but also on the total revenues to people also in a way that reflects on additional advantages due to reducing energy consumptions. Generally, energy is one of the key factors in the price of water supply in Yemen. This is not only expensive, it also causes extensive greenhouse gas emissions, there is an urgent need to the energy savings potential in SWSLC to reduce the burden on the electricity utility in Yemen. This will lead to additional capacity of the electricity for other people and industry, thus will enhance the economic situation in Yemen. In short, Sana'a city leaders should enhance to improve the energy use in water sector. Energy charges are directly related to the hours of use and equipments efficiencies. The hours of use can be reduced by the operation hours through water management and decreasing leak. An equipments efficiencies can be achieved by improving pumps and motors efficiencies which affects on reducing energy consumption due to reducing the wasted energy. As example our case study in this thesis SWSLC will achieve other benefits based energy saving according to replacing the existing pumps by efficient pumps-sets such as; reducing maintenance cost, increasing production of water and reducing production cost. Add to that, raising the efficiencies of the pumps would have a significant impact in improving the SWSLC performance and will reduce the number of customer's complaints. Furthermore, this savings in energy costs will give the SWSLC the ability to deliver the service to new customers to provide them with pure water, which means improving the overall health of the community.

In conclusion, improving energy efficiency will lead to improve the general health of citizen because the customers are obliged to use private wells due to the lack of water production by SWSLC wells during the maintenance times. As a result of this, certain health problems occur, such as impossibility of purification of private wells. Also, the percentage of citizens who obtain the service will increase substantially, which will spontaneously improve their general health.

4.3 Recommendations

According to the study, it is recommended that:

- SWSLC must provide all performance curves of all existing pumps .Then, re-installing them based on their best efficiencies.
- SWSLC should makes pumping test on all wells every year to know the current production, static level and drawdown of water level at each well .Or installing in data logger in wells to measure the static level and drawdown of water level during pumps operation.
- Replacing the existing pumps-sets with low efficiencies by pumps with high efficiencies.
- In order to achieve full energy efficiency, SWSLC engineers must take care about the specific system operating conditions to size a submersible pumps correctly.
- SWSLC designers and engineers need to select a suitable electric motor because selecting motor big capacities cause motors to work inefficiently at low load. Also, replacing standard motors with the premium or energy – efficient motors
- Maintaining the pumps-sets whose efficiencies start to decrease
- Using pumps with VSD in case the water is pumping to networks directly.
- SWSLC management should concerns about regular maintenance and operations. Qualified training for pumps-sets is important and should be existing within and outside the country which means increasing the training of staff who are responsible of maintain, select and installation of pumps-sets.
- It is recommended to create new department to monitor the efficiency of energy consumption because it will achieve a great importance in reducing costs.
- SWSLC must install modern system such as SCAADA system to measure all pumps indicators such as flow, energy, pressure, voltage, current, frequency and power factor. In addition, to send alarm about the type of problem and to try to avoid bigger problems.
- SWSLC make categories of pumps into groups then providing an alternative pumps to be installed in the event the pump stopped due to faults.
- Quality of water in each well should be known especially if the water contains sand, iron bacteria and methane gas.
- Using check valves (non-return valve) must be in installed in drop pipes each 60 m.
- Using sleeve around the submersible pump, when installing the pump in a big diameter of well or installing pumps in front of the well screen.

- For any pumping system, it is necessary to evaluate the initial(capital)cost and the operating cost to create proper decisions on continuous procedure of pumping systems according to choosing a good bid or tenders. It is very important and urgent necessity that SWSLC must take care about energy and maintenance cost during choosing pumps not only concerns about initial cost. Besides that, life cost cycle SWSLC must taken in consideration during the analysis of tenders.

References

Ahonen, T., Kortelainen, J., Tamminen, J., Ahola, J. Centrifugal pump operation monitoring with motor phase current measurement. *Electrical Power and Energy Systems* 2012;42:188-195.

Al-Hamdi, M. (2000): *competition for scarce groundwater in Sana'a plains, Yemen*

Alhindi, T., 2013. YR 5.7 *billion total indebtedness of the Foundation during the course of December last year*. http://www.sanaanews.net

Almahdi, A., 2012. *The challenge of the MDGs for water supply & sanitation* www.arab- waterweek.org

Alwathaf Y, ElMansouri B,2012. *Hydrodynamic modeling for groundwater assessment in Sana'a Basin, Yemen*

Bankston D, Baker E.1994. *Selecting the Proper Pump*

Dorota Z. Haman, Fedro S. Zazueta, Forrest T.,1994. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. *Selection Of Centrifugal Pumping Equipment.*

Census 2004. *Popualtion Central statistical organization.*

Energy and Water Technology Optimisation Services – Ewtops by JBA Energy.

Euro pump and Hydraulic Institute. 2004. *Variable speed pumping. A guide to successful applications.*

Evans J., *Centrifugal pump efficiency* – What, how, why and when?, www.pumped101.com, (2005)

Fassbinder S.2007 *Saving energy with high-efficiency motors* http://www.leonardo-energy.org

Financial administration 2013. *Overall outlook at main performance indicators in SWSLC.*

Gilbert, A. McCoy,1993., *Energy-Efficient Electric Motor Selection Handbook*

Giribone, P., Beebe, R., Hovstadius, G. *System Efficiency (a guide for energy efficient rotodynamic pumping systems*

Goulds Pumps and the ITT Engineered Blocks symbol are registered trademarks and trade names of ITT Industries, *Residential Pump Fundamentals*, 2001.

Grundfos, 2002. *HVAC Technical Data Booklet*.

Grundfos Engineering Manual for Groundwater Supply and Special Applications, 1999.

Grundfos Industery, 2004, *Pump Handbook*.

Grundfos research and technology,*The Centrifugal Pump*.

GTZ, 2009. German Agency for Technical Cooperation, *Yemen Urban Water supply and Sanitation Sector Reform.*

JBA energy. *Pumping efficiency opportunities*. JBA Renewable energy.

JICA 2007. Japan International Cooperation Agency. *The study for the water resources management and rural water supply improvement in the Republic of Yemen.* Water resources management action plan for Sana'a basin.

Kaya D, Yagmur A, Yigit S, Kilic F, Eren S, Celik C.,2008. *Energy efficiency in pumps*. Energy Conversion and Management 2008; 49: 1662-73

Ladouani, A., Nemdili, A. (2004), The 6th International Conference on Hydraulic Machinery and Hydrodynamics Timisoara, Romania, October 21-22, 2004 , *Optimal method of selecting pumping systems for viscous fluids*.

Mahlia, T., andYanti, P. Cost efficiency analysis and emission reduction by implementation of energy efficiency standards for electric motors. *Journal of Cleaner Production* 18 (2010) 365-374

Manoharan S, Devarajan N, Deivasahayam M, Ranganathan G. 2011. *Enriched Efficiency with Cost effective Manufacturing Technique in 3.7 kW Submersible pump sets us- ing DCR Technology*

Ministry of Legal Affairs (2000), *Presidential Decree Nr. 53 on the Establishment of Sana'a Water Supply and Sanitation Local Corporation of the Secretariat of the Capital.*

Ministry of Water and Environment (MWE) (2008), *Performance Indicators Information System (PIIS):* Annual Report, 2007, Sana'a, Yemen.

Nova Scotia, 2004. *Before You Construct a Water Well Facts a homeowner should know.*

PIIS 2012. *Performance Indicators Information System.* Ministry of water and environment.

Production Administration. 2013. *The monthly reports of water production in SWSLC*.

Randall, W, 2012. *Selecting a Centrifugal Pump by System Analysis*. PDH Online | PDH Center.

Saidur, R. *A review on electrical motors energy use and energy savings. Renewable and Sustainable Energy Reviews* 14 (2010) 877-898

Sana'a Water Supply and Sanitation Local Corporation (2010), *Water and Wastewater Tariff*, Commercial Department, Sana'a.

SWSLC 2013.*The budget status report in SWSLC for 2013*.

Staub M, Vautrin N, Rustler M. 2012.Optiwells-1 thesis report. Department *"Sustainable Use and Conservation of Groundwater Resources"*

Statistics and Planning 2013. Sanaa Water & Sanitation Local Corp. *The annual report of SWSLC for 2013*

U.S. Department of energy. *Energy Tips-pumping system .Industrial Technologies Program Energy Efficiency and Renewable Energy*. Pumping Systems Tip Sheet, 2005.

U.S. 2008. Department of Energy. *Improving Motor and Drive System Performance. Energy Efficiency and Renewable Energy Industrial Technologies Program.*

UNEP 2006., *Electrical Energy Equipment. Pumps and Pumping Systems.* Energy Efficiency Guide for Industry in Asia – www.energyefficiencyasia.org.

Violain, F., 2013. *Energy efficiency: The whole system savings approach*. World Pumps 2013, 36-40.

Volk, M., 2005. *Pump Characteristics and Applications.* Second edition.

Water Group Companies Inc, Water Group Companies Inc, dynaflo – *Deep Well Submersible Pumps Operating & Installation Instructions.*

WEC Water and Environmental Center 2007. *Adapting to water scarcity for Yemen's vulnerability communities.* case study, Sana'a city.

World pump, 2007. *Life cycle energy cost savings through careful system design and pump selection.*

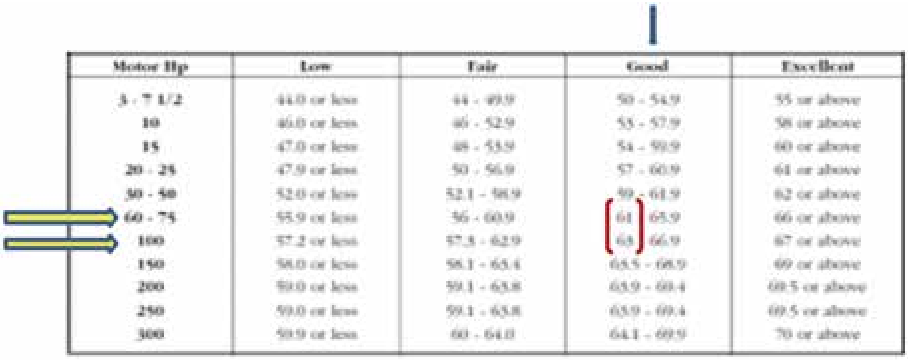
World pump, 2008. *Pump selection considerations.* Hydraulic Institute (HI).

Zhang, H., Xia, X., Zhang, J., 2012. *Optimal sizing and operation of pumping systems to achieve energy efficiency and load shifting*. Electric Power Systems Research 86, 41-50.

APPENDIX

Appendix 1

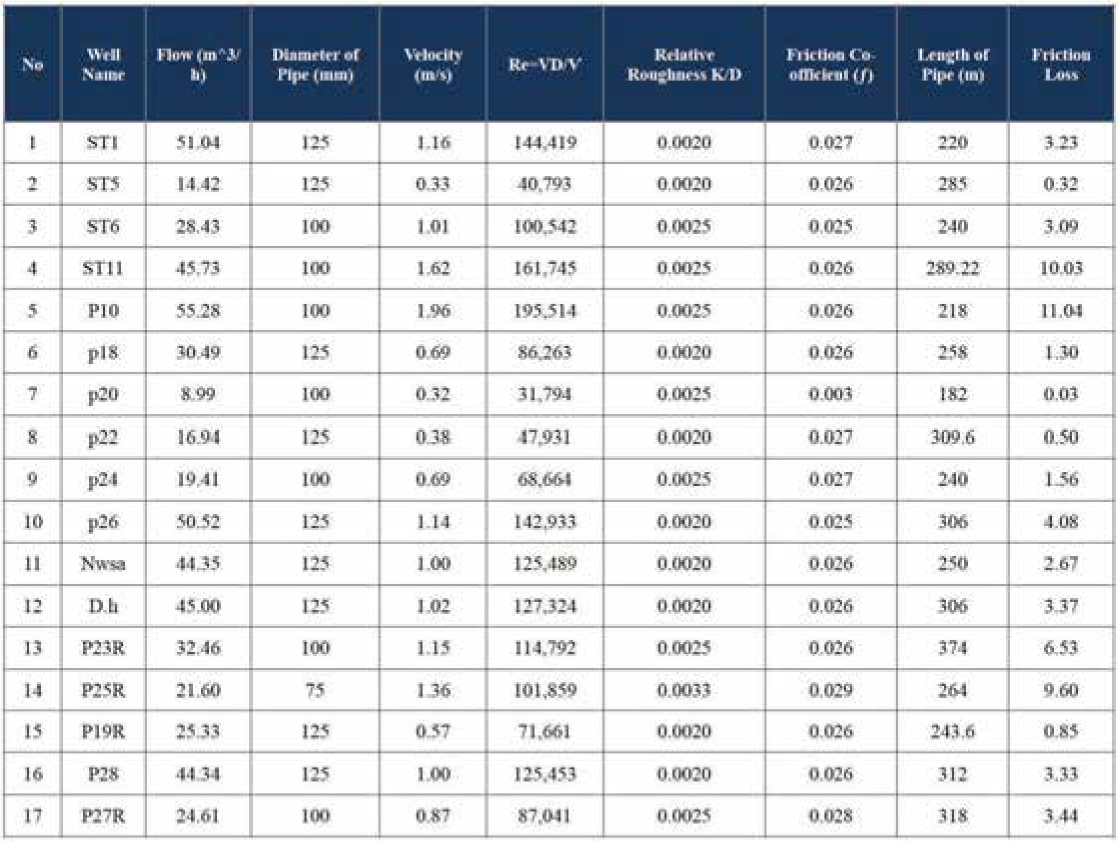
Overall efficiency categories based on Grundfos company. Source (Grundfos 1999)



Motor Hp	Low	Fair	Good	Excellent
3 - 7 1/2	44.0 or less	44 - 49.9	50 - 54.9	55 or above
10	46.0 or less	46 - 52.9	53 - 57.9	58 or above
15	47.0 or less	48 - 53.9	54 - 59.9	60 or above
20 - 25	47.9 or less	50 - 56.9	57 - 60.9	61 or above
30 - 50	52.0 or less	52.1 - 58.9	59 - 61.9	62 or above
60 - 75	55.9 or less	56 - 60.9	61 - 65.9	66 or above
100	57.2 or less	57.3 - 62.9	63 - 66.9	67 or above
150	58.0 or less	58.1 - 65.4	65.5 - 68.9	69 or above
200	59.0 or less	59.1 - 65.8	65.9 - 69.4	69.5 or above
250	59.0 or less	59.1 - 65.8	65.9 - 69.4	69.5 or above
300	59.9 or less	60 - 64.0	64.1 - 69.9	70 or above

Appendix 2

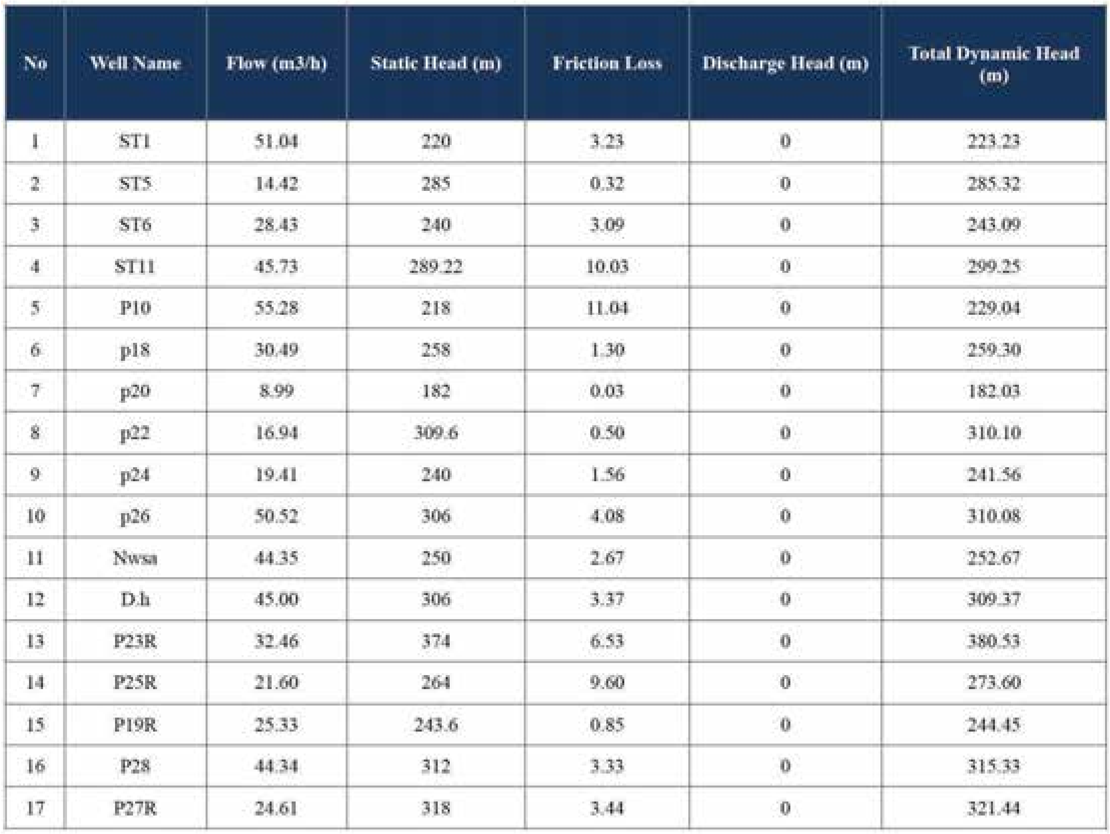
Calculation of friction losses – Western field



No	Well Name	Flow (m^3/h)	Diameter of Pipe (mm)	Velocity (m/s)	Re=VD/V	Relative Roughness K/D	Friction Co-officient (*f*)	Length of Pipe (m)	Friction Loss
1	ST1	51.04	125	1.16	144,419	0.0020	0.027	220	3.23
2	ST5	14.42	125	0.33	40,793	0.0020	0.026	285	0.32
3	ST6	28.43	100	1.01	100,542	0.0025	0.025	240	3.09
4	ST11	45.73	100	1.62	161,745	0.0025	0.026	289.22	10.03
5	P10	55.28	100	1.96	195,514	0.0025	0.026	218	11.04
6	p18	30.49	125	0.69	86,263	0.0020	0.026	258	1.30
7	p20	8.99	100	0.32	31,794	0.0025	0.003	182	0.03
8	p22	16.94	125	0.38	47,931	0.0020	0.027	309.6	0.50
9	p24	19.41	100	0.69	68,664	0.0025	0.027	240	1.56
10	p26	50.52	125	1.14	142,933	0.0020	0.025	306	4.08
11	Nwsa	44.35	125	1.00	125,489	0.0020	0.026	250	2.67
12	D.h	45.00	125	1.02	127,324	0.0020	0.026	306	3.37
13	P23R	32.46	100	1.15	114,792	0.0025	0.026	374	6.53
14	P25R	21.60	75	1.36	101,859	0.0033	0.029	264	9.60
15	P19R	25.33	125	0.57	71,661	0.0020	0.026	243.6	0.85
16	P28	44.34	125	1.00	125,453	0.0020	0.026	312	3.33
17	P27R	24.61	100	0.87	87,041	0.0025	0.028	318	3.44

Appendix 3

Calculation of total dynamic heads- Western field



No	Well Name	Flow (m3/h)	Static Head (m)	Friction Loss	Discharge Head (m)	Total Dynamic Head (m)
1	ST1	51.04	220	3.23	0	223.23
2	ST5	14.42	285	0.32	0	285.32
3	ST6	28.43	240	3.09	0	243.09
4	ST11	45.73	289.22	10.03	0	299.25
5	P10	55.28	218	11.04	0	229.04
6	p18	30.49	258	1.30	0	259.30
7	p20	8.99	182	0.03	0	182.03
8	p22	16.94	309.6	0.50	0	310.10
9	p24	19.41	240	1.56	0	241.56
10	p26	50.52	306	4.08	0	310.08
11	Nwsa	44.35	250	2.67	0	252.67
12	D.h	45.00	306	3.37	0	309.37
13	P23R	32.46	374	6.53	0	380.53
14	P25R	21.60	264	9.60	0	273.60
15	P19R	25.33	243.6	0.85	0	244.45
16	P28	44.34	312	3.33	0	315.33
17	P27R	24.61	318	3.44	0	321.44

Appendix 4

Comparing specific energy between existing and new pumps sets – Western field

No	Well Name	Flow (m^3/ h)	Total Dynamic Head (m)	Existing Overall efficiency	Existing Measured Power (kwh)	Existing Specific Energy (kwh/ m^3)	New Optimal Efficiency	New Optimal Power (kwh)	New Optimal specific energy (kwh/m^3)
1	ST1	51.04	223.23	0.45	68	1.34	0.63	49.28	0.97
2	ST5	14.42	285.32	0.16	72	5.00	0.63	17.79	1.23
x3	ST6	28.43	243.09	0.26	72	2.53	0.63	29.89	1.05
4	ST11	45.73	299.25	0.49	76	1.67	0.63	59.19	1.29
5	P10	55.28	229.04	0.42	82	1.49	0.63	54.77	0.99
6	p18	30.49	259.30	0.28	77	2.54	0.63	34.19	1.12
7	p20	8.99	182.03	0.09	49	5.48	0.63	7.08	0.79
8	p22	16.94	310.10	0.20	71	4.17	0.61	23.47	1.39
9	p24	19.41	241.56	0.42	31	1.58	0.61	20.95	1.08
10	p26	50.52	310.08	0.53	80	1.58	0.63	67.75	1.34
11	Nwsa	44.35	252.67	0.58	53	1.19	0.63	48.47	1.09
12	D.h	45.00	309.37	0.47	81	1.79	0.63	60.22	1.34
13	P23R	32.46	380.53	0.59	57	1.75	0.63	53.42	1.65
14	P25R	21.60	273.60	0.33	48	2.24	0.63	25.56	1.18
15	P19R	25.33	244.45	0.29	58	2.28	0.63	26.78	1.06
16	P28	44.34	315.33	0.55	69	1.55	0.63	60.47	1.36
17	P27R	24.61	321.44	0.49	44	1.80	0.61	35.34	1.44
				Existing average		2.35	Optimal average		1.20

Appendix 5

Calculation of potential saving option and payback periods–Western field

No	Well Name	Nominal power (kw)	Measured Power (kwh)	Existing efficiency	New Optimal Efficiency	New Optimal Power (kwh)	Energy Saving (kwh)	Annual Saving ($)	Cost of Investment ($)	Payback Period (Y)
1	ST1	92.00	68	0.45	0.63	49.28	19.08	24,853	45,000	1.81
2	ST5	75.00	72	0.16	0.63	17.79	54.26	70,662	35,000	0.50
3	ST6	75.00	72	0.26	0.63	29.89	41.95	54,638	35,000	0.64
4	ST11	75.00	76	0.49	0.63	59.19	17.09	22,255	35,000	1.57
5	P10	75.00	82	0.42	0.63	54.77	27.68	36,054	35,000	0.97
6	p18	75.00	77	0.28	0.63	34.19	43.11	56,146	35,000	0.62
7	p20	75.00	49	0.09	0.63	7.08	42.15	54,890	35,000	0.64
8	p22	45.00	71	0.20	0.61	23.47	47.21	61,483	20,000	0.33
9	p24	50.00	31	0.42	0.61	20.95	9.69	12,619	20,000	1.58
10	p26	92.00	80	0.53	0.63	67.75	12.18	15,856	45,000	2.84
11	Nwsa	93.00	53	0.58	0.63	48.47	4.12	5,370	45,000	8.38
12	D.h	93.00	81	0.47	0.63	60.22	20.41	26,576	45,000	1.69
13	P23R	64.00	57	0.59	0.63	53.42	3.41	4,446	25,000	5.62
14	P25R	60.00	48	0.33	0.63	25.56	22.90	29,817	25,000	0.84
15	P19R	64.00	58	0.29	0.63	26.78	30.97	40,336	25,000	0.62
16	P28	75.00	69	0.55	0.63	60.47	8.42	10,963	35,000	3.19
17	P27R	50.00	44	0.49	0.61	35.34	8.95	11,653	20,000	1.72
			1,417,212			878,596		538,616		

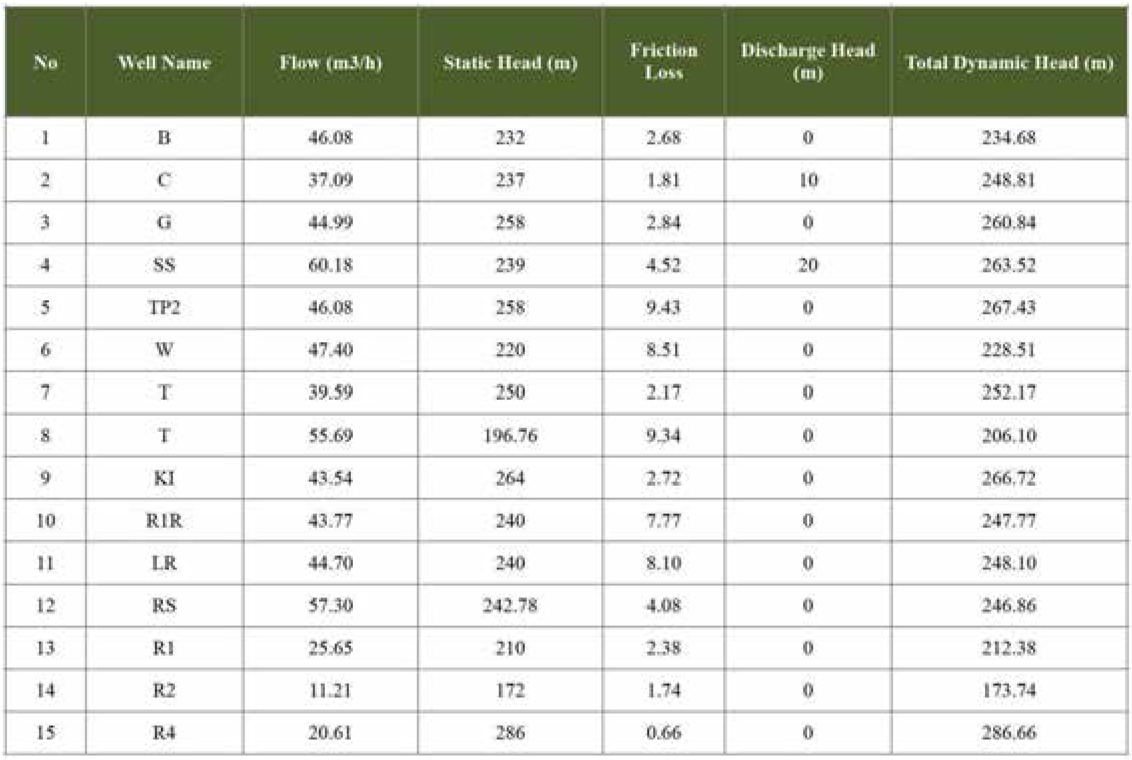
Appendix 6

Calculation of friction losses – Eastern field

No	Well Name	Flow (m^3/ h)	Diameter of Pipe (mm)	Velocity (m/ s)	Re=VD/V	Relative Roughness K/D	Friction Co-efficient (*f*)	Length of Pipe (m)	Friction Loss
1	B	46.08	125	1.04	130,392	0.0020	0.026	232	2.68
2	C	37.09	125	0.84	104,957	0.0020	0.0265	237	1.81
3	G	44.99	125	1.02	127,297	0.0020	0.026	258	2.84
4	SS	60.18	125	1.36	170,287	0.0020	0.025	239	4.52
5	TP2	46.08	100	1.63	162,960	0.0025	0.027	258	9.43
6	W	47.40	100	1.68	167,641	0.0025	0.027	220	8.51
7	Y	39.59	125	0.90	112,010	0.0020	0.0265	250	2.17
8	T	55.69	100	1.97	196,978	0.0025	0.024	196.76	9.34
9	KI	43.54	125	0.99	123,191	0.0020	0.026	264	2.72
10	R1R	43.77	100	1.55	154,794	0.0025	0.0265	240	7.77
11	LR	44.70	100	1.58	158,111	0.0025	0.0265	240	8.10
12	RS	57.30	125	1.30	162,126	0.0020	0.0245	242.78	4.08
13	R1	25.65	100	0.91	90,708	0.0025	0.027	210	2.38
14	R2	11.21	75	0.70	52,845	0.0033	0.03	172	1.74
15	R4	20.61	125	0.47	58,308	0.0020	0.026	286	0.66

Appendix 7

Calculation of total dynamic heads – Eastern field



No	Well Name	Flow (m3/h)	Static Head (m)	Friction Loss	Discharge Head (m)	Total Dynamic Head (m)
1	B	46.08	232	2.68	0	234.68
2	C	37.09	237	1.81	10	248.81
3	G	44.99	258	2.84	0	260.84
4	SS	60.18	239	4.52	20	263.52
5	TP2	46.08	258	9.43	0	267.43
6	W	47.40	220	8.51	0	228.51
7	T	39.59	250	2.17	0	252.17
8	T	55.69	196.76	9.34	0	206.10
9	KI	43.54	264	2.72	0	266.72
10	R1R	43.77	240	7.77	0	247.77
11	LR	44.70	240	8.10	0	248.10
12	RS	57.30	242.78	4.08	0	246.86
13	R1	25.65	210	2.38	0	212.38
14	R2	11.21	172	1.74	0	173.74
15	R4	20.61	286	0.66	0	286.66

Appendix 8

Comparing specific energy between existing and new pumps sets – Eastern field

No	Well Name	Flow (m^3/h)	Total Dynamic Head (m)	Existing Overall efficiency	Existing Measured Power (kwh)	Existing Specific Energy (kwh/m^3)	New Optimal Efficiency	New Optimal Power (kwh)	New Optimal specific energy (kwh/m^3)
1	B	46.08	234.68	0.31	94	2.05	0.63	46.78	1.02
2	C	37.09	248.81	0.38	67	1.80	0.63	39.92	1.08
3	G	44.99	260.84	0.52	62	1.38	0.63	50.76	1.13
4	SS	60.18	263.52	0.45	95	1.58	0.63	68.60	1.14
5	TP2	46.08	267.43	0.44	76	1.66	0.63	53.30	1.16
6	W	47.40	228.51	0.42	70	1.48	0.63	46.85	0.99
7	Y	39.59	252.17	0.44	62	1.57	0.63	43.18	1.09
8	T	55.69	206.10	0.34	92	1.65	0.61	51.28	0.92
9	KI	43.54	266.72	0.48	66	1.52	0.61	51.88	1.19
10	R1R	43.77	247.77	0.44	68	1.55	0.63	46.90	1.07
11	LR	44.70	248.10	0.47	64	1.44	0.63	47.97	1.07
12	RS	57.30	246.86	0.53	73	1.27	0.63	61.18	1.07
13	R1	25.65	212.38	0.40	37	1.46	0.63	23.56	0.92
14	R2	11.21	173.74	0.23	23	2.05	0.63	8.42	0.75
15	R4	20.61	286.66	0.28	40	1.94	0.63	25.55	1.24
				Existing average		1.63	Optimal average		1.06

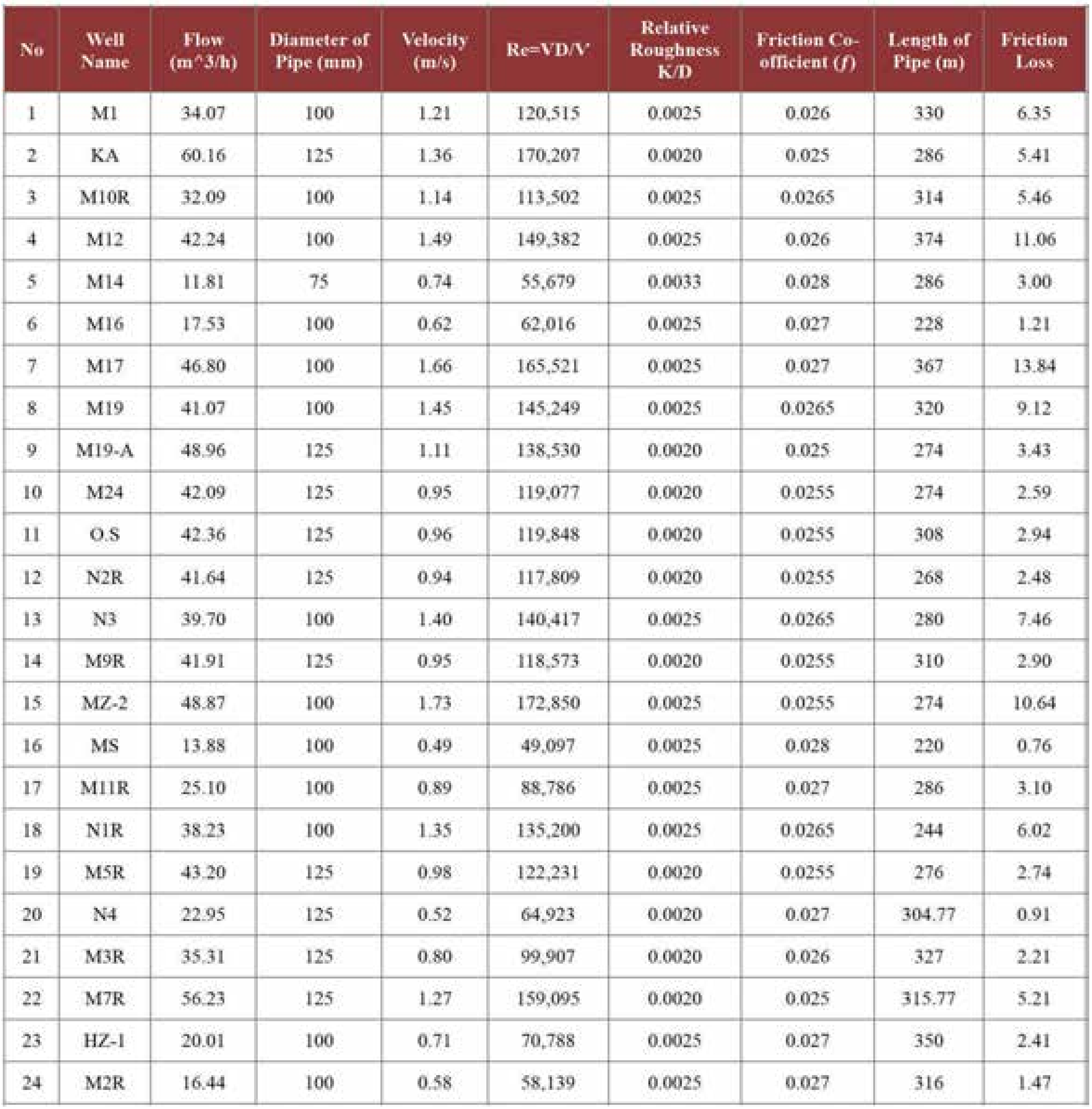
Appendix 9

Calculation of potential saving option and payback periods – Eastern field

No	Well Name	Nominal power (kw)	Measured Power (kwh)	Existing efficiency	New Optimal Efficiency	New Optimal Power (kwh)	Energy Saving (kwh)	Annual Saving ($)	Cost of Investment	Payback Period (Y)
1	B	92.00	94.39	0.31	0.63	46.78	47.61	62,007	45,000	0.73
2	C	75.00	66.66	0.38	0.63	39.92	26.74	34,819	35,000	1.01
3	G	75.00	61.90	0.52	0.63	50.76	11.14	14,503	35,000	2.41
4	SS	75.00	95.36	0.45	0.63	68.60	26.76	34,854	35,000	1.00
5	TP2	75.00	76.35	0.44	0.63	53.30	23.06	30,027	35,000	1.17
6	W	75.00	70.20	0.42	0.63	46.85	23.35	30,411	35,000	1.15
7	T	75.00	62.08	0.44	0.63	43.18	18.90	24,610	35,000	1.42
8	T	45.00	92.00	0.34	0.61	51.28	40.72	53,035	20,000	0.38
9	KI	50.00	66,18	0.48	0.61	51.88	14.30	18,624	20,000	1.07
10	R1R	92.00	67.77	0.44	0.63	46.90	20.87	27,176	45,000	1.66
11	LR	93.00	64.45	0.47	0.63	47.97	16.48	21,458	45,000	2.10
12	RS	93.00	72.80	0.53	0.63	61.18	11.62	15,129	45,000	2.97
13	R1	64.00	37.34	0.40	0.63	23.56	13.78	17,952	25,000	1.39
14	R2	60.00	23.01	0.23	0.63	8.42	14.58	18,993	25,000	1.32
15	R4	64.00	40.00	0.28	0.63	25.55	14.45	18,816	25,000	1.33
			1,289,937			867,524		422,413		

Appendix 10

Calculation of friction losses – Musaik field



No	Well Name	Flow (m^3/h)	Diameter of Pipe (mm)	Velocity (m/s)	Re=VD/V	Relative Roughness K/D	Friction Co-officient (*f*)	Length of Pipe (m)	Friction Loss
1	M1	34.07	100	1.21	120,515	0.0025	0.026	330	6.35
2	KA	60.16	125	1.36	170,207	0.0020	0.025	286	5.41
3	M10R	32.09	100	1.14	113,502	0.0025	0.0265	314	5.46
4	M12	42.24	100	1.49	149,382	0.0025	0.026	374	11.06
5	M14	11.81	75	0.74	55,679	0.0033	0.028	286	3.00
6	M16	17.53	100	0.62	62,016	0.0025	0.027	228	1.21
7	M17	46.80	100	1.66	165,521	0.0025	0.027	367	13.84
8	M19	41.07	100	1.45	145,249	0.0025	0.0265	320	9.12
9	M19-A	48.96	125	1.11	138,530	0.0020	0.025	274	3.43
10	M24	42.09	125	0.95	119,077	0.0020	0.0255	274	2.59
11	O.S	42.36	125	0.96	119,848	0.0020	0.0255	308	2.94
12	N2R	41.64	125	0.94	117,809	0.0020	0.0255	268	2.48
13	N3	39.70	100	1.40	140,417	0.0025	0.0265	280	7.46
14	M9R	41.91	125	0.95	118,573	0.0020	0.0255	310	2.90
15	MZ-2	48.87	100	1.73	172,850	0.0025	0.0255	274	10.64
16	MS	13.88	100	0.49	49,097	0.0025	0.028	220	0.76
17	M11R	25.10	100	0.89	88,786	0.0025	0.027	286	3.10
18	N1R	38.23	100	1.35	135,200	0.0025	0.0265	244	6.02
19	M5R	43.20	125	0.98	122,231	0.0020	0.0255	276	2.74
20	N4	22.95	125	0.52	64,923	0.0020	0.027	304.77	0.91
21	M3R	35.31	125	0.80	99,907	0.0020	0.026	327	2.21
22	M7R	56.23	125	1.27	159,095	0.0020	0.025	315.77	5.21
23	HZ-1	20.01	100	0.71	70,788	0.0025	0.027	350	2.41
24	M2R	16.44	100	0.58	58,139	0.0025	0.027	316	1.47

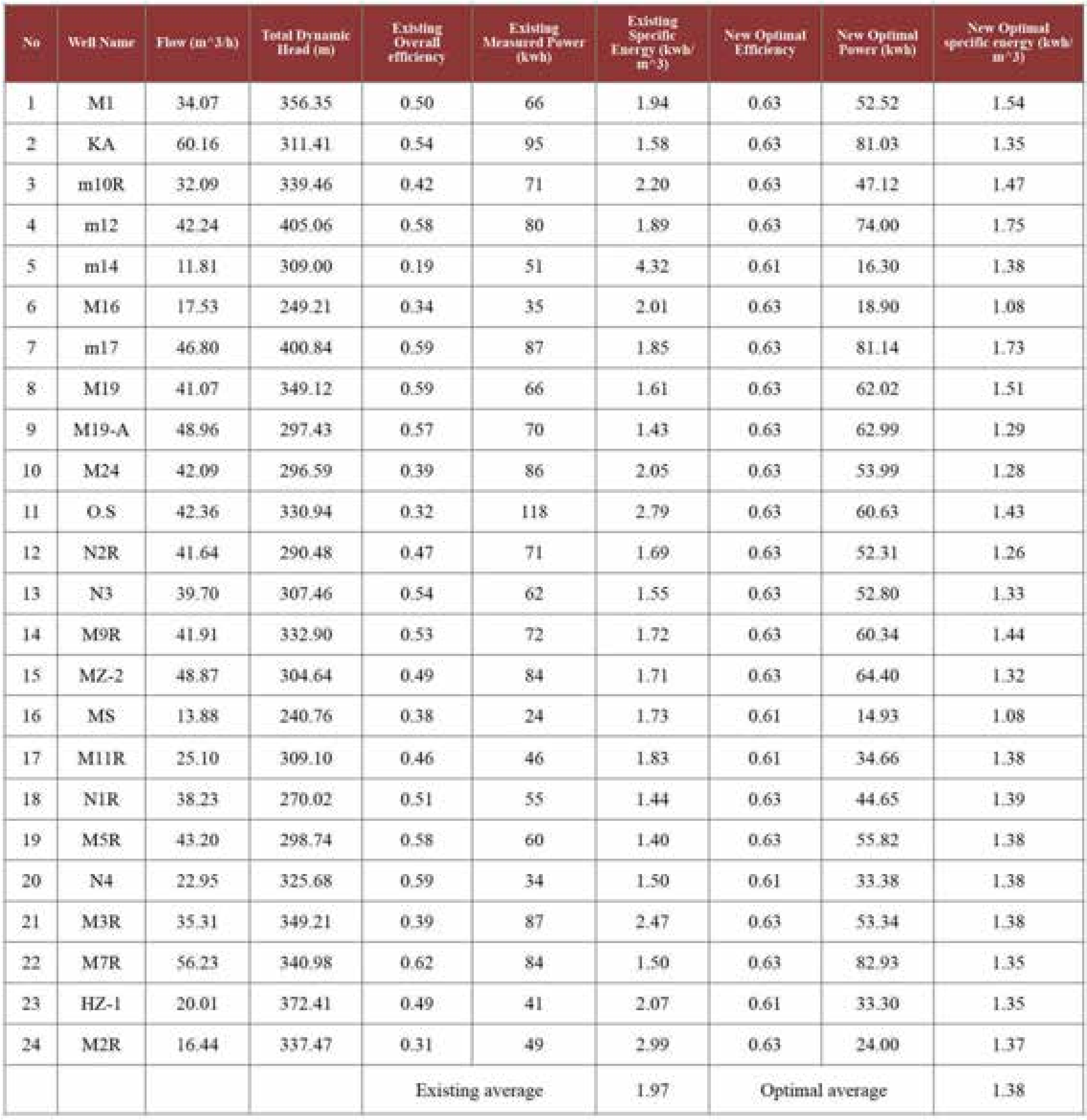
Appendix 11

Calculation of total dynamic heads – Musaik field

No	Well Name	Flow (m3/h)	Static Head (m)	Friction Loss	Discharge Head (m)	Total Dynamic Head (m)
1	M1	34.07	330	6.35	20	356.35
2	KA	60.16	286	5.41	20	311.41
3	M10R	32.09	314	5.46	20	339.46
4	M12	42.24	374	11.06	20	405.06
5	M14	11.81	286	3.00	20	309.00
6	M16	17.53	228	1.21	20	249.21
7	M17	46.80	367	13.84	20	400.84
8	M19	41.07	320	9.12	20	349.12
9	M19-A	48.96	274	3.43	20	297.43
10	M24	42.09	274	2.59	20	296.59
11	O.S	42.36	308	2.94	20	330.94
12	N2R	41.64	268	2.48	20	290.48
13	N3	39.70	280	7.46	20	307.46
14	M9R	41.91	310	2.90	20	332.90
15	MZ-2	48.87	274	10.64	20	304.64
16	MS	13.88	220	0.76	20	240.76
17	M11R	25.10	286	3.10	20	309.10
18	N1R	38.23	244	6.02	20	270.02
19	M5R	43.20	276	2.74	20	298.74
20	N4	22.95	304.77	0.91	20	325.68
21	M3R	35.31	327	2.21	20	349.21
22	M7R	56.23	315.77	5.21	20	340.98
23	HZ-1	20.01	350	2.41	20	372.41
24	M2R	16.44	316	1.47	20	337.47

Appendix 12

Comparing specific energy between existing and new pumps- sets – Musaik field



No	Well Name	Flow (m^3/h)	Total Dynamic Head (m)	Existing Overall efficiency	Existing Measured Power (kwh)	Existing Specific Energy (kwh/m^3)	New Optimal Efficiency	New Optimal Power (kwh)	New Optimal specific energy (kwh/m^3)
1	M1	34.07	356.35	0.50	66	1.94	0.63	52.52	1.54
2	KA	60.16	311.41	0.54	95	1.58	0.63	81.03	1.35
3	m10R	32.09	339.46	0.42	71	2.20	0.63	47.12	1.47
4	m12	42.24	405.06	0.58	80	1.89	0.63	74.00	1.75
5	m14	11.81	309.00	0.19	51	4.32	0.61	16.30	1.38
6	M16	17.53	249.21	0.34	35	2.01	0.63	18.90	1.08
7	m17	46.80	400.84	0.59	87	1.85	0.63	81.14	1.73
8	M19	41.07	349.12	0.59	66	1.61	0.63	62.02	1.51
9	M19-A	48.96	297.43	0.57	70	1.43	0.63	62.99	1.29
10	M24	42.09	296.59	0.39	86	2.05	0.63	53.99	1.28
11	O.S	42.36	330.94	0.32	118	2.79	0.63	60.63	1.43
12	N2R	41.64	290.48	0.47	71	1.69	0.63	52.31	1.26
13	N3	39.70	307.46	0.54	62	1.55	0.63	52.80	1.33
14	M9R	41.91	332.90	0.53	72	1.72	0.63	60.34	1.44
15	MZ-2	48.87	304.64	0.49	84	1.71	0.63	64.40	1.32
16	MS	13.88	240.76	0.38	24	1.73	0.61	14.93	1.08
17	M11R	25.10	309.10	0.46	46	1.83	0.61	34.66	1.38
18	N1R	38.23	270.02	0.51	55	1.44	0.63	44.65	1.39
19	M5R	43.20	298.74	0.58	60	1.40	0.63	55.82	1.38
20	N4	22.95	325.68	0.59	34	1.50	0.61	33.38	1.38
21	M3R	35.31	349.21	0.39	87	2.47	0.63	53.34	1.38
22	M7R	56.23	340.98	0.62	84	1.50	0.63	82.93	1.35
23	HZ-1	20.01	372.41	0.49	41	2.07	0.61	33.30	1.35
24	M2R	16.44	337.47	0.31	49	2.99	0.63	24.00	1.37
				Existing average		1.97	Optimal average		1.38

Appendix 13

Calculation of potential saving option and payback periods – Musaik field

No	Well Name	Nominal power (kw)	Measured Power (kwh)	Existing efficiency	New Optimal Efficiency	New Optimal Power (kwh)	Energy Saving (kwh)	Annual Saving ($)	Cost of Investme nt	Payback Period (Y)
1	M1	92.00	66.10	0.50	0.63	52.52	13.58	17,689	45000	2.54
2	KA	95.00	94.93	0.54	0.63	81.03	13.90	18,106	45000	2.49
3	M10R	75.00	70.53	0.42	0.63	47.12	23.41	30,487	35000	1.15
4	M12	75.00	79.71	0.58	0.63	74.00	5.71	7,436	35000	4.71
5	M14	50.00	51.02	0.19	0.61	16.30	34.73	45,224	20000	0.44
6	M16	66.00	35.33	0.34	0.63	18.90	16.43	21,396	35000	1.64
7	M17	93.00	86.56	0.59	0.63	81.14	5.42	7,058	45000	6.38
8	M19	75.00	66.00	0.59	0.63	62.02	3.98	5,188	35000	6.75
9	M19-A	92.00	69.93	0.57	0.63	62.99	6.94	9,041	45000	4.98
10	M24	93.00	86.35	0.39	0.63	53.99	32.36	42,143	45000	1.07
11	O.S	92.00	118.39	0.32	0.63	60.63	57.76	75,217	45000	0.60
12	N2R	75.00	70.55	0.47	0.63	52.31	18.23	23,747	35000	1.47
13	N3	92.00	61.67	0.54	0.63	52.80	8.87	11,551	45000	3.90
14	M9R	93.00	72.16	0.53	0.63	60.34	11.82	15,396	45000	2.92
15	MZ-2	93.00	83.54	0.49	0.63	64.40	19.14	24,931	45000	1.80
16	MS	45.00	24.06	0.38	0.61	14.93	9.13	11,895	20000	1.68
17	M11R	64.00	45.94	0.46	0.61	34.66	11.28	14,688	25000	1.70
18	N1R	93.00	55.18	0.51	0.63	44.65	10.53	13,711	45000	3.28
19	M5R	75.00	60.27	0.58	0.63	55.82	4.44	5,788	35000	6.05
20	N4	50.00	34.33	0.59	0.61	33.38	0.95	1,237	20000	16.17
21	M3R	92.00	87.16	0.39	0.63	53.34	33.82	44,044	45000	1.02
22	M7R	83.00	84.13	0.62	0.63	82.93	1.20	1,557	45000	28.91
23	HZ-1	45.00	41.34	0.49	0.61	33.30	8.04	10,468	20000	1.91
24	M2R	93.00	49.19	0.31	0.63	24.00	25.19	32,808	45000	1.37
			2,076,383			1,585,578		490,805		

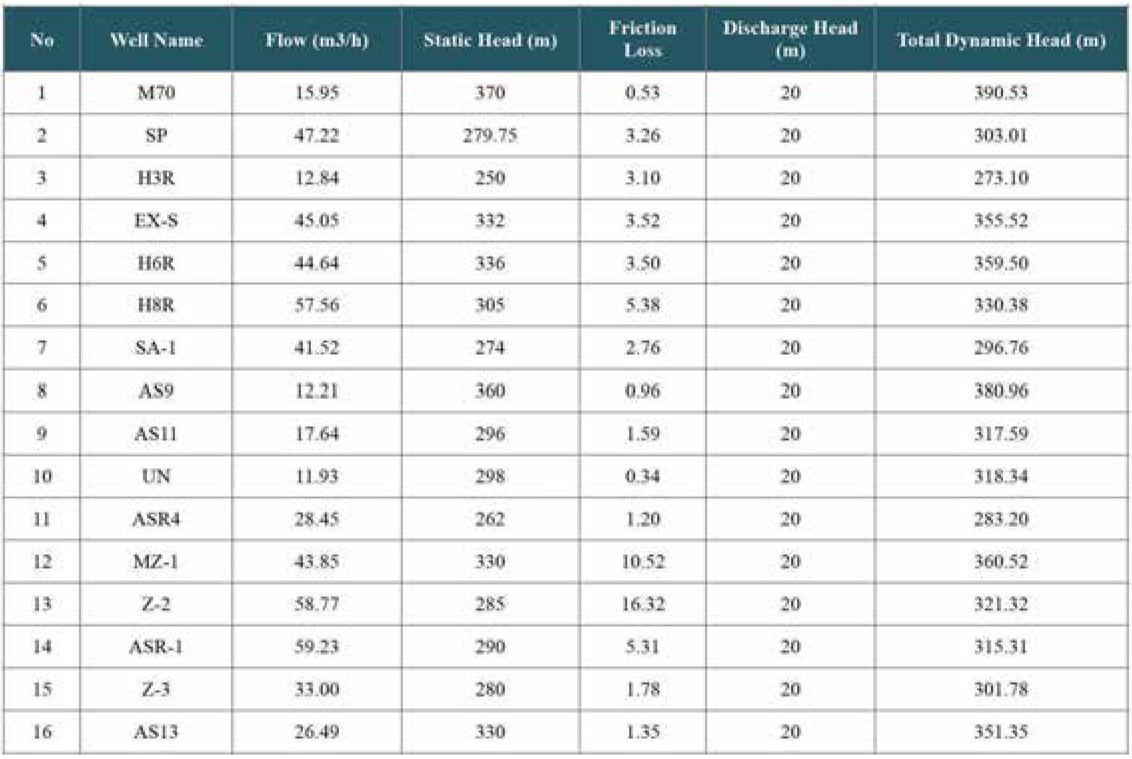
Appendix 14

Calculation of friction losses – Asser field

No	Well Name	Flow (m^3/h)	Diameter of Pipe (mm)	Velocity (m/s)	Re=VD/V	Relative Roughness K/D	Friction Co-officient (*f*)	Length of Pipe (m)	Friction Loss
1	M70	15.95	125	0.36	45,117	0.0020	0.027	370	0.53
2	SP	47.22	125	1.07	133,616	0.0020	0.025	279.75	3.26
3	H3R	12.84	75	0.81	60,556	0.0033	0.028	250	3.10
4	EX-S	45.05	125	1.02	127,479	0.0020	0.025	332	3.52
5	H6R	44.64	125	1.01	126,319	0.0020	0.025	336	3.50
6	H8R	57.56	125	1.30	162,858	0.0020	0.0255	305	5.38
7	SA-1	41.52	125	0.94	117,484	0.0020	0.028	274	2.76
8	AS9	12.21	100	0.43	43,185	0.0025	0.028	360	0.96
9	AS11	17.64	100	0.62	62,386	0.0025	0.027	296	1.59
10	UN	11.93	75	0.75	56,246	0.0033	0.003	298	0.34
11	ASR4	28.45	125	0.64	80,501	0.0020	0.027	262	1.20
12	MZ-1	43.85	100	1.55	155,078	0.0025	0.026	330	10.52
13	Z-2	58.77	100	2.08	207,873	0.0025	0.026	285	16.32
14	ASR-1	59.23	125	1.34	167,579	0.0020	0.025	290	5.31
15	Z-3	33.00	125	0.75	93,371	0.0020	0.028	280	1.78
16	AS13	26.49	125	0.60	74,956	0.0020	0.028	330	1.35

Appendix 15

Calculation of total dynamic heads – Asser field



No	Well Name	Flow (m3/h)	Static Head (m)	Friction Loss	Discharge Head (m)	Total Dynamic Head (m)
1	M70	15.95	370	0.53	20	390.53
2	SP	47.22	279.75	3.26	20	303.01
3	H3R	12.84	250	3.10	20	273.10
4	EX-S	45.05	332	3.52	20	355.52
5	H6R	44.64	336	3.50	20	359.50
6	H8R	57.56	305	5.38	20	330.38
7	SA-1	41.52	274	2.76	20	296.76
8	AS9	12.21	360	0.96	20	380.96
9	AS11	17.64	296	1.59	20	317.59
10	UN	11.93	298	0.34	20	318.34
11	ASR4	28.45	262	1.20	20	283.20
12	MZ-1	43.85	330	10.52	20	360.52
13	Z-2	58.77	285	16.32	20	321.32
14	ASR-1	59.23	290	5.31	20	315.31
15	Z-3	33.00	280	1.78	20	301.78
16	AS13	26.49	330	1.35	20	351.35

Appendix 16

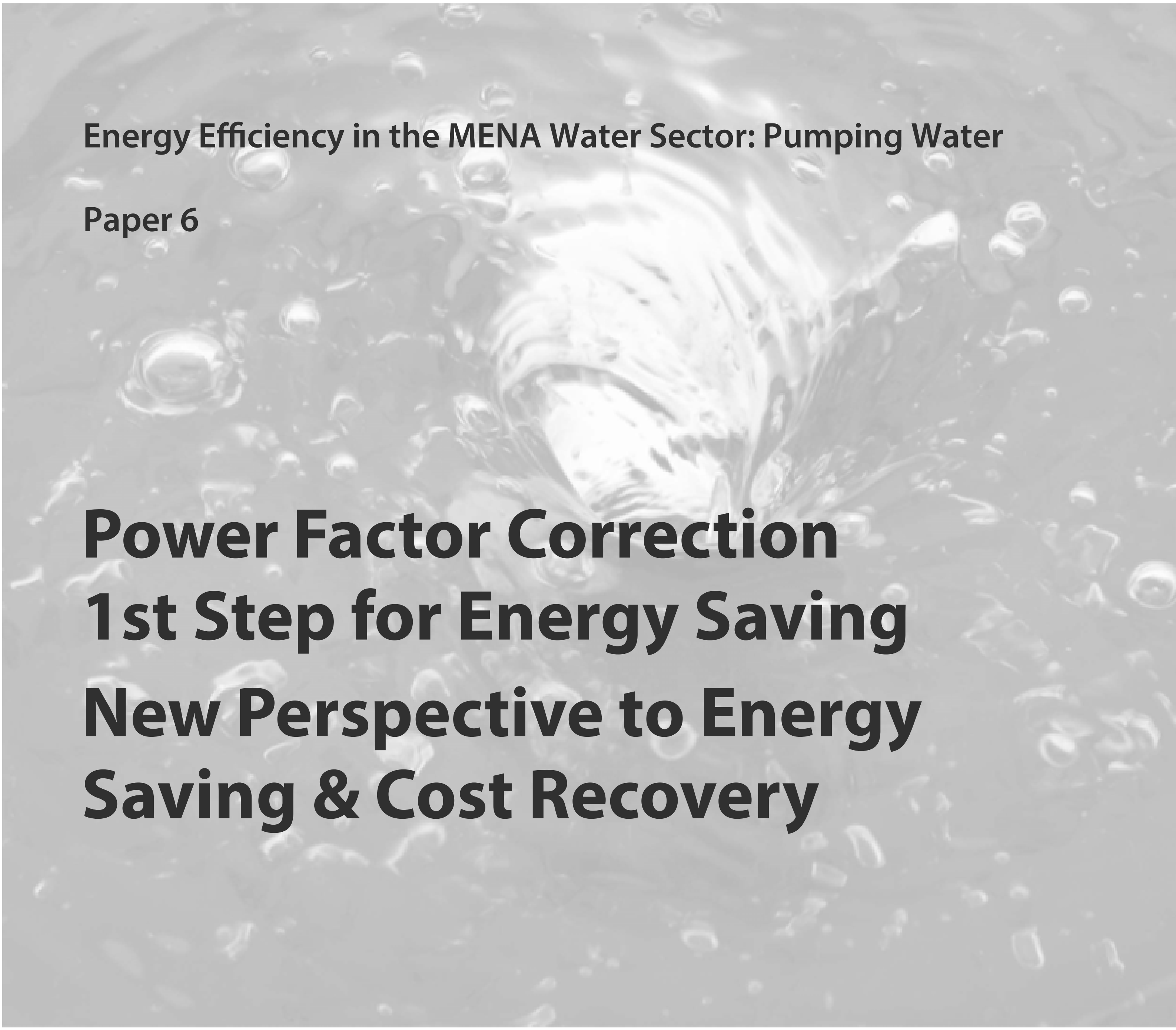
Comparing specific energy between existing and new pumps sets – Asser field

No	Well Name	Flow (m^3/h)	Total Dynamic Head (m)	Existing Overall efficiency	Existing Measured Power (kwh)	Existing Specific Energy (kwh/m^3)	New Optimal Efficiency	New Optimal Power (kwh)	New Optimal specific energy (kwh/m^3)
1	M70	15.95	390.53	0.43	40	2.49	0.63	26.94	1.69
2	SP	47.22	303.01	0.54	73	1.54	0.63	61.89	1.31
3	H3R	12.84	273.10	0.28	34	2.64	0.61	15.67	1.22
4	EX-S	45.05	355.52	0.52	85	1.88	0.63	69.28	1.54
5	H6R	44.64	359.50	0.46	94	2.11	0.63	69.42	1.55
6	H8R	57.56	330.38	0.61	84	1.47	0.63	82.25	1.43
7	SA-1	41.52	296.76	0.43	79	1.89	0.63	53.30	1.28
8	AS9	12.21	380.96	0.37	35	2.83	0.61	20.78	1.70
9	AS11	17.64	317.59	0.19	81	4.59	0.63	24.23	1.37
10	UN	11.93	318.34	0.24	43	3.62	0.61	16.96	1.42
11	ASR4	28.45	283.20	0.35	63	2.22	0.63	34.85	1.22
12	MZ-1	43.85	360.52	0.58	74	1.68	0.63	68.37	1.56
13	Z-2	58.77	321.32	0.60	86	1.46	0.63	81.69	1.39
14	ASR-1	59.23	315.31	0.60	84	1.42	0.63	80.78	1.36
15	Z-3	33.00	301.78	0.61	44	1.35	0.63	43.08	1.31
16	AS13	26.49	351.35	0.31	83	3.13	0.63	40.26	1.52
				Existing average		2.27	Optimal average		1.43

Appendix 17

Calculation of potential saving option and payback periods – Asser field

No	Well Name	Nominal power (kw)	Measured Power (kwh)	Existing efficiency)	New Optimal Efficiency	New Optimal Power (kwh)	Energy Saving (kwh)	Annual Saving ($)	Cost of Investment	Payback Period (Y)
1	M70	92	39.67	0.43	0.63	26.94	12.74	16,587	45000	2.71
2	SP	92	72.73	0.54	0.63	61.89	10.84	14,113	45000	3.19
3	H3R	50	33.84	0.28	0.61	15.67	18.17	23,670	20000	0.84
4	EX-S	83	84.63	0.52	0.63	69.28	15.34	19,980	45000	2.25
5	H6R	93	94.37	0.46	0.63	69.42	24.95	32,495	45000	1.38
6	H8R	83	84.43	0.61	0.63	82.25	2.18	2,833	45000	15.88
7	SA-1	95	78.67	0.43	0.63	53.30	25.37	33,043	45000	1.36
8	AS9	45	34.56	0.37	0.61	20.78	13.78	17,951	20000	1.11
9	AS11	75	81.05	0.19	0.63	24.23	56.82	73,998	35000	0.47
10	UN	45	43.22	0.24	0.61	16.96	26.26	34,198	20000	0.58
11	ASR4	95	63.30	0.35	0.63	34.85	28.45	37,052	45000	1.21
12	MZ-1	75	73.70	0.58	0.63	68.37	5.33	6,936	35000	5.05
13	Z-2	93	85.91	0.60	0.63	81.69	4.22	5,499	45000	8.18
14	ASR-1	93	84.20	0.60	0.63	80.78	3.42	4,458	45000	10.10
15	Z-3	83	44.44	0.61	0.63	43.08	1.37	1,782	45000	25.25
16	AS13	110	83.00	0.31	0.63	40.26	42.74	55,661	55000	0.99
			1,408,769			1,028,514		380,255		



Energy Efficiency in the MENA Water Sector: Pumping Water

Paper 6

Power Factor Correction 1st Step for Energy Saving

New Perspective to Energy Saving & Cost Recovery

Written by:
Mohamed Ahmed Talaat, Operation & Maintenance Division, HCWW-Egypt

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

Abstract

POWER FACTOR CORRECTION

1st step for energy saving, Eng. Mohamed Ahmed Talaat

Wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower your power factor, the less economically your system operates.

The actual amount of power being used, or dissipated, in a circuit is called true power. Reactive loads such as inductors and capacitors make up what is called reactive power. The linear combination of true power and reactive power is called apparent power or total power.

Power system loads consist of resistive, inductive, and capacitive loads. Examples of resistive loads are incandescent lighting and electric heaters. Examples of inductive loads are induction motors, transformers, and reactors. Examples of capacitive loads are capacitors, generators, and synchronous motors.

Power factor correction (PFC) is usually achieved by adding capacitive load to offset the inductive load present in the power system. The power factor of the power system is constantly changing due to variations in the size and number of the motors being used at one time. This makes it difficult to balance the inductive and capacitive loads continuously.

There are many benefits to having PFC. As a customer the cost doesn't get passed on for having a low power factor. As a utility company, equipment has a much longer life span and maintenance costs remain low.

In this case studies energy saving was studied, where the power consumption has been recorded and analyzed, PFC systems have been installed to improve the power factor. The results show that there is a considerable amount of energy and money saving have been achieved.

As PFC system of 240 KVAR is installed costing 32,000 EGP in El-Nasria Wastewater Pump Station located in Aswan city, PF improved from 0.82 to 0.96 in addition to eradicate the penalty of 8% (17,000 EGP/yr) and bonus of 3.5% (7,300 EGP/yr) was gained by Electrical Utility company leading to R.O.I. of 76 % in the first year.

So HCWW developed an energy saving policy in its new strategic plan through power factor correction to be implemented to all affiliated sites as possible.

Table of Contents

1.INTRODUCTION

Wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower your power factor, the less economically your system operates. The actual amount of power being used, or dissipated, in a circuit is called true power. Reactive loads such as inductors and capacitors make up what is called reactive power. The linear combination of true power and reactive power is called apparent power or total power.

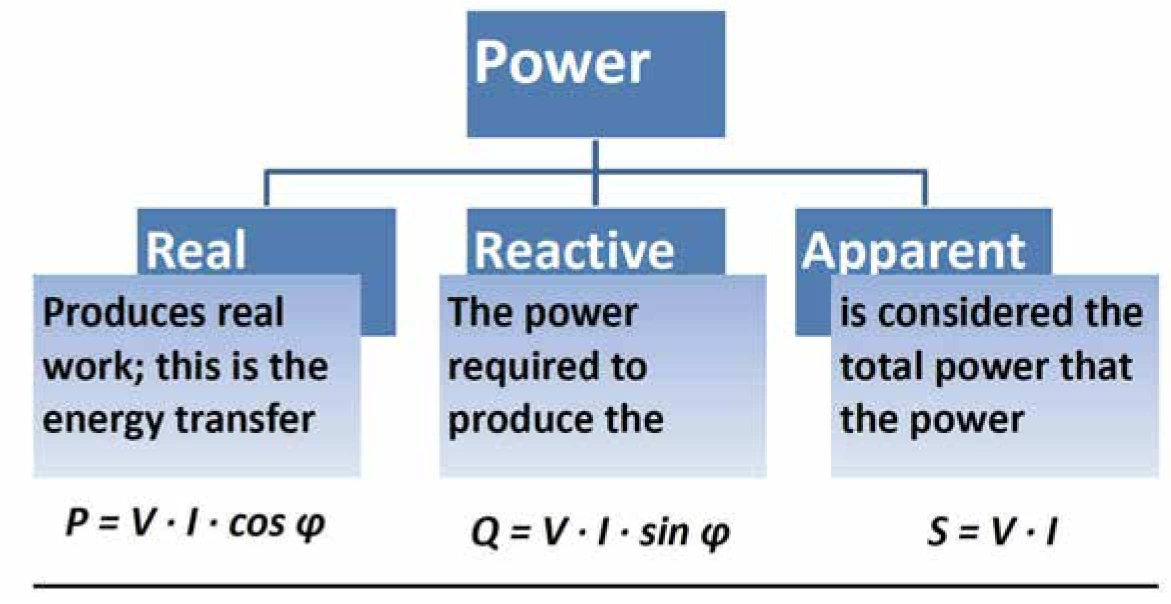
Power system loads consist of resistive, inductive, and capacitive loads. Examples of resistive loads are incandescent lighting and electric heaters. Examples of inductive loads are induction motors, transformers, and reactors. Examples of capacitive loads are capacitors, generators, and synchronous motors.

Egypt now is suffering Power (energy) shortage across the country which leads the government to strictly decided to implement energy saving actions in addition to new energy production procedures, So HCWW developed an energy saving policy in its new strategic plan entail power factor correction to be implemented to all affiliated sites as possible.

Power factor correction (PFC) is one of the best investments to reduce energy costs with a short payback period.

2. Power Concept

2.1 Power



2.2 What is Power Factor?

Power Factor (PF) is defined as the ratio of the real power (P) to apparent power (S) that represents the phase angle between the current and voltage waveforms as shown in fig.1 and 2.

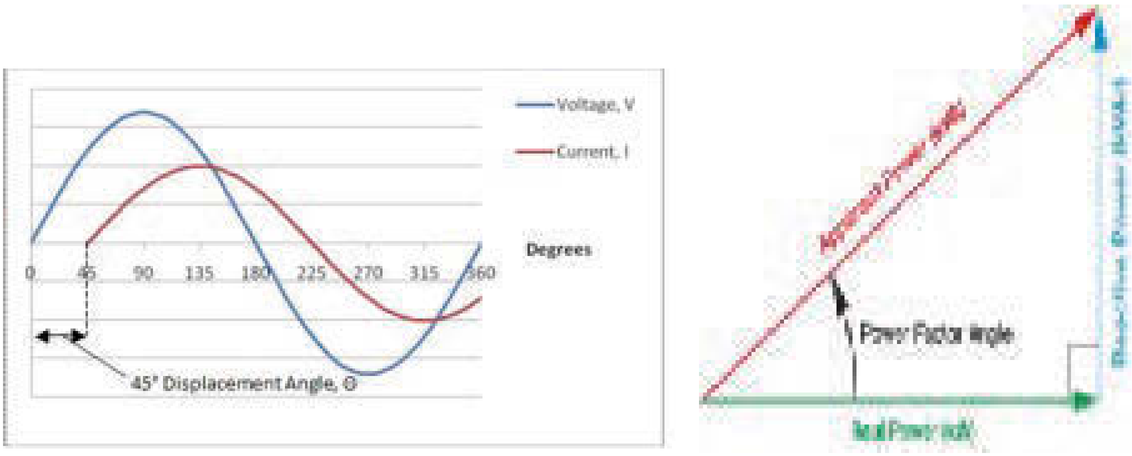


Figure 2

2.3 Power Factor Correction

Energy saving through power factor correction (PFC) does not mean reducing consumption as much as using most efficient technique that limits the losses of no availed energy used while meeting the required purpose.

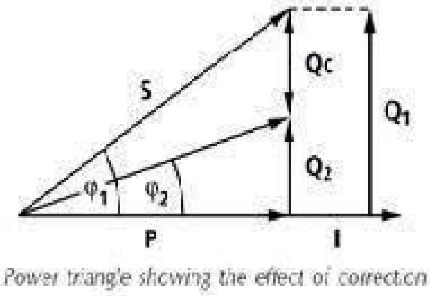


Figure 3

As shown in (Fig.3) for example, the reactive power QC corrected by the capacitor is given by the difference between the inductive reactive power Q1 before correction and the reactive power Q2 after correction, i.e. QC = Q1 – Q2.

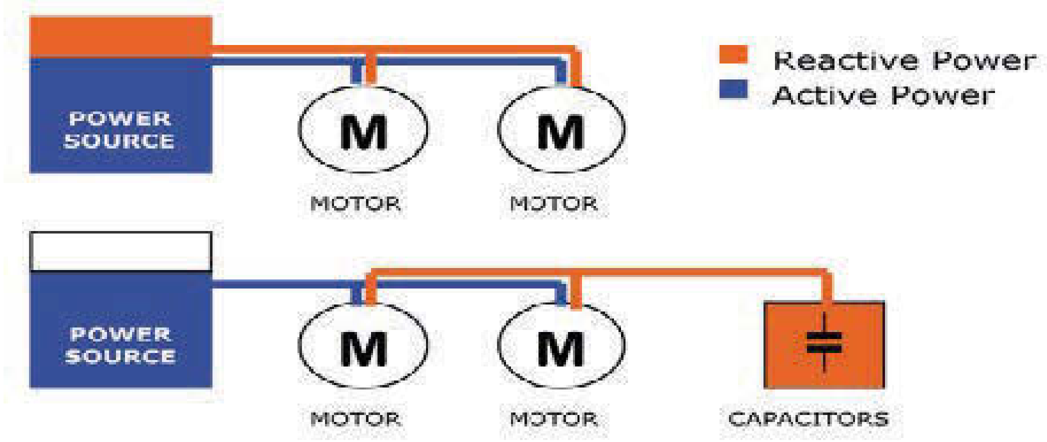


Figure 4

Figure 4 shows that capacitors in a facility produce reactive energy that motors require to produce magnetizing current for induction motors and transformers. This reduces the overall current needed from the power supply. This translates into reduced loads on both transformers and feeder circuits.

2.4 Central Power Factor Correction

The power factor correction capacitance is installed at a central point, for example, at the main low voltage distribution board (figure 5). This system covers the total reactive power demand. The capacitance is divided into several sections (steps) which are automatically switched in and out of service by automatic controller and contactors to suit load conditions.

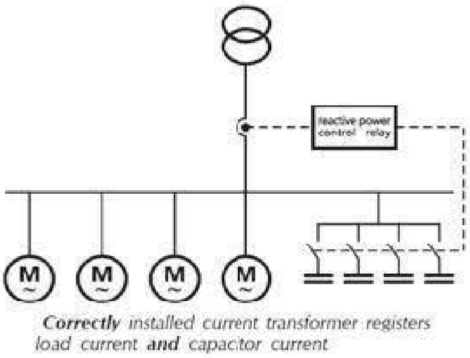


Figure 5

A centrally located power factor correction system is easy to monitor. Modern reactive power control relays enable the contactor status, PF, active and reactive currents in the power distribution system to be monitored continuously.

Usually the overall capacitance installed is less, since the coincidence factor for the entire industrial operation can be taken into account when designing the system. This installed capacitance is also better utilized. It does not, however, eliminate the reactive current circulating within the user's internal power distribution system, but if adequate conductor cross sections are installed, this is no disadvantage.

3. Determination of Required Capacitor Rating

3.1 Measurement of Actual current and power factor:

Power analyzer (Ammeters and power factor meters) are often installed in the main low-voltage distribution board, but clamp meters are equally effective for measuring current. Measurements are made in the main supply line or in the line feeding the equipment whose power factor is to be corrected.

The active power *(P)* is calculated from the measured voltage *(V)*, apparent current *(I)* and power factor *(Cos Φ)*:

$$P\,[\mathrm{kW}] = \sqrt{3} \cdot \sqrt{}\,[\mathrm{V}] \cdot I\,[\mathrm{A}] \cdot \cos\Phi \cdot 10^{3}$$

If the desired power factor *(Cos Φ)* has been specified, the capacitor power rating can be calculated from the following formula:

$$Q_C\,[\mathrm{KVAr}] = P\,[\mathrm{KW}] \cdot (\tan\Phi_1 - \tan\Phi_2)$$

Where

Cos Φ_1: Actual measured Power Factor

Cos Φ_2: Desired Power Factor

Note:

Measurements made as described above naturally only give momentary values. The load conditions can, however, vary considerably depending on the time of day and the season of the year. Measurements should therefore be made by someone who is familiar with the installation. Several measurements should be made, ensuring that the consumers whose power factor is to be corrected are actually switched on.

3.2 Measurements with recording of active and reactive power

More reliable results are obtained with recording instruments (power analyzer). The parameters can be recorded over a longer period of time, peak values also being included. Required capacitor power rating is then calculated as follows:

$$Q_C = Q_L - (P \cdot \tan\Phi_2)$$

Where

Q_C : required capacitor rating

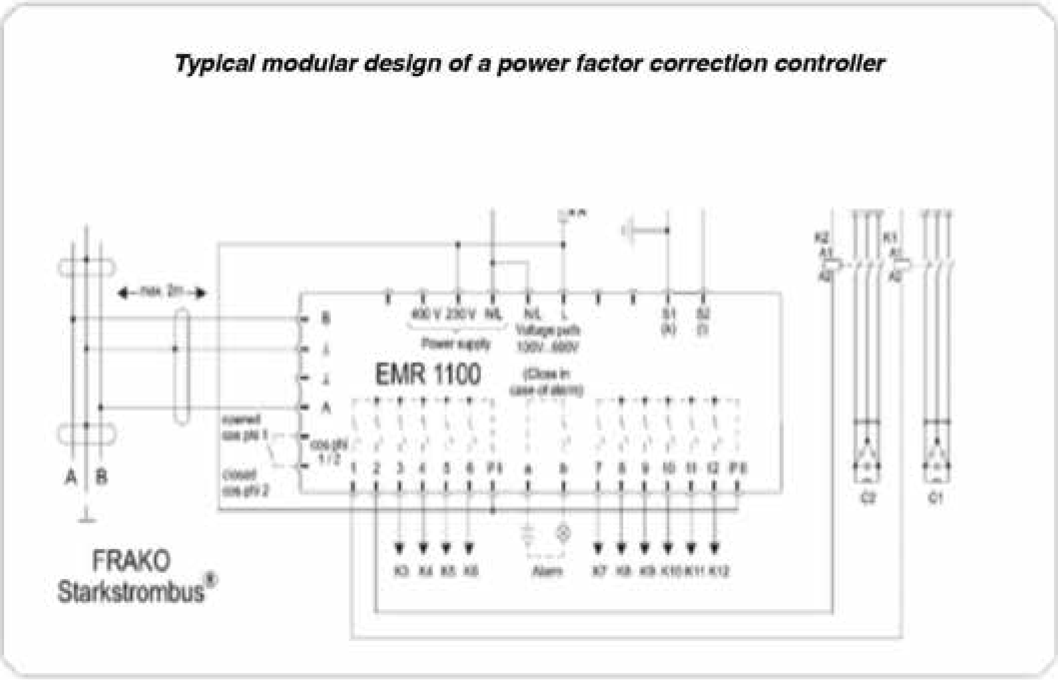
Q_L : measured reactive power

P : measured active power

tan Φ_2 : the corresponding value of tan Φ_2 at the desired (PF) Cos Φ_2

4. Power Factor Correction Controller

Power factor correction systems are installed in power distribution networks where the reactive power demand fluctuates . The capacitor power rating is divided into several sections (steps) that can be switched in and out by an automatic reactive power control relay (see figure 6) via contactors or steadystate switches to suit load conditions.



Typical modular design of a power factor correction controller

Figure 6

A centralized power factor correction system is easy to monitor. Power factor controller enable switch status, Cos Φ , active current, reactor current to be monitored continuously.

5. Power Factor Correction Advantages:

Improvin the PF leading to:

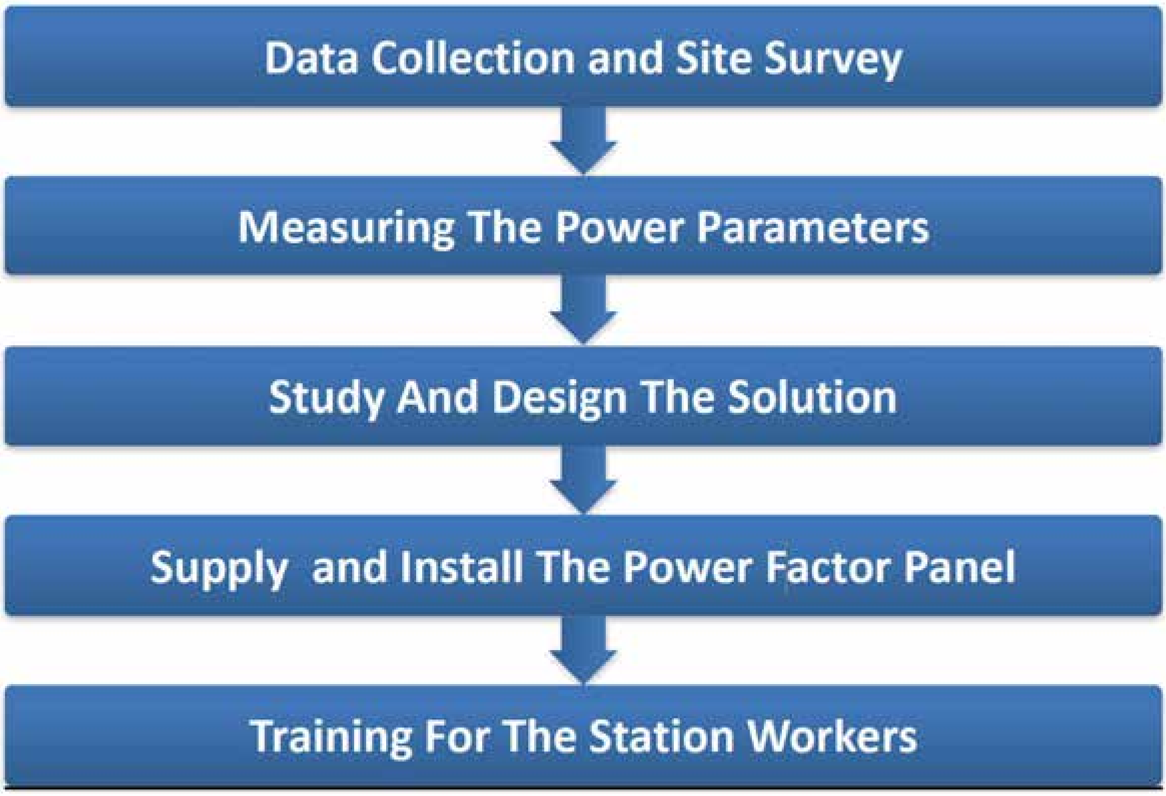
- Reduced Utility Bills
  - Penalties elimination (PF <0.9)*
  - Bonus gain (0.95 ≥ PF ≥ 0.92)*
- Power Quality Increase
  - Electric Current Decrease
  - Improved Voltage Levels
  - Reduced Line Losses (I^2R)
  - Increase System Capacity
  - Extended equipments life
  - Reliable Harmonics Mitigation
  - Environmental Benefit

*This values is related to Egypt Elctrical Utilities

6. Project Activities

El-Nasrea Wastewater Pump Station

Aswan co. – Egypt



6.1 Data Collection and Site Survey

. Population served : 40,000

. Design capacity: 17000 m^3/day

. Actual capacity: 22600 m^3/day

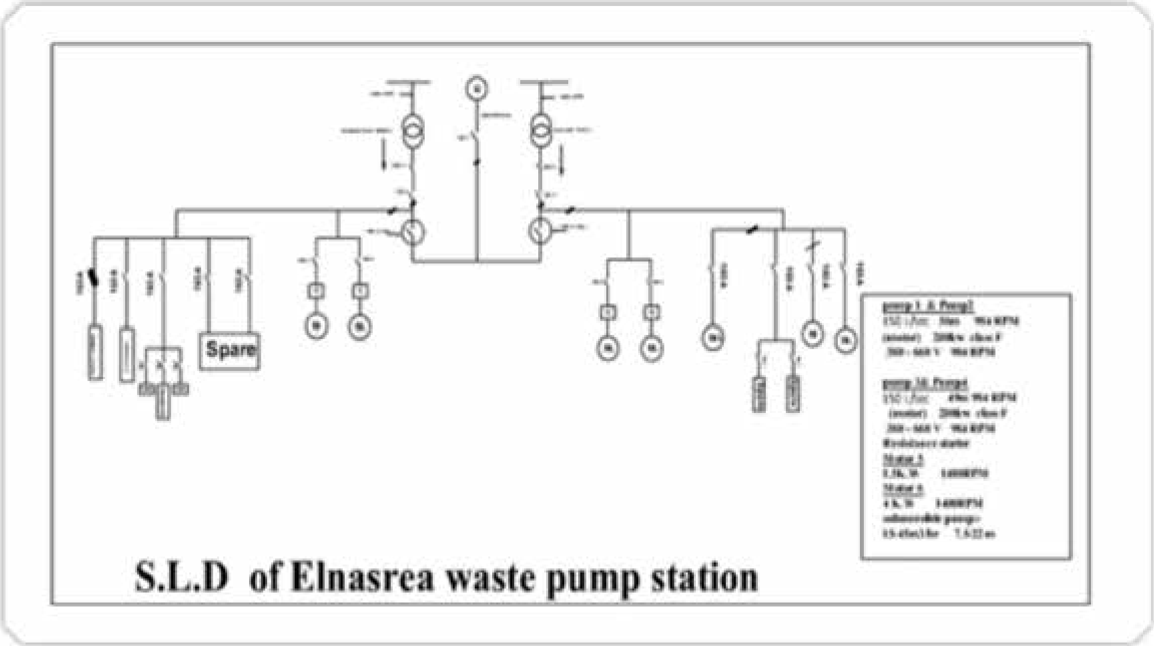
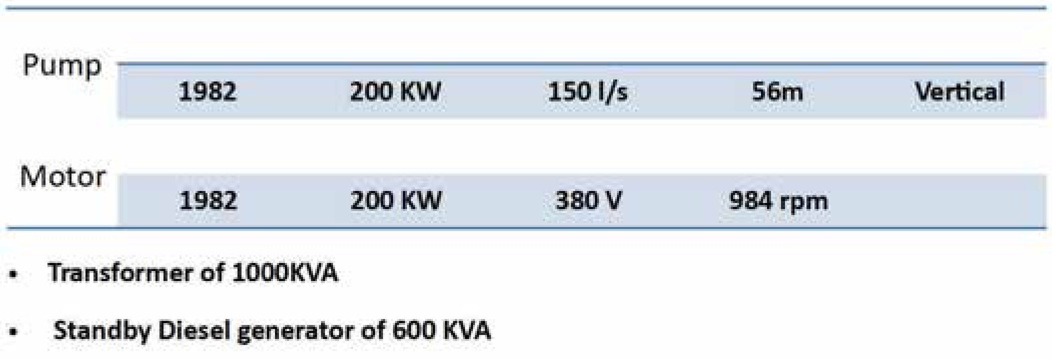


Figure 7

Main loads: No. of pump units: 4 (2 running/ 2 standby):



Pump	1982	200 KW	150 l/s	56m	Vertical
Motor	1982	200 KW	380 V	984 rpm	

- **Transformer of 1000KVA**
- **Standby Diesel generator of 600 KVA**

6.2 Measuring The Power Parameters

The following figures (8, 9, 10 and 11) show the measuring process through power analyzer installed at the low voltage side (output terminals) of transformer (figure 8). This measurements covers the total active and reactive power demand aiming to install a centrally located power factor correction system.

Figure 8

Figure 9

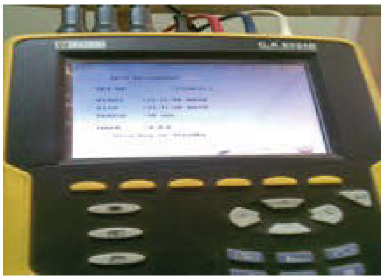


Figure 10

Figure 11

Procedures:

- Install the power analyzer meter on the output terminals power of Transformer.
- Adjust the power analyzer to register the reading of parameters every 10 minutes for 24 hours on normal day operation.
- Plot the minimum, average and maximum.

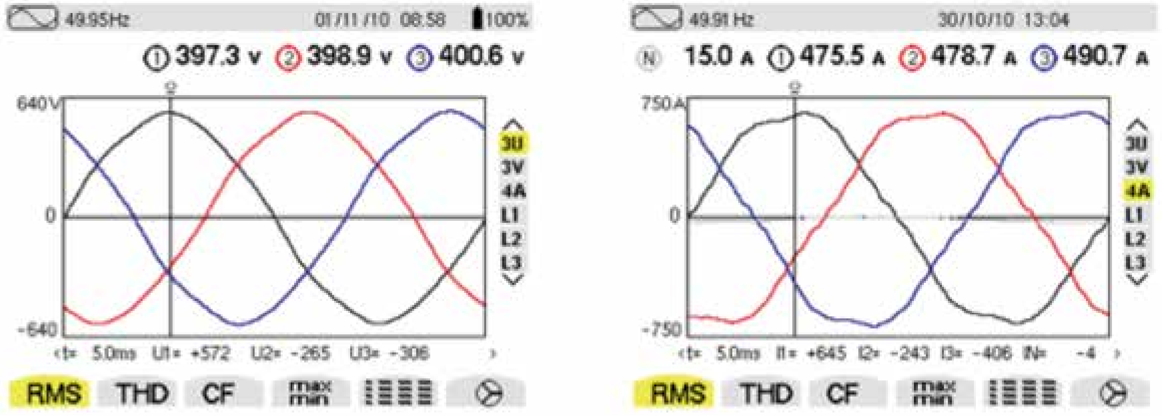


Figure 12

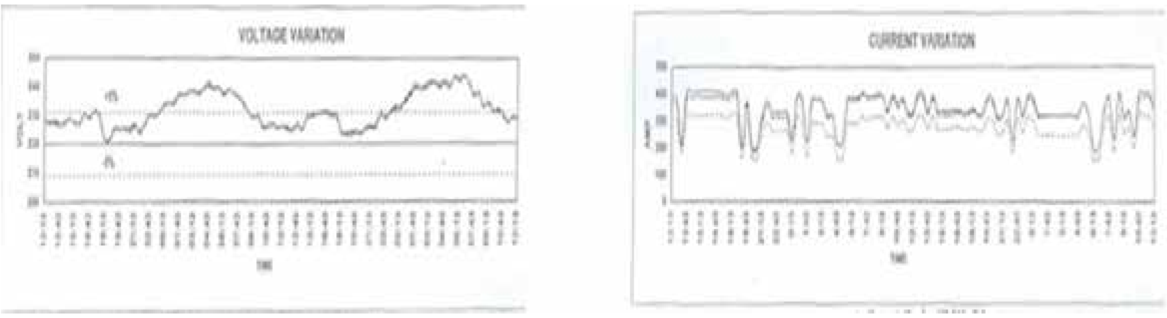


Figure 13

Figures 12 and 13 shows the variation of voltage and current with time across the day as the power consumption varies where Average Values as the following:

voltage	Current	Power Factor	Power
380 V	480 A	0.758	

6.3 Study And Design The Solution

- Normal operation is variable through normal day operation according to the incoming flow as the following:

	State	Active Power
Running Pump States:	0	0 KW
	1	134 KW
	2	296 KW

- Using the average values of the whole day measurements taking Peak values into consideration.

- Use:

  - Average measured PF ($Cos\Phi_1$): 0.758
  - Maximum Active Power: 296 KW
  - Desired PF ($Cos\Phi_2$): 0.96

  Apply in the equation:

  $Q_{Desired}$ (KVAR)= P (KW) ($\tan \Phi_1 - \tan \Phi_2$)

  $Q_{Desired}$ = 296 *(08605 _ 0.2916) 168.4 KVAR

- You can use (tablel 1 in appendix)to get the value of ($\tan \Phi_1 - \tan \Phi_2$)
- By adding safety factor 15%; The desired reactive Power will be 200 KVAR.
- Use a cable of 3 x 185/95 mm (see table 2 in appendix)
- The desired reactive Power (200 KVAR) will be divided into 6 steps to achieve the desired PF with variable loads as the following:

  1. Step1 50 KVAR
  2. Step2 50 KVAR
  3. Step3 25 KVAR
  4. Step4 25 KVAR
  5. Step5 25 KVAR
  6. Step6 25 KVAR

Power Factor Correction Panel (Fig.14)

1. Reactive Power Controller
2. Network connection points
3. Slow-blow Fuses
4. Contactors
5. Capacitors (single-phase or three-phase units, delta-connection)
6. Transformer Suitable voltage transformation to suit control power

Figure 14

6.4 Supply and Install The Power Factor Panel

Start-up is greatly simplified by the fact that the control relay performs this function itself. The choice of the phase in which the current transformer is fitted and the polarity with which the current transformer is connected to the control relay is left to the installer. Phase angle and direction of power flow are determined by the control relay in the course of calibration. At the same time it measures the power ratings of the capacitor stages (steps) to which it is connected and disables those control relay output contacts that are not in use.

If the installation is faulty, the control relay gives precise information on what is lacking to ensure correct operation. Indication and messages of all variables measured by the control relay can be shown in the display.

Figures 15 and 16 shows the installation process taking in consideration to use the proper terminals, cable entry etc.

Figure 15

Figure 16

6.5 Training For The Station Workers

When installation work is carried out, it’s better to give the utility workers a brief training to deal with the power factor correction panel and controller to achieve a good feedback (see figure 17 and 18).

Figure 17

Figure 18

7. Financial Study:

. Electrical Consumption Invoice per year is 91,400 EGP*.

. Penalty Paid per year is 12.132 EGP*.

. Gaining bonus of 3 % of electric bill per year 2,742 EGP*.

. Power Factor correction panel total cost: 30,000 EGP*.

. Total cost reduction per year is (2,742+12,132) = 14,874 EGP*.

. Payback period = total cost I reduction cost

. Payback Period is 2 years and 2 months.

* Euro= 8.315 EGP (26/01/2014)..

* Exchange rate will be available updated through National Bank of Egypt in the following link: http:J/www.nbe.comegJen/ExchangeRate.aspx

8. Power Factor Controller Status

As shown in figures 19 and 20, the power factor controller display PF of value 0.83 before correction and 0.96 after correction which is the desired value.

Figure 19

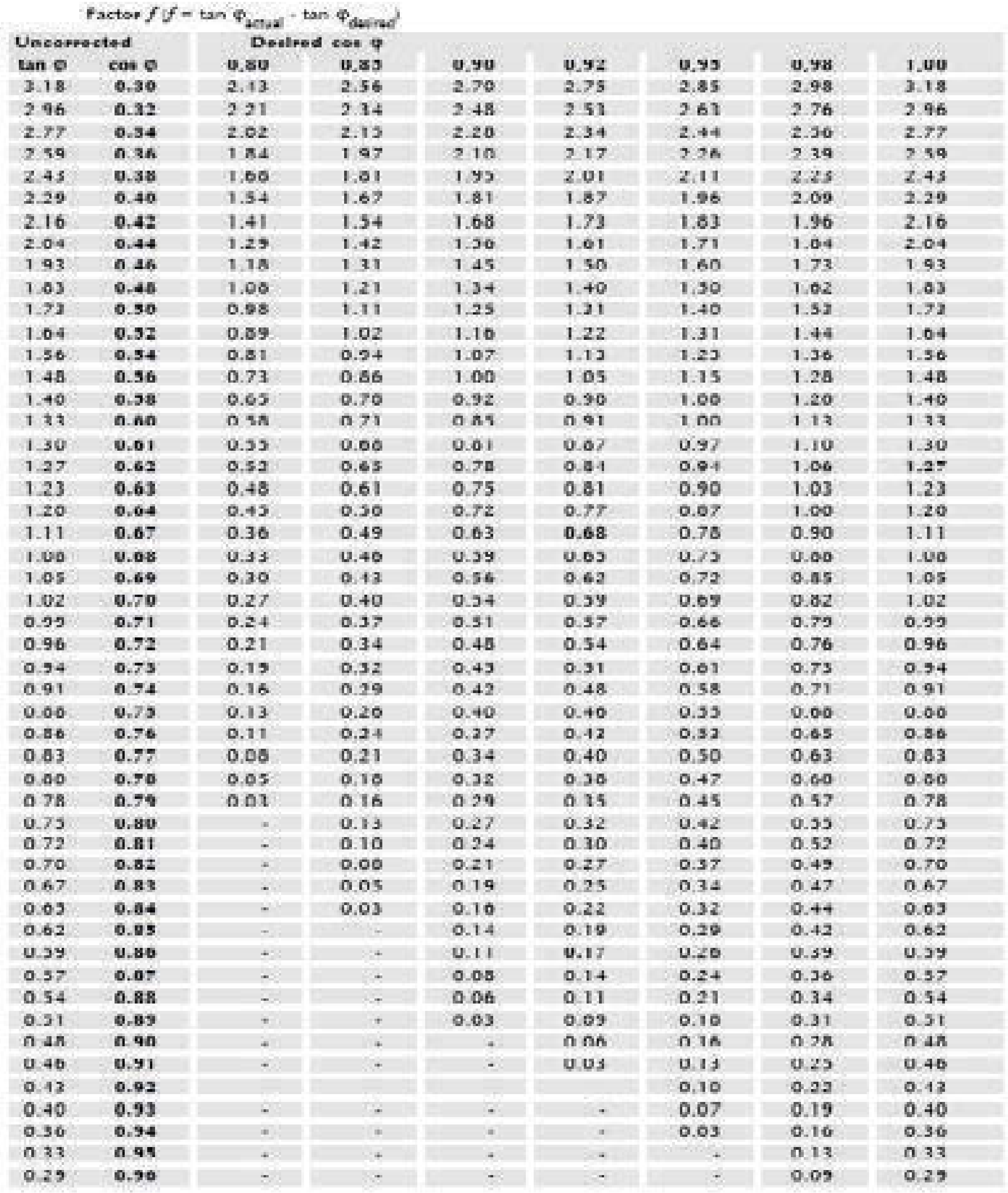
Figure 20

CURRENT STATUS:

- Power factor panel of 200 KVAR is installed.
- Power factor became 0.96.
- Penalties became zero.
- Decreasing electric consumption by 1,5%.

9. Appendix

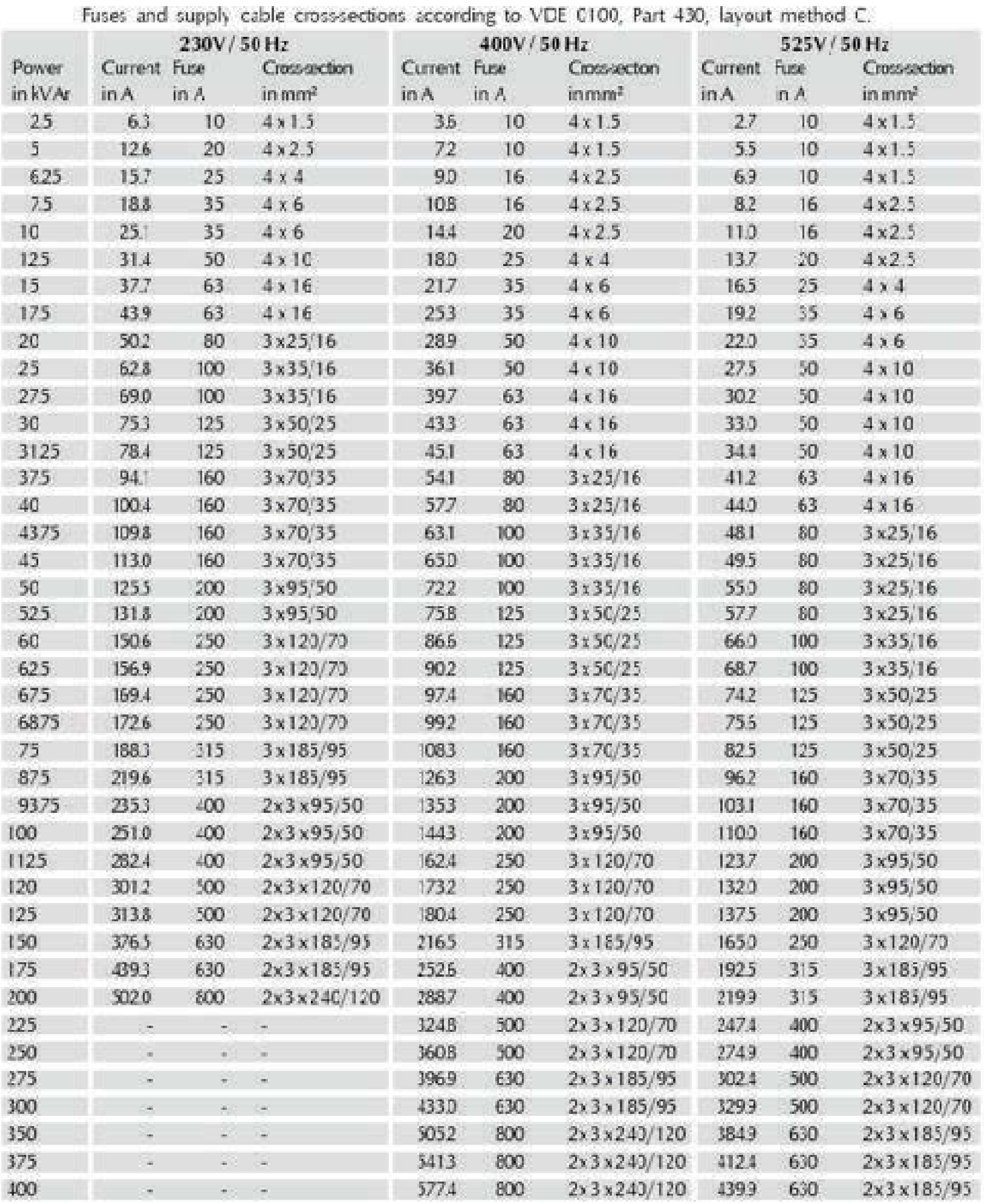
Table 1: Determination of required capacitor rating



Factor f ($f = \tan \varphi_{actual} - \tan \varphi_{desired}$)

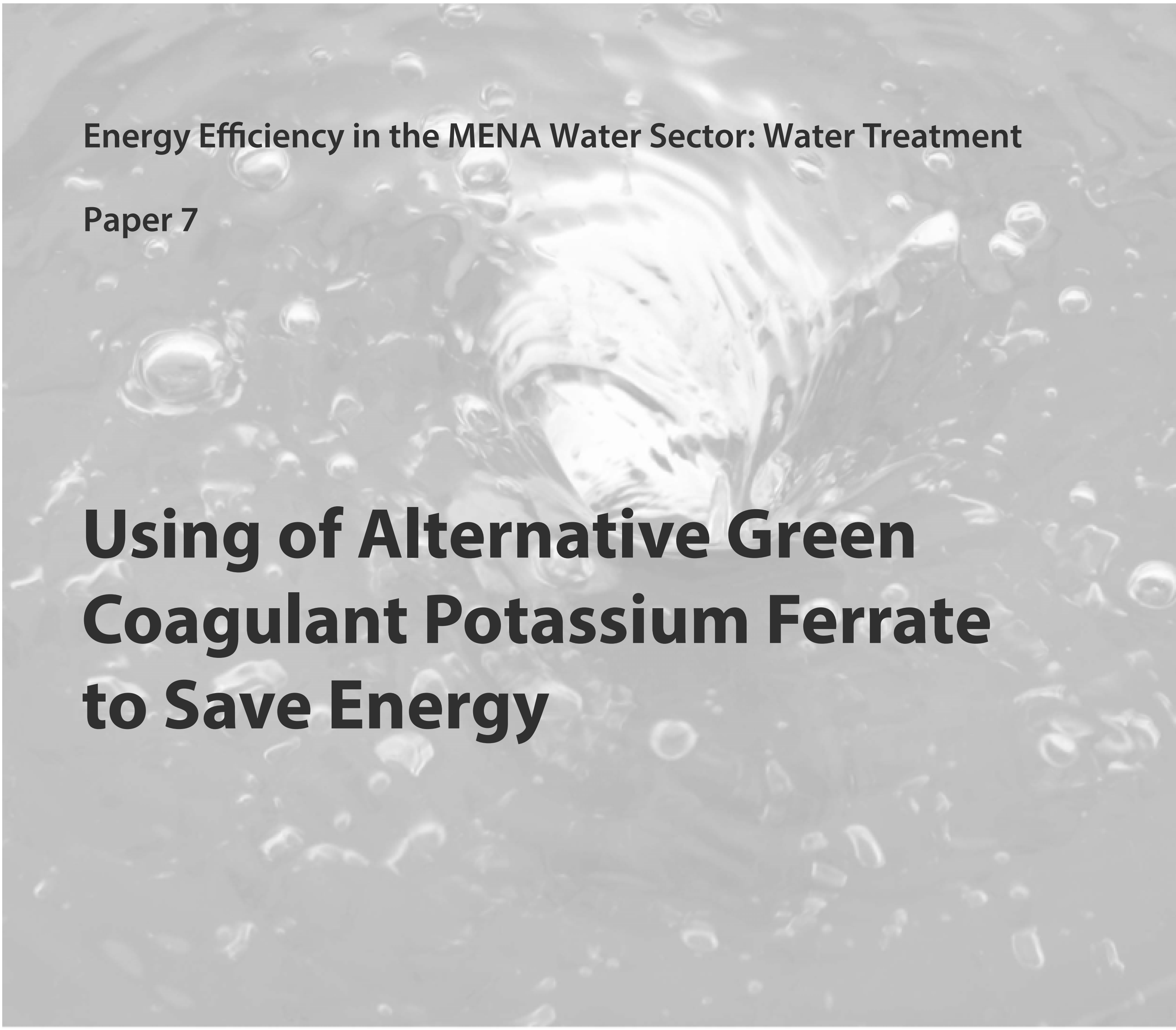
Uncorrected		Desired cos φ						
tan φ	cos φ	0.80	0.85	0.90	0.92	0.95	0.98	1.00
3.18	0.30	2.13	2.56	2.70	2.75	2.85	2.98	3.18
2.96	0.32	2.21	2.34	2.48	2.53	2.63	2.76	2.96
2.77	0.34	2.02	2.15	2.28	2.34	2.44	2.56	2.77
2.59	0.36	1.84	1.97	2.10	2.17	2.26	2.39	2.59
2.43	0.38	1.68	1.81	1.95	2.01	2.11	2.23	2.43
2.29	0.40	1.54	1.67	1.81	1.87	1.96	2.09	2.29
2.16	0.42	1.41	1.54	1.68	1.73	1.83	1.96	2.16
2.04	0.44	1.29	1.42	1.56	1.61	1.71	1.84	2.04
1.93	0.46	1.18	1.31	1.45	1.50	1.60	1.73	1.93
1.83	0.48	1.08	1.21	1.34	1.40	1.50	1.62	1.83
1.73	0.50	0.98	1.11	1.25	1.31	1.40	1.53	1.73
1.64	0.52	0.89	1.02	1.16	1.22	1.31	1.44	1.64
1.56	0.54	0.81	0.94	1.07	1.13	1.23	1.36	1.56
1.48	0.56	0.73	0.86	1.00	1.05	1.15	1.28	1.48
1.40	0.58	0.65	0.78	0.92	0.98	1.08	1.20	1.40
1.33	0.60	0.58	0.71	0.85	0.91	1.00	1.13	1.33
1.30	0.61	0.55	0.68	0.81	0.87	0.97	1.10	1.30
1.27	0.62	0.52	0.65	0.78	0.84	0.94	1.06	1.27
1.23	0.63	0.48	0.61	0.75	0.81	0.90	1.03	1.23
1.20	0.64	0.45	0.58	0.72	0.77	0.87	1.00	1.20
1.11	0.67	0.36	0.49	0.63	0.68	0.78	0.90	1.11
1.08	0.68	0.33	0.46	0.59	0.65	0.75	0.88	1.08
1.05	0.69	0.30	0.43	0.56	0.62	0.72	0.85	1.05
1.02	0.70	0.27	0.40	0.54	0.59	0.69	0.82	1.02
0.99	0.71	0.24	0.37	0.51	0.57	0.66	0.79	0.99
0.96	0.72	0.21	0.34	0.48	0.54	0.64	0.76	0.96
0.94	0.73	0.19	0.32	0.45	0.51	0.61	0.73	0.94
0.91	0.74	0.16	0.29	0.42	0.48	0.58	0.71	0.91
0.88	0.75	0.13	0.26	0.40	0.46	0.55	0.68	0.88
0.86	0.76	0.11	0.24	0.37	0.43	0.53	0.65	0.86
0.83	0.77	0.08	0.21	0.34	0.40	0.50	0.63	0.83
0.80	0.78	0.05	0.18	0.32	0.38	0.47	0.60	0.80
0.78	0.79	0.03	0.16	0.29	0.35	0.45	0.57	0.78
0.75	0.80	-	0.13	0.27	0.32	0.42	0.55	0.75
0.72	0.81	-	0.10	0.24	0.30	0.40	0.52	0.72
0.70	0.82	-	0.08	0.21	0.27	0.37	0.49	0.70
0.67	0.83	-	0.05	0.19	0.25	0.34	0.47	0.67
0.65	0.84	-	0.03	0.16	0.22	0.32	0.44	0.65
0.62	0.85	-	-	0.14	0.19	0.29	0.42	0.62
0.59	0.86	-	-	0.11	0.17	0.26	0.39	0.59
0.57	0.87	-	-	0.08	0.14	0.24	0.36	0.57
0.54	0.88	-	-	0.06	0.11	0.21	0.34	0.54
0.51	0.89	-	-	0.03	0.09	0.18	0.31	0.51
0.48	0.90	-	-	-	0.06	0.16	0.28	0.48
0.46	0.91	-	-	-	0.03	0.13	0.25	0.46
0.43	0.92					0.10	0.22	0.43
0.40	0.93	-	-	-	-	0.07	0.19	0.40
0.36	0.94	-	-	-	-	0.03	0.16	0.36
0.33	0.95	-	-	-	-	-	0.13	0.33
0.29	0.96	-	-	-	-	-	0.09	0.29

Table 2: Cable Cross Sections



Fuses and supply cable cross-sections according to VDE 0100, Part 430, layout method C.

Power in kVAr	230V / 50 Hz Current in A	Fuse in A	Cross-section in mm²	400V / 50 Hz Current in A	Fuse in A	Cross-secton in mm²	525V / 50 Hz Current in A	Fuse in A	Cross-section in mm²
2.5	6.3	10	4 x 1.5	3.6	10	4 x 1.5	2.7	10	4 x 1.5
5	12.6	20	4 x 2.5	7.2	10	4 x 1.5	5.5	10	4 x 1.5
6.25	15.7	25	4 x 4	9.0	16	4 x 2.5	6.9	10	4 x 1.5
7.5	18.8	35	4 x 6	10.8	16	4 x 2.5	8.2	16	4 x 2.5
10	25.1	35	4 x 6	14.4	20	4 x 2.5	11.0	16	4 x 2.5
12.5	31.4	50	4 x 10	18.0	25	4 x 4	13.7	20	4 x 2.5
15	37.7	63	4 x 16	21.7	35	4 x 6	16.5	25	4 x 4
17.5	43.9	63	4 x 16	25.3	35	4 x 6	19.2	35	4 x 6
20	50.2	80	3 x 25/16	28.9	50	4 x 10	22.0	35	4 x 6
25	62.8	100	3 x 35/16	36.1	50	4 x 10	27.5	50	4 x 10
27.5	69.0	100	3 x 35/16	39.7	63	4 x 16	30.2	50	4 x 10
30	75.3	125	3 x 50/25	43.3	63	4 x 16	33.0	50	4 x 10
31.25	78.4	125	3 x 50/25	45.1	63	4 x 16	34.4	50	4 x 10
37.5	94.1	160	3 x 70/35	54.1	80	3 x 25/16	41.2	63	4 x 16
40	100.4	160	3 x 70/35	57.7	80	3 x 25/16	44.0	63	4 x 16
43.75	109.8	160	3 x 70/35	63.1	100	3 x 35/16	48.1	80	3 x 25/16
45	113.0	160	3 x 70/35	65.0	100	3 x 35/16	49.5	80	3 x 25/16
50	125.5	200	3 x 95/50	72.2	100	3 x 35/16	55.0	80	3 x 25/16
52.5	131.8	200	3 x 95/50	75.8	125	3 x 50/25	57.7	80	3 x 25/16
60	150.6	250	3 x 120/70	86.6	125	3 x 50/25	66.0	100	3 x 35/16
62.5	156.9	250	3 x 120/70	90.2	125	3 x 50/25	68.7	100	3 x 35/16
67.5	169.4	250	3 x 120/70	97.4	160	3 x 70/35	74.2	125	3 x 50/25
68.75	172.6	250	3 x 120/70	99.2	160	3 x 70/35	75.6	125	3 x 50/25
75	188.3	315	3 x 185/95	108.3	160	3 x 70/35	82.5	125	3 x 50/25
87.5	219.6	315	3 x 185/95	126.3	200	3 x 95/50	96.2	160	3 x 70/35
93.75	235.3	400	2x3 x 95/50	135.3	200	3 x 95/50	103.1	160	3 x 70/35
100	251.0	400	2x3 x 95/50	144.3	200	3 x 95/50	110.0	160	3 x 70/35
112.5	282.4	400	2x3 x 95/50	162.4	250	3 x 120/70	123.7	200	3 x 95/50
120	301.2	500	2x3 x 120/70	173.2	250	3 x 120/70	132.0	200	3 x 95/50
125	313.8	500	2x3 x 120/70	180.4	250	3 x 120/70	137.5	200	3 x 95/50
150	376.5	630	2x3 x 185/95	216.5	315	3 x 185/95	165.0	250	3 x 120/70
175	439.3	630	2x3 x 185/95	252.6	400	2x 3 x 95/50	192.5	315	3 x 185/95
200	502.0	800	2x3 x 240/120	288.7	400	2x 3 x 95/50	219.9	315	3 x 185/95
225	-	-	-	324.8	500	2x 3 x 120/70	247.4	400	2x3 x 95/50
250	-	-	-	360.8	500	2x 3 x 120/70	274.9	400	2x3 x 95/50
275	-	-	-	396.9	630	2x 3 x 185/95	302.4	500	2x3 x 120/70
300	-	-	-	433.0	630	2x 3 x 185/95	329.9	500	2x3 x 120/70
350	-	-	-	505.2	800	2x 3 x 240/120	384.9	630	2x3 x 185/95
375	-	-	-	541.3	800	2x 3 x 240/120	412.4	630	2x3 x 185/95
400	-	-	-	577.4	800	2x 3 x 240/120	439.9	630	2x3 x 185/95



Energy Efficiency in the MENA Water Sector: Water Treatment

Paper 7

Using of Alternative Green Coagulant Potassium Ferrate to Save Energy

Written by:
Mahmoud Abd Al Rahman Saad – Egypt – HCWW

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

Executive Summary

Using of Alternative Green Coagulant Potassium Ferrate to Save Energy

by Mahmoud Abd Al Rahman Saad

Egypt suffers from a serious energy problem nowadays, because the gap between electrical energy producing and consuming all over the country reach to 6000 MW.

Chemical dosing in water treatment plant is an important and an essential step in water treatment industry. The dosing pumps consume a considerable amount of water treatment plant energy about 8 % (including chlorine dosing, alum dosing and Slurry discharge pump) of the energy needed to operate the treatment plant.

In a single application, Potassium Ferrate can simultaneously perform as an oxidant, coagulant, and disinfectant. Potassium Ferrate is more powerful than other oxidants such as ozone and chlorine dioxide. It can replace coagulants such as ferric chloride, alum and polymers for the removal of metals, non-metals and humic acids. It outperforms other disinfectants such as UV, hydrogen peroxide, and chlorine; it can kill many chlorine resistant organisms such as aerobic spore-formers and sulphite-reducing clostridia.

Potassium Ferrate is a multi-function chemical reagent has the potential to perform oxidation, coagulation, and disinfection in one single treatment step.

A survey along Rossita branch (from River Nile) was done to detect the most polluted site (hot spot), in order to carry out the experimental work on it. This point was at EL Suif water treatment plant intake in EL Mahmudiya canal.

The experimental work was done first in bench scale using jar test to select the optimum Potassium Ferrate dose to compare the gained results with the results of using both (chlorine/alum), the result shows that Potassium Ferrate prove itself as a possible alternative of both (chlorine/alum) because a lower dose of Potassium Ferrate (30 ppm) achieve improved water quality if compared with traditional treatment using chlorine and alum, Potassium Ferrate achieve removal of ammonia, turbidity and total coliform by 92.2%, 82.1% and 99.99% respectively which is higher than using of both alum and chlorine with doses 40 and 80 ppm.

The produced slurry from Potassium Ferrate was found to be 10 ml which is less than the volume of slurry produced when (chlorine/alum) was used = 16 ml.

Additional experimental work was done in a mobile water treatment plant and the energy consumption was compared incase of using Potassium Ferrate and chlorine/alum the Potassium Ferrate was found to achieve (27.3%) reduction in the energy consumption of the mobile water treatment plant and produce water with improved quality than using chlorine/alum.

Potassium Ferrate achieve reduction in use of slurry discharge pump by about (40%) from using alum and chlorine because Potassium Ferrate produce less slurry by 40 % if compared with alum as a coagulant.

Background/Situation

Egypt suffers from a serious energy problem, this last summer (2013) the energy deficiency reach to an unprecedented level, the gap between electrical energy production and consumption all over the country reach to 6000 MW [1]

Drinking water industry consumes considerable amount about 7% out of 26.91 million kW the total electricity in Egypt (2010 estimated) so saving of some energy in water industry would directly effect on the electricity situation [2].

Water and sewer tariffs in Egypt are among the lowest tariffs in the world. Despite their affordability, almost half the bills are not paid and politicians are reluctant to increase tariffs, especially since the Arab Spring, thus only a fraction of costs is recovered through revenues from tariffs. The shortfall in revenues is partly made up by government subsidies for investment and operations at the tune of USD 2.5 billion per year, of which only about 10 percent is financed by external donors, the government subsidies shrink to 750 million per year for the past three years this increase the gap between the revenue and expenses [3].

After the last actions taking by the government to reform the subsides in June 2014, the prices of heavily subsidized energy products raised up to 78 percent, and so the annual electricity tariff paid by the holding company and its affiliated companies increased by 204 million pounds annually, that put a lot of challenge on the shoulders of the holding company to take all the necessary actions to reduce and save energy.

In general, all water treatment processes aim to remove suspended solids which increase turbidity and cause change in color and odor also to remove pathogens. Water treatment processes can be diagrammed as in figure (1) See Annex

Chemical dosing in water treatment plant is an important and main step in water treatment industry. The chemical dosing done using pumps to deliver both chlorine (for the disinfection) and alum (for the coagulation). The dosing pumps, slurry discharge pumps and pumps used to operate and wash the activated carbon filter consume a considerable amount of water treatment plant electricity about 8 % of the energy needed to operate the treatment plant. Table (1)See Annex Show the distribution and capacities of water treatment plants belongs to Cairo Water Company from the table the average consumption of energy for the production of a cubic meter of drinking water is 400 watt, this cost about 0.3 LE only for electricity this represent (24%) of the real production cost of the cubic meter. The using of alum produce slurry which need finally to be discharged out of the treatment plant which also consume a considerable amount of energy to discharge.

Potassium Ferrate is a truly unique compound that offers a friendly and economical impact, alternative to conventional water and wastewater treatment technologies. For many applications, the capital equipment cost and aggregate operating expenses associated with Potassium Ferrate are appreciably less than other methods of treatment[4].

Potassium Ferrate synthesis uses commercially available chemicals already found in most water and wastewater treatment plants, and a Potassium Ferrate treatment system utilizes less real estate and consumes less energy. In terms of its impact on the environment, Potassium Ferrate is a genuinely green technology that is both effective and affordable[5].

In a single application, Potassium Ferrate can simultaneously perform as an oxidant, coagulant, and disinfectant. Potassium Ferrate is more powerful than other oxidants such as ozone and chlorine dioxide. It can replace coagulants such as ferric chloride, alum and polymers for the removal of metals, non-metals and humic acids. It outperforms other disinfectants such as UV, hydrogen peroxide, and chlorine and can kill many chlorine resistant organisms such as aerobic spore-formers and sulphite-reducing clostridia. Potassium Ferrate is a versatile, powerful, multi-use water and wastewater treatment technology this mean the ability to replace both chlorine and alum dosing process by Potassium Ferrate single step dosing to save energy and achieve disinfection by lower dose and limited production of slurry.

Objectives

- Saving the dosing energy used for both alum and chlorine by using a novel multifunctional green coagulant Potassium Ferrate.
- Saving energy of slurry discharge (Potassium Ferrate produce low slurry).
- Saving the cost by using low and effective dose of Potassium Ferrate instead of using (chlorine/alum).
- Eliminating the risk of producing hazardous chemical byproducts.
- Lowering capital, running costs, and less management are required, comparing with the conventional two-unit system using disinfectant and coagulant separately.
- Studying the ability to use Potassium Ferrate in wastewater treatment and also achieving removal of ammonia which is a specific challenge in Rossita Branch with lower dose (less consumption of energy) of Potassium Ferrate 3.3 mg/l Potassium Ferrate dose for each 1 mg/l ammonia comparing to the chlorine 10-11 mg/l chlorine for each 1 mg/l ammonia.
- Saving treatment cost (No need to use activated carbon).

Approach

Our practices were done on both lab and pilot scale by using a mobile water treatment pilot plant from Alexandria Company for water. This pilot plant allows the using of the same treatment steps by the same sequence in conventional treatment with ability to change the raw water source as shown in the following figure (2) See Annex

A survey was done through Rossita Branch to detect the critical and most polluted point to undertake the experimental work on it.

Jar test was conducted in bench scale to detect the optimum dose of Potassium Ferrate used to achieve both chemical and microbiological treatment.

The superior performance of Potassium Ferrate (VI) was demonstrated via comparison between using Potassium Ferrate only instead of both alum and chlorine through many experiments. The practical aspect of many of them was to demonstrate the feasibility of the online generation and application of Potassium Ferrate (VI) for water treatment, which could lead to the implementation of Potassium Ferrate (VI) technology in water and wastewater treatment practice.

The comparison includes the mentoring of the following three aspects:

- Energy when Potassium Ferrate was used only instead of both alum and chlorine.
- Energy to drain the produced slurry when Potassium Ferrate was used only instead of both alum and chlorine.
- The type and amount of harmful byproducts when Potassium Ferrate was used only instead of both alum and chlorine.

Activities and achieved results

1- A Survey on Rossita Branch

River Nile travels along Egypt for about 950 km starting from downstream High Aswan Dam to upstream Delta Barrage, where it divides into two branches Rosetta and Damietta branches each of them runs separately to the Mediterranean Sea, forming the Delta region between these both branches.

Rosetta branch and EL Mahmudiya canal represents the main freshwater stream that extends northwards for about 239 km on the western boundary of the Nile Delta from Egypt's Delta Barrage [1]

The area of this study extended about 200 km in Rosetta branch, starting from El lkhsas village up to Edfina barrage, and about 40 km in EL Mahmudiya Canal with starting from El Suif WTP to El Attaf village 14 sites were chosen. Samples were collected from the middle of the waterway in each of the Rosetta branch and EL Mahmudiya Canal.

Samples were collected at a sample rate of 5 kilometers with a total 48 sample. As shown in Figure (3)

Figure (3). The sampling points on EL Mahmudiya canal.

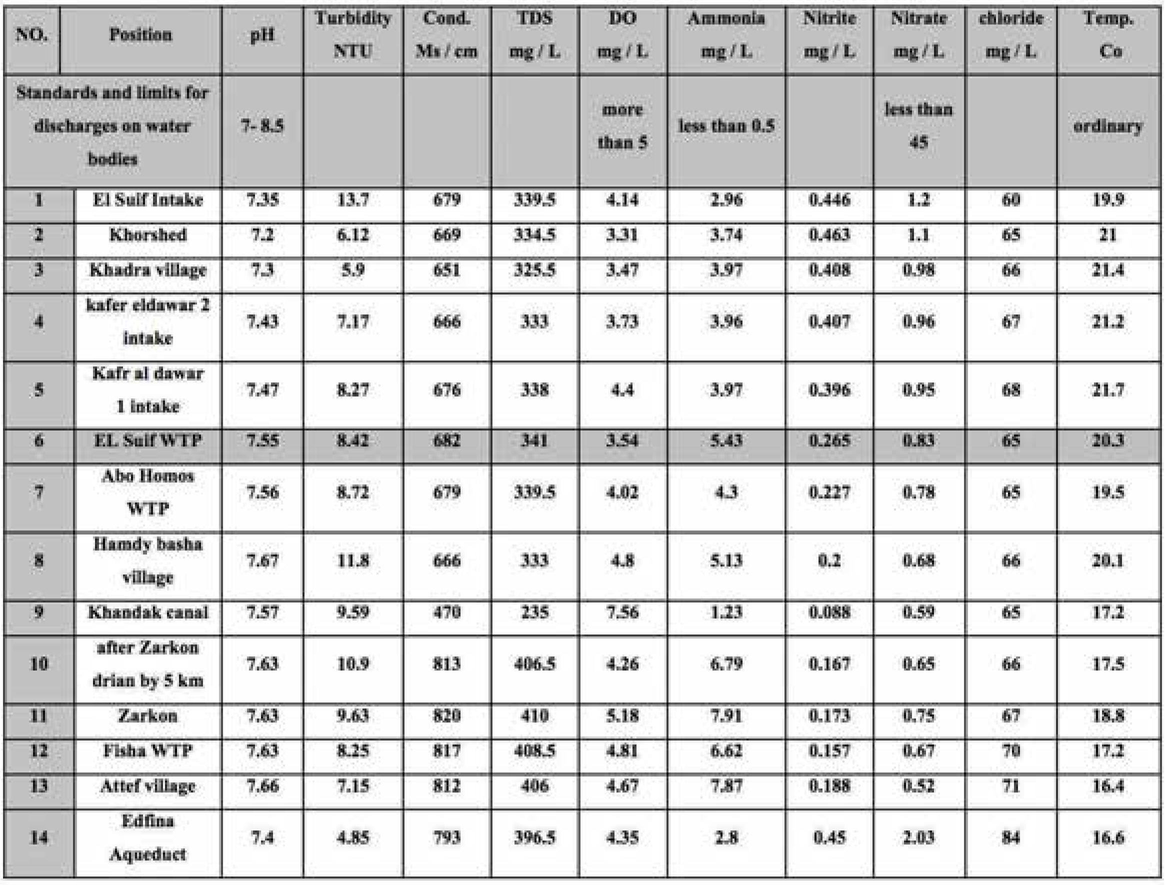
1-1 Sample analysis:

Physical and chemical analyses were carried out according to "Standard Methods for Examination of Water and Wastewater" [6]. Field parameters (temperature, pH, electric conductivity (EC), dissolved oxygen (DO) and total dissolved solids (TDS) were measured in-site using multi-probe system. ammonia, nitrite and nitrate were carried out by a colorimetric method and the chloride done by argenometeric method.

1-2 Survey Results

The following table (2) shows the results of Physical and chemical analyses of the water of 14 sites from EL Mahmudiya canal.

Tables (2). Results of physical & chemical analyses of water samples collected from EL Mahmudiya Canal during winter 2013.



NO.	Position	pH	Turbidity NTU	Cond. Ms / cm	TDS mg / L	DO mg / L	Ammonia mg / L	Nitrite mg / L	Nitrate mg / L	chloride mg / L	Temp. Co
Standards and limits for discharges on water bodies		7- 8.5				more than 5	less than 0.5		less than 45		ordinary
1	El Suif Intake	7.35	13.7	679	339.5	4.14	2.96	0.446	1.2	60	19.9
2	Khorshed	7.2	6.12	669	334.5	3.31	3.74	0.463	1.1	65	21
3	Khadra village	7.3	5.9	651	325.5	3.47	3.97	0.408	0.98	66	21.4
4	kafer eldawar 2 intake	7.43	7.17	666	333	3.73	3.96	0.407	0.96	67	21.2
5	Kafr al dawar 1 intake	7.47	8.27	676	338	4.4	3.97	0.396	0.95	68	21.7
6	EL Suif WTP	7.55	8.42	682	341	3.54	5.43	0.265	0.83	65	20.3
7	Abo Homos WTP	7.56	8.72	679	339.5	4.02	4.3	0.227	0.78	65	19.5
8	Hamdy basha village	7.67	11.8	666	333	4.8	5.13	0.2	0.68	66	20.1
9	Khandak canal	7.57	9.59	470	235	7.56	1.23	0.088	0.59	65	17.2
10	after Zarkon drian by 5 km	7.63	10.9	813	406.5	4.26	6.79	0.167	0.65	66	17.5
11	Zarkon	7.63	9.63	820	410	5.18	7.91	0.173	0.75	67	18.8
12	Fisha WTP	7.63	8.25	817	408.5	4.81	6.62	0.157	0.67	70	17.2
13	Attef village	7.66	7.15	812	406	4.67	7.87	0.188	0.52	71	16.4
14	Edfina Aqueduct	7.4	4.85	793	396.5	4.35	2.8	0.45	2.03	84	16.6

1-2-1 Ammonia:

From Table (2), the results show that the level of ammonia in EL Mahmudiya Canal is a maximum at Attef village = 7.87 ppm after Zarkon drain. Which main that the drain has a large effect on EL Mahmudiya canal. This can be shown in Figure (4).

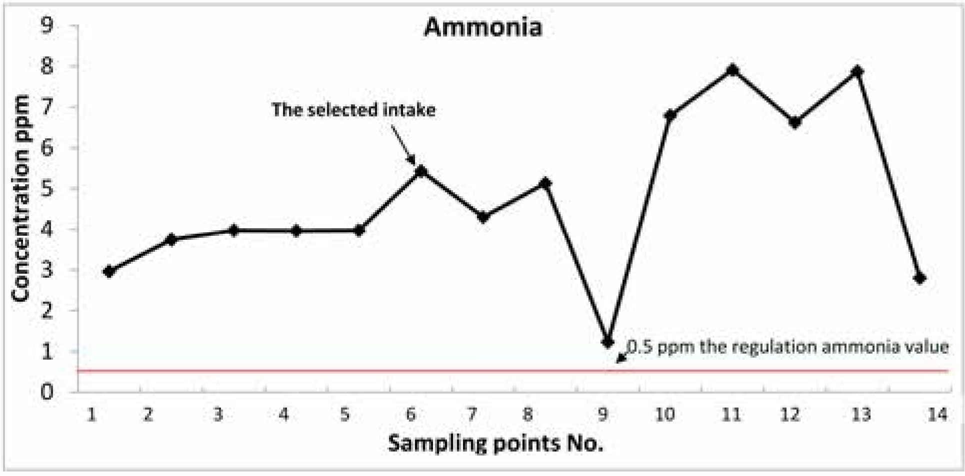


Figure (4). Level of ammonia a long EL Mahmudiya canal.

1-3 survey conclusion

The survey results demonstrate that the ammonia level at EL Mahmudiya canal is around 5 ppm with high concentration of both nitrate and nitrite, this will lead to using of a higher doses of chlorine around 60 ppm in order to reach the break point, and so a higher energy consumption up to 600% of the regular chlorine dose >10 ppm.

2- Jar test using Potassium Ferrate

The selected raw water from EL Mahmudiya canal was then distributed into 6 beakers to conduct jar test on it, in order to select the optimum Potassium Ferrate dose (which achieve removal of ammonia and pathogens). The used Potassium Ferrate was prepared in the lab using Wet method for preparation using the following chemicals (ferric chloride, sodium hydroxide and potassium permanganate from Merck Co.).

Tests were carried out using 1000 mL samples. After flash mixing began the Potassium Ferrate (VI) doses were added. The presence of Potassium Ferrate in the samples was tested using potassium iodide (KI). Once the Potassium Ferrate had reacted in the fast mixing step for 1 minute, the mixing speed was then reduced to allow coagulation for about 20 minutes, and finally sedimentation of flocs for 6 minutes.

Samples were then tested for the following parameter (ammonia, turbidity and total bacterial count). The data is shown in Table (3).

Table (3). The Potassium Ferrate jar test results.

Potassium Ferrate Dose (ppm)	Ammonia (ppm)	Ammonia Removal percent (%)	Turbidity (NTU)	Turbidity Removal Percent (%)	Total Coliform percent Removal (CFU/mL) (%)
10	1.43	73.5	3.2	61.9	98
20	0.95	82.4	2.6	69.0	99
30	**0.42**	**92.2**	**1.5**	**82.1**	**99.99**
40	0.15	97.2	1.4	83.3	99.99
50	0.01	99.8	1.9	77.4	99.999
60	0.009	99.8	2.2	73.8	99.9999

The data in table (3) demonstrate the effectiveness of Potassium Ferrate in removal of ammonia and turbidity and accomplish of a sufficient disinfection.

3- Jar test using Chlorine/Alum

By the same way the selected raw water from EL Mahmudiya canal was then distributed into 6 beakers to conduct jar test using chlorine as disinfectant and alum as coagulant.

Tests were carried out using 1000 mL samples. After flash mixing began the chlorine/alum doses were added, the mixing speed was then reduced to allow coagulation, and finally sedimentation of flocs.

Samples were then tested for the following parameter (ammonia, turbidity and Total bacterial count). The data is shown in Table (4)

Table (4). The Chlorine/Alum jar test results.

Chlorine Dose (ppm)	Alum Dose (ppm)	Ammonia (ppm)	Ammonia Removal percent (%)	Turbidity (NTU)	Turbidity Removal Percent (%)	Total Coliform percent Removal (CFU/mL) (%)
20	10	2.5	53.7	4.2	50.0	90
40	20	1.82	66.3	2.9	65.5	95
60	30	1.52	71.9	1.8	78.6	99
80	**40**	**0.95**	**82.4**	**1.8**	**78.6**	**99.9**
100	50	0.51	90.6	2.3	72.6	99.99
120	60	0.22	95.9	2.7	67.9	99.999

4- Comparison between Potassium Ferrate and (Chlorine/Alum)

The following figure (5) shows a comparison between the optimum dose of Potassium Ferrate and different doses of both (Chlorine/Alum).

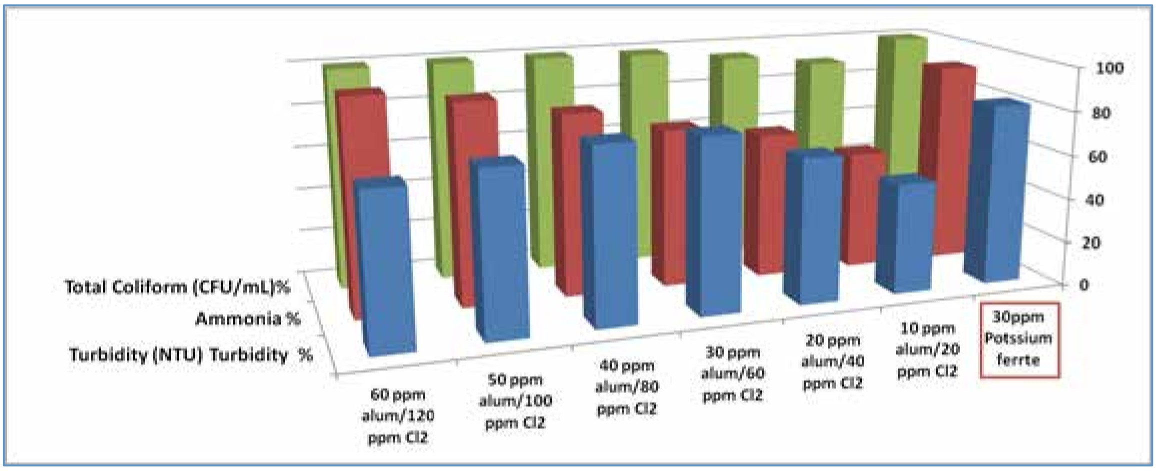


Figure (5). A comparison between the optimum dose of Potassium Ferrate and different doses of both (Chlorine/Alum).

It's obvious from the figure that Potassium Ferrate by 30 ppm dose achieves removal of ammonia, turbidity and total coliform by 92.2%, 82.1% and 99.99% respectively which is higher than using of both alum and chlorine with doses 40 and 80 ppm.

The produced slurry from Potassium Ferrate was found to be 10 ml which is less than the volume of slurry produced when (chlorine/alum) was used = 16 ml.

From the bench scale results it is clear that using of Potassium Ferrate will save energy by replacing both alum and chlorine pumps by only one dosing pump for delivering Potassium Ferrate.

Also, from the amount of slurry results the using of Potassium Ferrate will save energy used to discharge the slurry because Potassium Ferrate produce less slurry by 40 % from using alum as a coagulant.

5- Mobile Pilot application

The mobile pilot water treatment plant is a pilot system that contains all treatment steps in the same train as in the large scale, which allows the simulation for the treatment plant and allows making experiments in the level of a small scale as in the water treatment plant.

Pilot units are used in feasibility studies. They enable the acquisition of data to confirm the viability of the process, the projected operational costs and the full scale design parameters.

The mobile pilot water treatment plant contains the following components as shown in the following flow diagram. See figure (6).

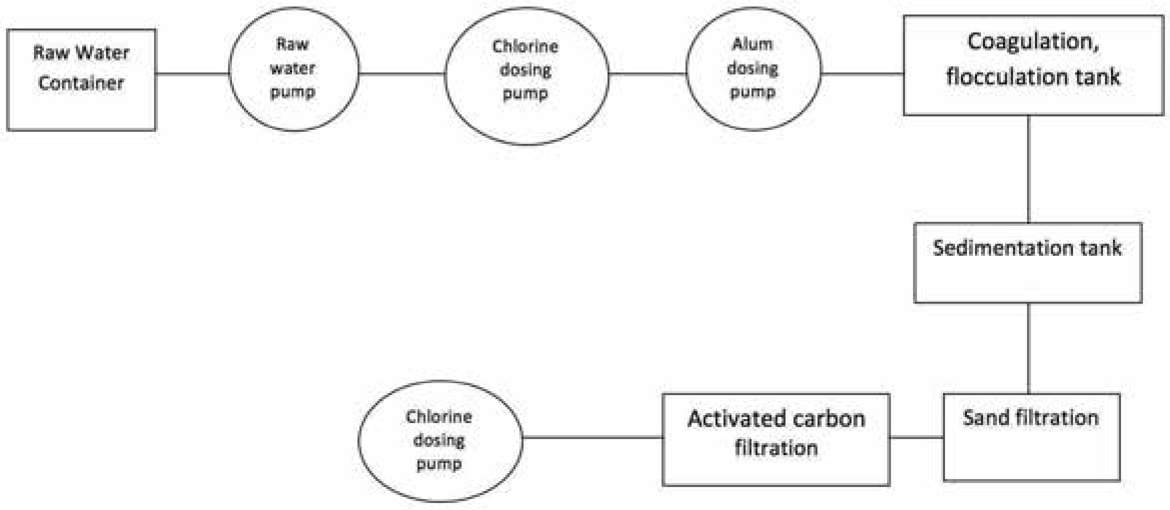


Figure (6). Mobile pilot water treatment plant flow diagram.

Using of Potassium Ferrate allows producing of water by improved quality and with only addition of Potassium Ferrate instead of the following three steps chlorine dosing, alum dosing and activated carbon as shown in the following figure (7).

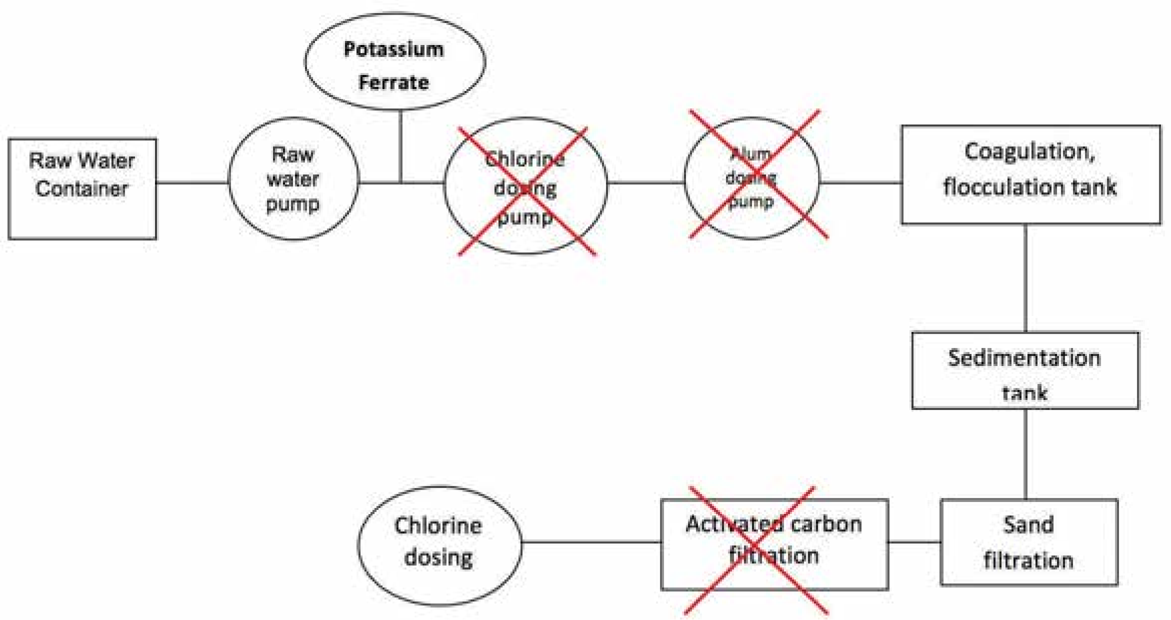


Figure (7). Mobile water treatment plant in case of using Potassium Ferrate.

5-1. Effect of using of Potassium Ferrate in the total energy consumption.

Using of Potassium Ferrate achieved saving in energy by total (27.3%) from the total energy required for operating the pilot plant, this is by saving the energy of alum, chlorine dosing pump and also saving the energy of activated carbon filter backwash pump.

Potassium Ferrate achieve reduction in use of slurry discharge pump by about (40%) from using alum and chlorine because Potassium Ferrate produce less slurry by 40 % from using alum as a coagulant.

These results are illustrated in table (5) which represent the energy consumption in case of using of chlorine/alum as a coagulant and disinfectant, and table (6) show the energy consumption in case of replacement of alum/chlorine with a single dosing of Potassium Ferrate.

These all results are shown in the figure (8) which demonstrates the effect of using Potassium Ferrate in the energy consumption instead of using chlorine/alum

Table (5). Mobile pilot plant energy consumption in case of using chlorine/alum.

Component	Energy consumption by Watt
Raw water pump	162
Chlorine dosing pump	30
Alum dosing pump	30
Filter air compressor	60
Filter backwash pump	90
Activated carbon filter back wash pump	90
Slurry discharge pump	50
Total energy	512

Table (5). Mobile pilot plant energy consumption in case of using Potassium Ferrate.

Component	Energy consumption by Watt
Raw water pump	162
Potassium Ferrate dosing pump	30
Alum dosing pump	….
Filter air compressor	60
Filter backwash pump	90
Activated carbon filter back wash pump	….
Slurry discharge pump	50 * 0.6 = 30
Total energy	372

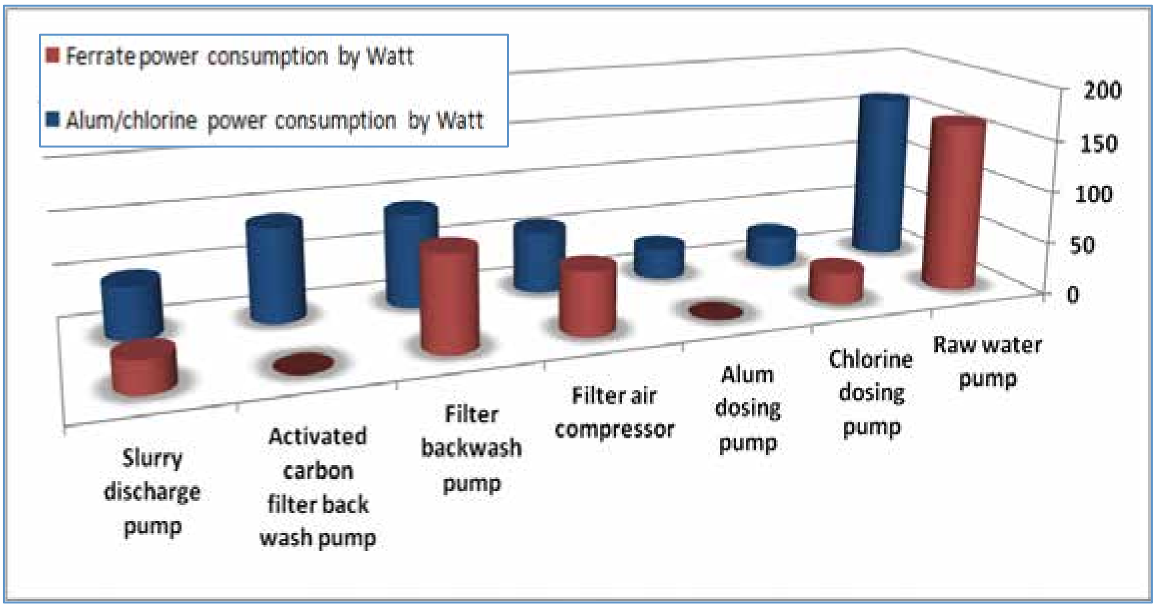


Figure (8). Shows the effect of using Potassium Ferrate in the energy consumption.

6-Advantages/benefits

From the practical work in both bench and pilot scale levels, Potassium Ferrate proved that it is one of the unique materials that can be used in water treatment and have the following advantages:

1- Saving energy of chemical dosing.

2- Saving energy of slurry discharge.

3- Saving the energy required for activated carbon filter back wash.

4- Produce no disinfection by products (green coagulant).

5- Achieve the needed treatment with lower doses.

6- Wastewater treatment (applicable in disinfection).

7- Implementation Problems

The main problem which rose during implementation is the preparation of Potassium Ferrate which required safety precaution (gas mask, gloves and protective glasses).

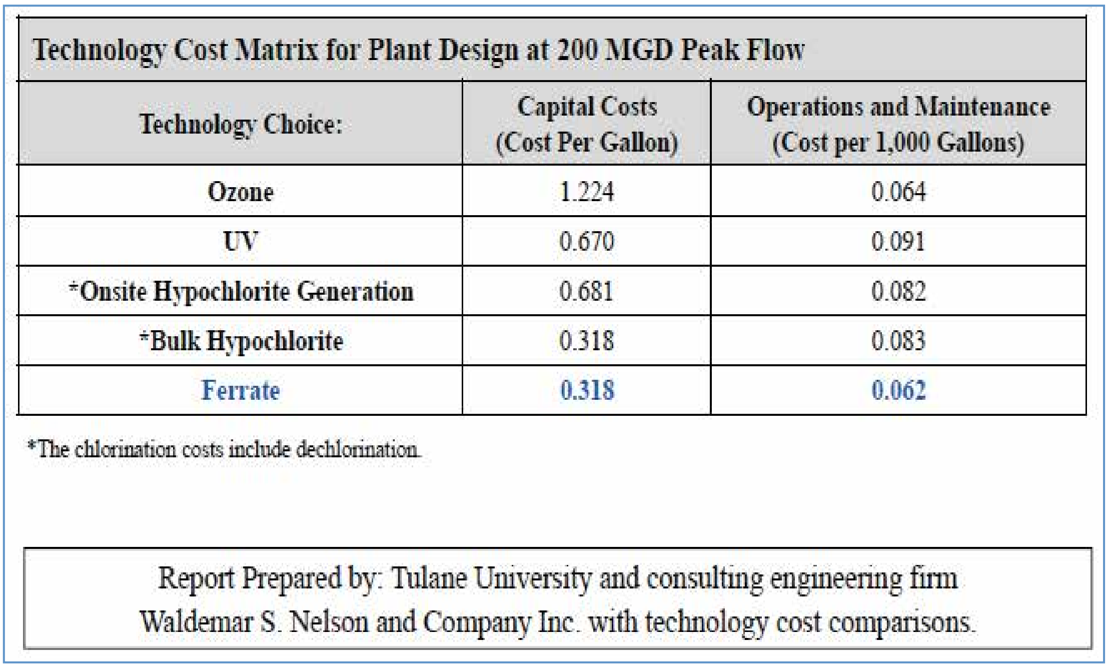
So the most challenging point for us is to produce Potassium Ferrate onsite, which will reduce even the cost of chemical transportation and storage with a simple on site generation step.

8- Cost

Referring to the cost of Potassium Ferrate and the investment to replace the alum/chlorine dosing by Potassium Ferrate:

- According to the following table adapted from *Potassium Ferrate solves treatment challenges in multiple applications across board global industries, Potassium Ferrate treatment technologies, LLC, Applications across board global industries, and Florida Energy Summit – October 15, 2013.*

Table(6). Cost comparison



Technology Cost Matrix for Plant Design at 200 MGD Peak Flow

Technology Choice:	Capital Costs (Cost Per Gallon)	Operations and Maintenance (Cost per 1,000 Gallons)
Ozone	1.224	0.064
UV	0.670	0.091
*Onsite Hypochlorite Generation	0.681	0.082
*Bulk Hypochlorite	0.318	0.083
Ferrate	**0.318**	**0.062**

*The chlorination costs include dechlorination.

Report Prepared by: Tulane University and consulting engineering firm
Waldemar S. Nelson and Company Inc. with technology cost comparisons.

- The same pump used for dosing alum could be used to dose the Potassium Ferrate so the cost of replacing system will be nothing but the only additive cost will be to but on site generator of Potassium Ferrate which according to the pervious table is the lowest in the capital cost.
- Our goal is to make on site generator of Potassium Ferrate to test it on the large scale.

Lessons learnt

- Egypt has a big energy deficient problem which is due to, the gap between electrical energy producing and consuming all over the country, but providing safe drinking water for citizens is a must, so it becomes a great challenge but with using Potassium Ferrate more energy will be saved and more performance will be achieved.
- Chemical dosing is one essential step in the water treatment industry. In Egypt, conventional treatment requires chlorine/alum dosing. Using of Potassium Ferrate will achieve the same required water treatment quality in one step and with lower dose because of its high oxidation potential (more than ozone) and multifunctional property as both coagulant and disinfectant.
- Potassium Ferrate will require no more additional treatment step it could only replace the alum dosing pump.
- Using of Potassium Ferrate in the pilot scale achieved saving in energy by total (27.3%) from the total energy required for operating the pilot plant, this is by saving the energy of alum, chlorine dose and also saving the energy of activated carbon filter backwash pump.
- Using of Potassium Ferrate in water treatment will produce lower slurry and this will have direct reduction to the cost of energy required to the slurry discharge and also, the cost of energy required to treat this slurry before discharging into environment.
- Preparation of Potassium Ferrate requires ordinary chemicals which usually present in any water treatment facility.
- It is possible to make the process of producing Potassium Ferrate sustainable by making on site generation of Potassium Ferrate.
- Ammonia raised level is one of Egypt specific challenge especially in winter, the presence of such high ammonia concentration requires more and more chlorine, with the usage of Potassium Ferrate this problem could be solved in large scale.
- Better drinking water quality is produced using Potassium Ferrate in normal operating conditions.
- Preparation of Potassium Ferrate require safety precaution such as (gas mask, gloves and protective glasses)

Recommendations:

- Using of Potassium Ferrate as a multifunction green coagulant instead of both chlorine/alum to save the energy required for dosing.
- Making further attempts to use Potassium Ferrate on large scale.
- More work should be done to produce Potassium Ferrate on site to save the cost of chemical transportation and storage.

Impact and sustainability

Environmental impact:

- Using of Potassium Ferrate will protect environment by producing lower amount of slurry.

- Using of Potassium Ferrate will save energy and thus using of Potassium Ferrate has a lower carbon foot print.

Health impact:

- Water produced from treatment with Potassium Ferrate is of a higher quality as illustrated from both bench scale and pilot scale results.
- Potassium Ferrate is a green coagulant has no byproducts comparing with chlorine which form THM and other byproducts which known to be carcinogenic.

Economical impact:

- Using of Potassium Ferrate in large scale will reduce the energy required for chemical dosing and the energy required to discharge the slurry.
- With Potassium Ferrate using activated carbon is not needed this will save the cost for using activated carbon.

Using of Potassium Ferrate could be more simple, easy and sustainable process by developing onsite preparation method, knowing that all required chemicals for the preparation are available commercially.

References

1. The Guardian, Wednesday 20 August 2014 14.47 BST.
2. CIA WORLD FACTBOOK (2014).
3. World Bank: Project Completion Report, Arab Republic of Egypt, Beheira Provincial Potable Water Supply Project, June 30, 1995, p. 1-3, retrieved on July 23, (2011).
4. Optimization WordPress Plugins & Solutions by W3 EDGE, CrescentCityTimes.com, (2014).
5. C. Li, X.Z. Li, N. Graham and N.Y. GAO, the aqueous degradation of bisphenol a and steroid estrogens by Potassium Ferrate, Water Res., 42 (2008) 109–120. (b) G.A.K. Anquandah and V.K. Sharma, Oxidation of octylphenol by Potassium Ferrate(VI), J. Environ. Sci. Health Part A, 44 (2009) 62–66.
6. Standard Methods for the Examination of Water and Waste Water, 21, 1000-3000 (2005).

Annex

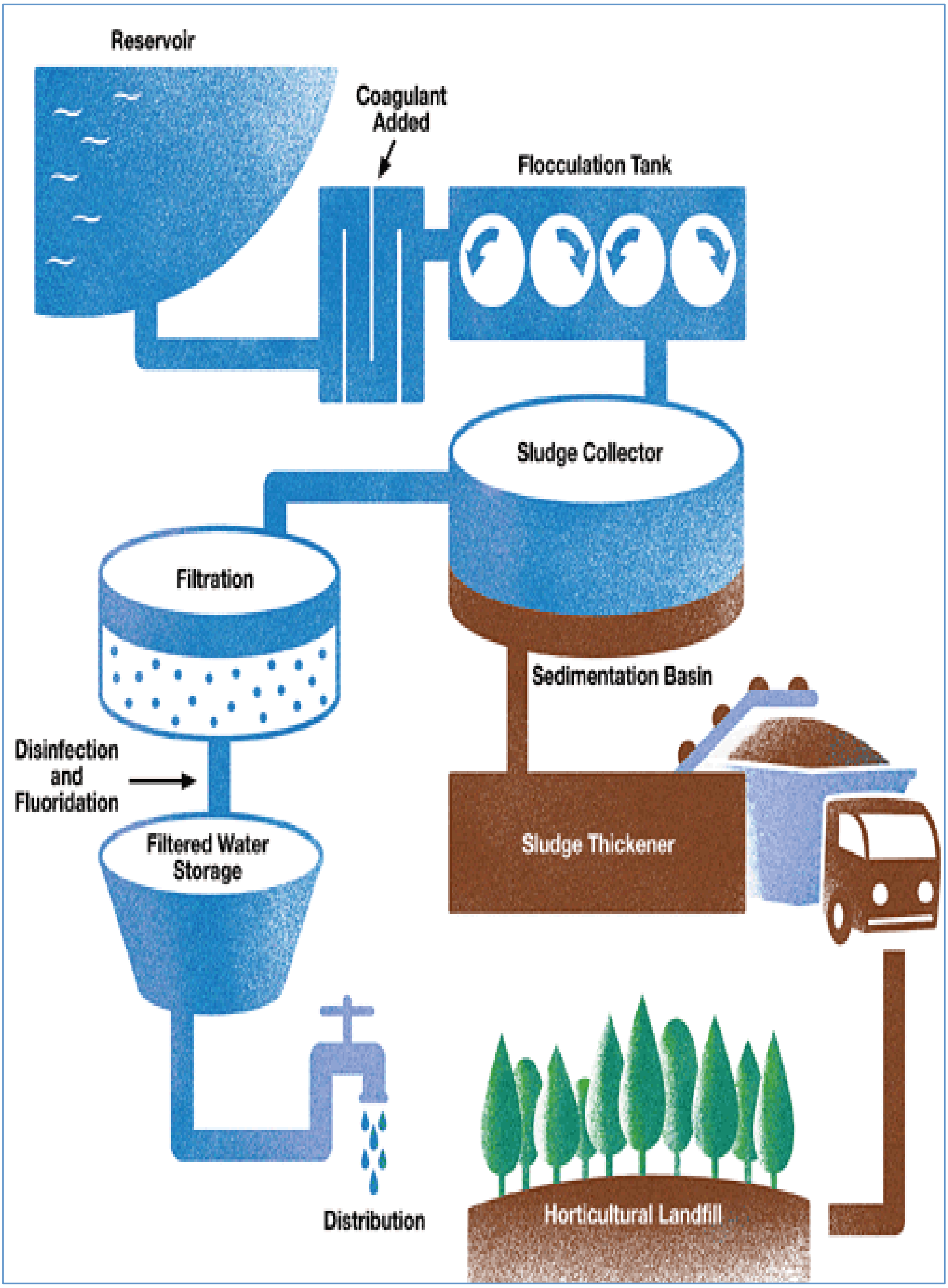


Figure (1) Water treatment processes diagram

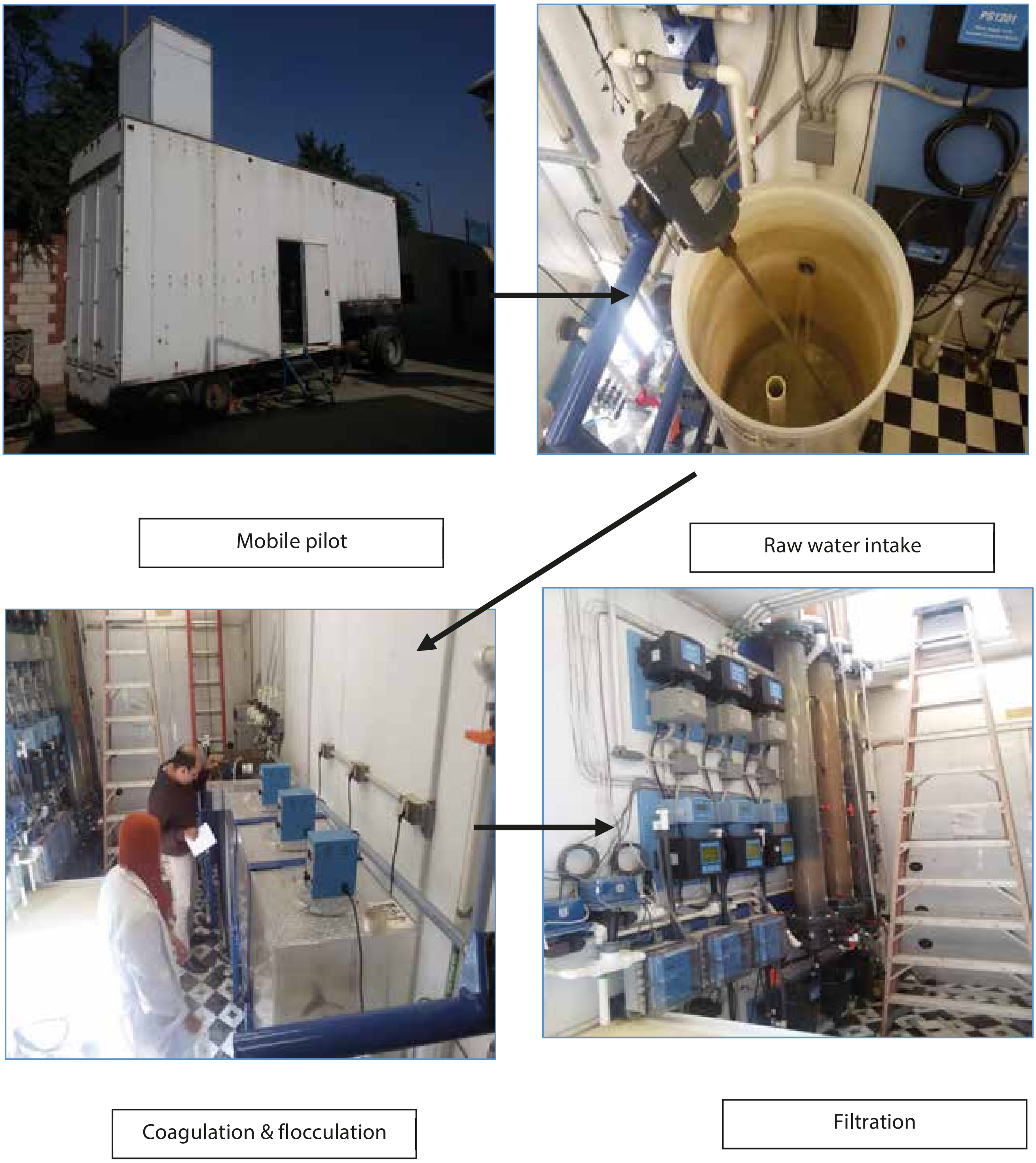
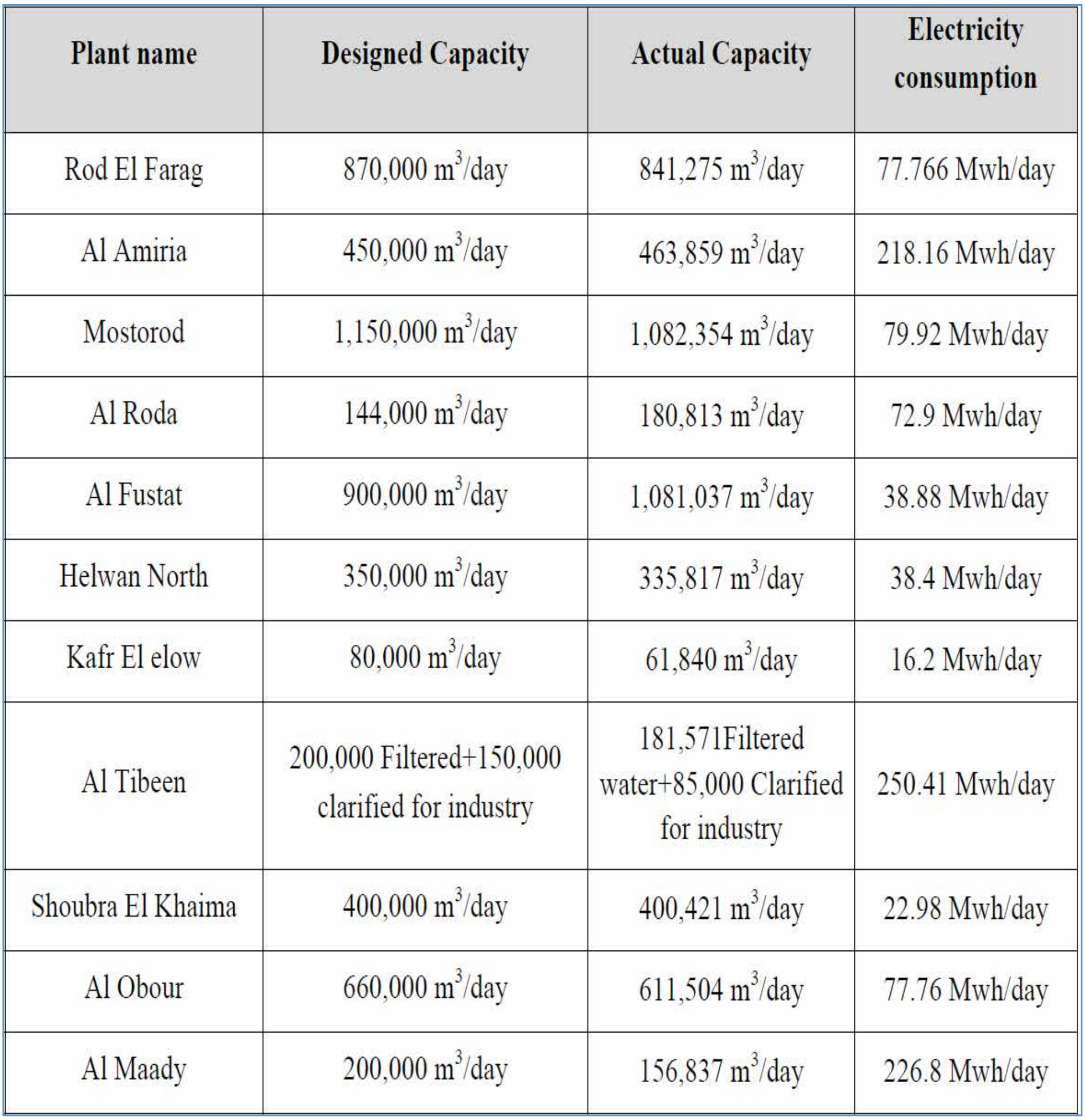


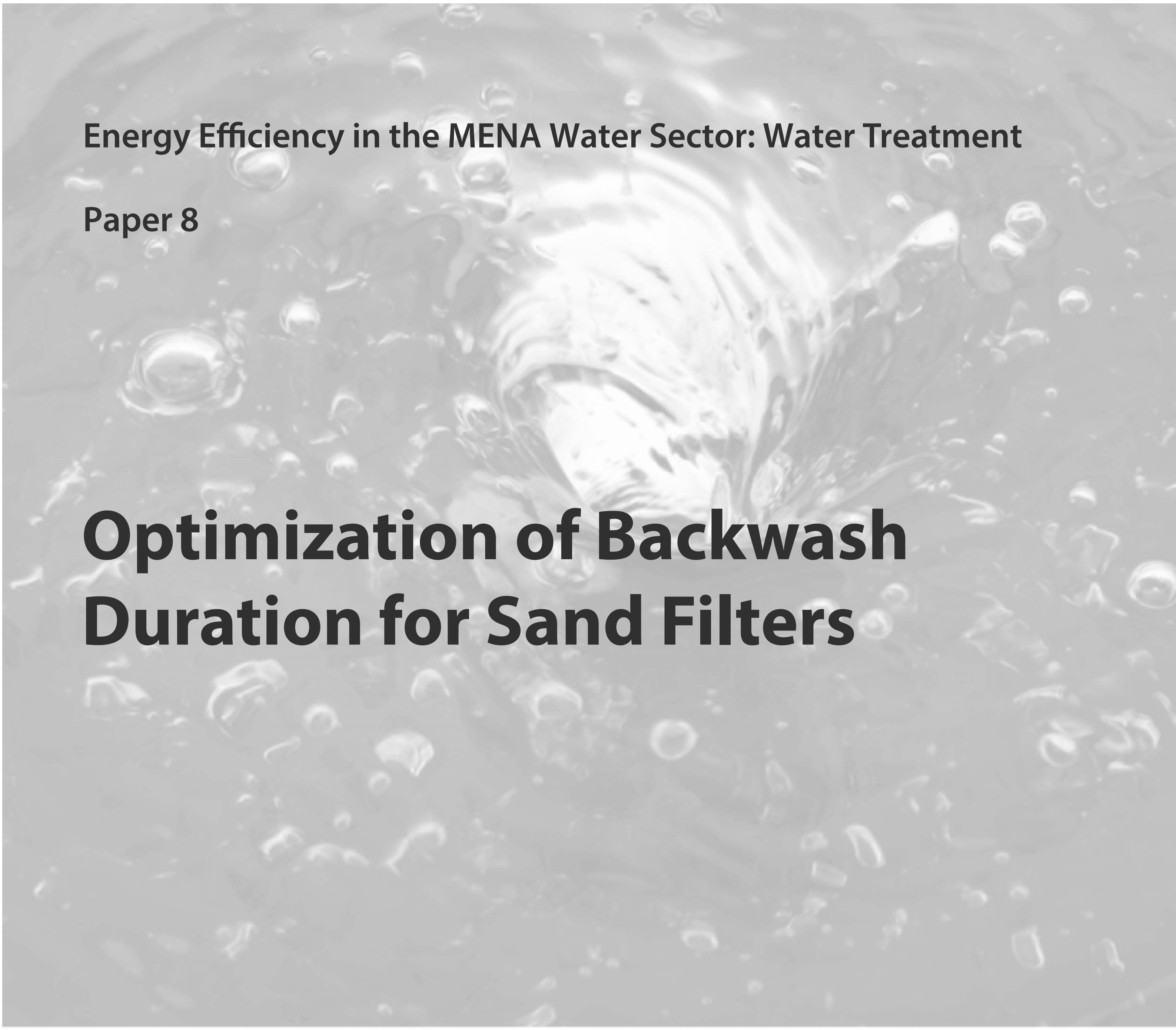
Figure (2) Mobile water treatment pilot plant from Alexandria Company for water

Tables

Table (1) Show the distribution and capacities of water treatment plants belongs to Cairo Water Company



Plant name	Designed Capacity	Actual Capacity	Electricity consumption
Rod El Farag	870,000 m^3/day	841,275 m^3/day	77.766 Mwh/day
Al Amiria	450,000 m^3/day	463,859 m^3/day	218.16 Mwh/day
Mostorod	1,150,000 m^3/day	1,082,354 m^3/day	79.92 Mwh/day
Al Roda	144,000 m^3/day	180,813 m^3/day	72.9 Mwh/day
Al Fustat	900,000 m^3/day	1,081,037 m^3/day	38.88 Mwh/day
Helwan North	350,000 m^3/day	335,817 m^3/day	38.4 Mwh/day
Kafr El elow	80,000 m^3/day	61,840 m^3/day	16.2 Mwh/day
Al Tibeen	200,000 Filtered+150,000 clarified for industry	181,571Filtered water+85,000 Clarified for industry	250.41 Mwh/day
Shoubra El Khaima	400,000 m^3/day	400,421 m^3/day	22.98 Mwh/day
Al Obour	660,000 m^3/day	611,504 m^3/day	77.76 Mwh/day
Al Maady	200,000 m^3/day	156,837 m^3/day	226.8 Mwh/day



Energy Efficiency in the MENA Water Sector: Water Treatment

Paper 8

Optimization of Backwash Duration for Sand Filters

Written by:
Mohamed Abodief, Holding company for Water & Wastewater, EGYPT

Arab Countries Water Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german cooperation
DEUTSCHE ZUSAMMENARBEIT
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

CONTENTS

Filter Evaluation Safety instructions

Never walk directly on filter media.

Ensure filter is FULLYdrained before entering filter box.

Beware offilterappurtenances – Wear a hard hat.

Use a safety harness where applicable.

*[1]: some evaluation Steps in checking filters instrumentafions and Diagnosis of water pretreatment problems can be very useful for initiate full audit procedure.

Executive Summary

Operation process optimization is the most important approach to developing countries which are not able to invest directly in energy field.

Backwash dura8on optimization is the most effective action in Operation process optimization and Rationalizing both energy and water in conventional water treatment plants.

Rapid granular media filters are widely used in drinking water treatment to remove particulate and microbial contaminants prior to disinfection. In order to function properly, these filters must be backwashed regularly to remove accumulated deposits. Experience has shown that whenever filter influent is pretreated with coagulants (sometimes also referred to as flocculants), especially polymers, up flow water wash alone is insufficient to prevent mud balling.

The operating of sand filter always has to backwash every certain time according to some variables. Backwash cycle consume about 4:6% treated water and 4% of annul energy consumption.– figure (1) page 5.

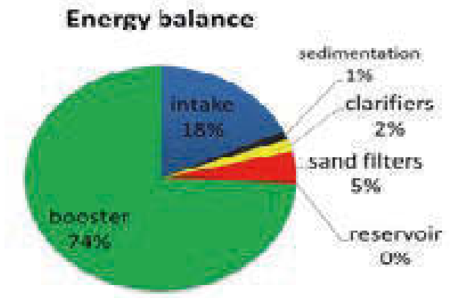


Figure (1)

The objectives of backwashing are (ref.*):

1. Remove deposits from the surface ofthe filter material grains and to transport these out of the filter so as to recover the available voids for particle deposition and obtain a satisfactory back-to-service (“starting”) head loss.
2. Remove or prevent the growth of “permanent” undesirable biological or chemical deposits on the filter media, while allowing some degree of biological or chemical “maturation”.
3. Prepare the filter for the subsequent filter run; this can mean restoring media stratification in multi-layer filters, and might involve dosing extra chemicals to prepare the media or the influent water.

IMPORTANCE OF FILTER BACKWASH (ref*)

During filtration, influent particles attach to the surface of the filter media grains and accumulate in the pore spaces resulting in a reduction in flow area and consequent increase in filter head loss. Once the filtrate quality begins to deteriorate and/or the maximum available head loss has been reached, the filter must be backwashed in order to continue operating correctly. Filters with inefficient backwash tend to accumulate aggregates of dirt, media and coagulant known as mud balls. These can grow into inactive sub-surface masses of clogged material, which increase local velocities in the filter with a potentially negative impact on filtrate turbidity and filter run time. Clogged regions of the filter also tend to contract as the head loss increases, leading to the development of cracks in the bed, which result in short circuiting of the filter influent and a decline in filtered water quality.

Filter backwash procedures (ref*)

Deposition of floc on media grains during filtration results in the grains becoming cemented together especially near the top of the filter where most deposition occurs. The first step of backwashing is to break up the clogged layer which forms in the top sections of the filter bed (and also at the media interfaces of dual and multimedia filters). Once the grains have been separated, it is then necessary to strip away most of the remaining film coating individual media particles. Note that it is neither possible nor desirable for every grain in the bed to be completely clean since a small amount offloc remaining in the bed is believed to improve the efficiency of removal of influent floc at the beginning of the next filter run. However, a large number of dirty filter grains in direct contact with each other at the end of backwash can lead to the development of mud balls as described in and to filter cracking. Once floc particles have been detached from the filter grains, they must be transported out of the filter bed and out of the filter compartment to prevent them settling back into the filter at the end of backwash.

Failure to flush these particles out will accelerate clogging in the subsequent run and may result in high initial filtrate turbidities. However editing the wash steps to the backwash sequence can greatly reduce filtrate turbidity at the beginning of the next run.

Importance of filter optimization is:

1. Optimizing filtration and backwash.
2. Improving the quality of filter output.
3. Reducing filter stopped time.
4. Reducing turbidity/meet with standard.
5. Identifying filter operating problems.
6. Identifying current filter media condition.
7. Establishing operation adjustment.
8. Predicting filter media replacement times.

All of the previous elements have to be checked for general optimization.

For the proposed good practices we will concentrate on backwash efficiency

Filter efficiency = (water filtered – water backwash) / (water filtered) %

So, to optimize the backwash cycle. it is important to apply the following evaluation steps:

Figure (2)

1. Carry out **preliminary Audit** procedures (ROUTINE BACKWASH OBSERVATION) to insure good statement of the sand filters and Avoid any troubles can be effect to apply the proposed actions.
2. Determine the **backwash efficiency** after backwash process by measuring the sludge retention in filter media. The target to be in limit of 30:60 NTU/100 grams
3. Determine the **desirable backwash duration** that defined as the time of washing needed to minimize the turbidity to the acceptable range (1045 NTU). The target duration is six to eight minutes.
4. Determine the backwash cost to **obtain the saving of both energy and water** which would help in decision making process for any action.

The evaluation steps sequence is illustrate in figure 2 page 7.

The operation time of the sand filters depend mainly on some parameters need routinely check to optimize the ideal operating time of the sand filter vice versa the time of filter backwash. Some of these parameters is the quality of the water that feed the filters that's depend mainly on the efficiency of the clarifiers. And other important parameter in Egypt is phenomena of increasing alga at the winter during duration of storage Nile water before the high Dam. For these I use an indicator which will illustrate next.

Background/Situation

With slow growing financial situation in Egypt and most of MENA region, countries make a big challenge for development and apply real energy strategy nowadays.

The direct action (low invest, fast impact, easy audit) that depended on optimization of operating cycle act as magic solutions for passing many problem faced the energy sector. One of the famous actions is Optimize the backwash cycle.

An audit was performed in 2014 at Dakahlia Water Company to mention the advantages and results of optimize the backwash cycle, during the audit, training in filter profiling, including sludge (fioc) retention analysis, was provided.

Reasons to Be Good Practices:

1. The turbidity and quality of raw water varied widely over the year due that the river water is stored in winter and consumed at summer make level of river varied.
2. Type of the control the sand filters is manual in the most water plants depend on the labor skills. Backwash rates in any filter may decline over time due to wear and tear on the backwash pumps, blockages or leaks in the backwash water lines and valves and the great costs, maintenance requirements, therefore the filter media efficiency will not be constant.

Regular filter inspection and maintenance and proper operator training are critical regardless of the backwash method used. Therefore it is important to check the backwash rates on a regular basis. apply routine audit and convert to automatic system (especially for rural areas) would help to optimize the filtration process.

Objectives

Optimize the backwash duration time fall into following audit category:

i. Carry out preliminary audit check to assess the main problems could affect the filter improvement.
ii. Determine the backwash efficiency after backwash cycle by measure the sludge retention in filter media. The target to be in limit of 30:60 NTU/100 grams.
iii. Determine the desirable backwash duration that defined as the time it takes for the backwash water turbidity to drop to the 10-15 NTU range.
iv. Determine the backwash cost to obtain the energy and water saved and help to make a decision for any action.
v. Estimated rationalize for both of energy and water.

Approach

Audit procedures for improving sand filters:

The filters O&M area to improve and audit check divided in 5 section as following

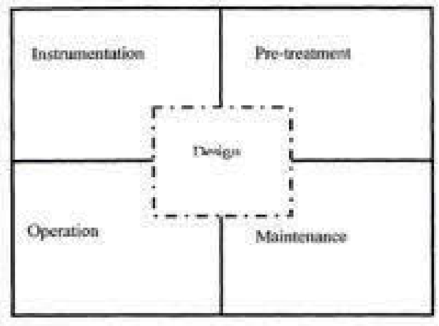


Figure 3

According to the "Filter Maintenance and Operations Guidance Manual", the audit procedures for improve filter operation and maintenance will shown in following figures (figures no. 4 page 10 and page 11), and for complete audit action used to improve sand filter can use (figures no. 8, 9 page 27) at the end of this practices.

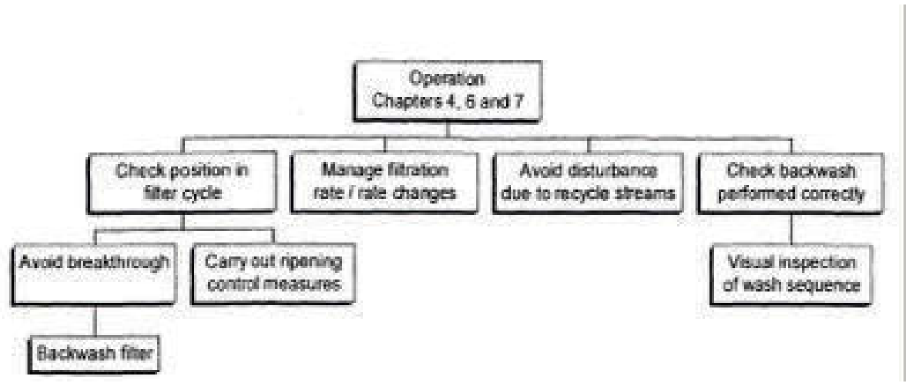


Figure 4

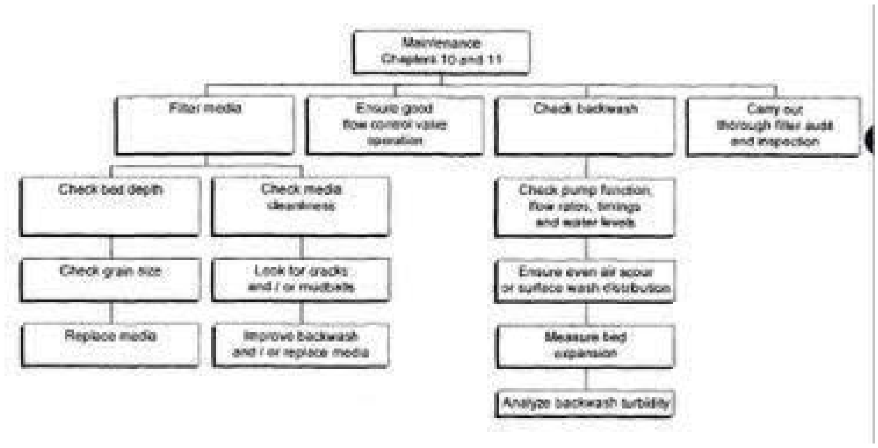


Figure 5

The results and data are collected from **Meet-Khamis** WTP at Dakahlla Water Company - Mansoura city.

General Data for Meet- Khamis WTP:

- Rated capacity 110.000m^3/day and average energy consumption 0.23 kWh/m^3.
- Also to be mention here that plants have a management system certified (TSM$_{\text{Egypt}}$) with good maintenance system.
- 8 rabid sand filters
- Total filtration output: 1395 l/s.
- Wash cycle: (3 min x AIR) + (2 min x mix AIR&WATER) + (8:10 min x WATER).
- Average backwash rate 24 h.

(Refer to photos 10 - page 27)

Laboraty experiments for Optimize filters:

Using the standard and best practices for optimize filter we will use two laboratory experiments:

1. Experiment 1: Sludge Retention Profile or sludge removal percentage to define the backwash efficiency after backwash cycle.

   * I prefer to use experiment 1 instead of experiment 1' but in Egypt the experiment 1' is used with refer to Egyptian codes for operation and maintenance the water plants.

   Experiment 1': Sludge contents percentage to define the backwash efficiency after backwash cycle in the same way.

2. Experiment 2: Backwash Water Turbidity Analysis to define the backwash duration and energy consumed.

Activities & Achieved Results

1. Backwash Preliminary Audit (Audit walk through).

When downward flows out of the filter and stops at the end of the filter run, operators must:

1. Release bubbles that result when air is trapped within a filter bed during the run.

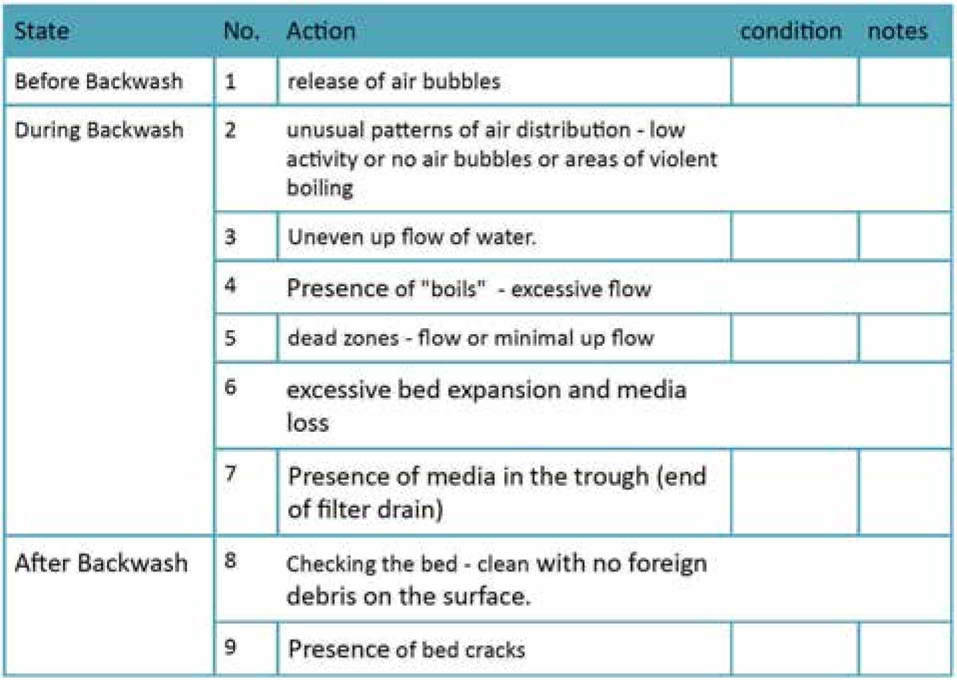
Or when the source of water is supersaturated with oxygen as a result of an algal bloom, air binding can take place within the filter bed.

Observation of the initial stages of backwashing is important for any open, gravity filter that can be observed by the operator. In the beginning of water wash, operators may be able to detect filter problems by watching for:

2. Uneven up flow of water.
3. “Boils” where the flow is excessive.
4. Dead zones that would indicate no up flow or minimal up flow.
5. Released the air at the start of a backwash if air can get into backwash piping.
6. Any unusual patterns of air distribution, including areas of low activity or no air bubbles or areas of violent boiling.
7. Checking the bed before and after backwash for cracks in the bed.
8. Checking the bed after backwash, the bed should be clean and level, with no foreign debris on the surface.
9. Excessive bed expansion and media loss occur during backwashing.
10. Presence of media in the trough (end of filter drain) after backwashing is a good indication of the need to review backwashing procedures.

The following check form in table no.1 can be used for preliminary audit

Table 1: Preliminary Audit Form



State	No.	Action	condition	notes
Before Backwash	1	release of air bubbles		
During Backwash	2	unusual patterns of air distribution - low activity or no air bubbles or areas of violent boiling		
	3	Uneven up flow of water.		
	4	Presence of "boils" - excessive flow		
	5	dead zones - flow or minimal up flow		
	6	excessive bed expansion and media loss		
	7	Presence of media in the trough (end of filter drain)		
After Backwash	8	Checking the bed - clean with no foreign debris on the surface.		
	9	Presence of bed cracks		

2. Determine the backwash efficiency

2.1 Experiment 1 – Sludge Retention Profile:

Purpose:

The Sluddge Retention Profile is a way of determining how mcuh sludge remains in the filter.

The retained sludge in a properly backwashed and adequately ripened filter should be in the range of 30-60 NTU.

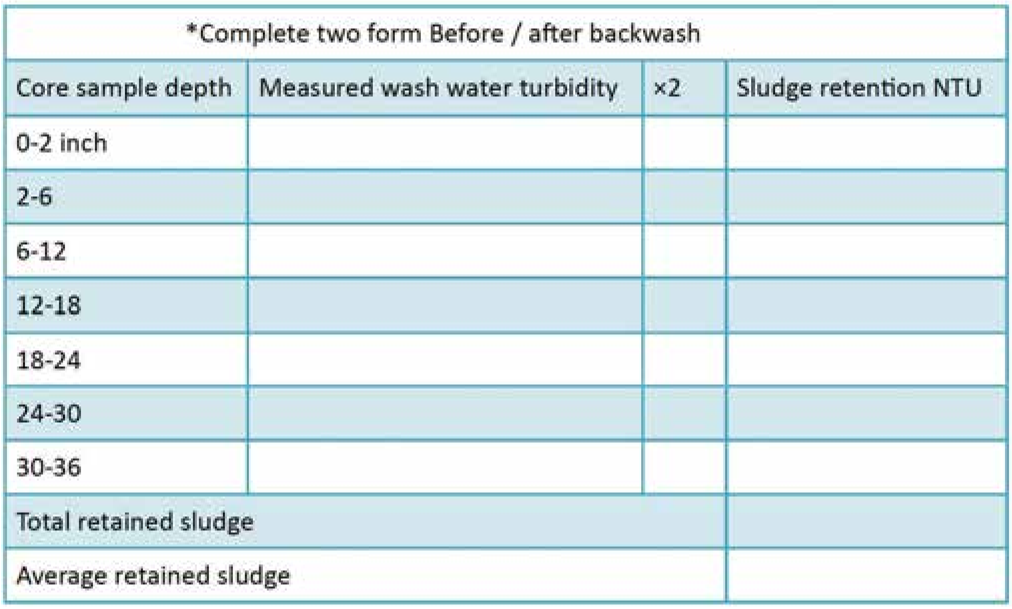
Equipment Required:

1. 24 to 36 one-gallon resalable plastic bags
2. Core sampler
3. 100-ml graduated cylinder
4. Pint Jar
5. 50-ml beaker
6. Tap water
7. Bench-top turbidity meter
8. 1-liter Erlenmeyer Flask

Procedure:

1. Measure out 50m1 of sample from the “Before Backwash Bag” marked”O-2 in”, using the 100-ml graduated cylinder.
2. Transfer the 50-ml sample to the 500-mi flask.
3. Add 100-ml of the tap water to the sample and shake vigorously for 60 seconds.
4. Pour the turbid water into the 1-liter Erlenmeyer flask.
5. Using the same media sample, repeat step 3 and 4 four more times until there is a total of 500-ml of turbid water in the beaker.
6. Stir the 500-ml sample of the turbid water.
7. Pour the required amount of turbid water into the membrane and read the turbidity of the sample.
8. Multiply the turbidity reading by two and record that value on the Sludge Retention Profile Evaluation Form – table (2).
9. Repeat steps 2 thru 8 for the remaining samples.
10. Review the result with allowable standard rate – table 2.

Table (2): Sludge Retention Profile Evaluation Form

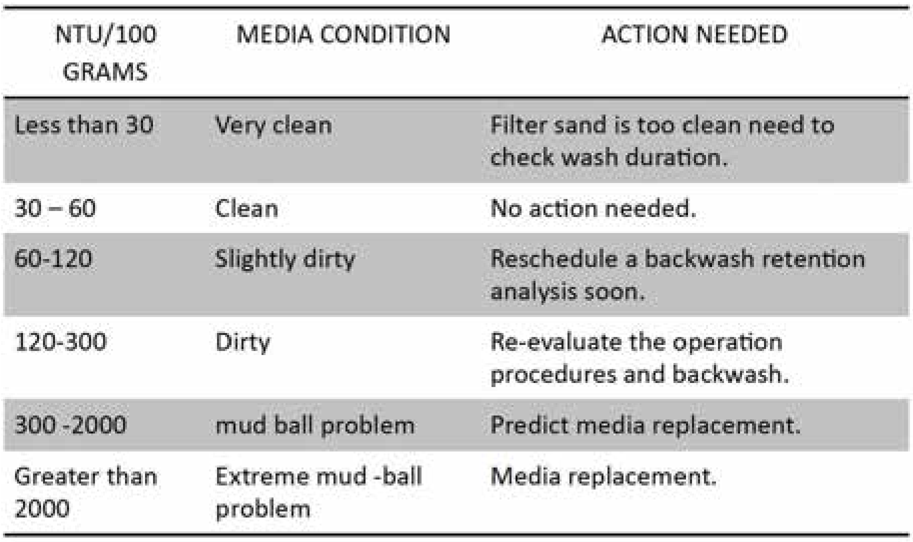


*Complete two form Before / after backwash			
Core sample depth	Measured wash water turbidity	×2	Sludge retention NTU
0-2 inch			
2-6			
6-12			
12-18			
18-24			
24-30			
30-36			
Total retained sludge			
Average retained sludge			

Allowable Rates for sludge removal:

The allowable rates for sludge removal results can be guide for assess the filters situation as indicate at table (3)

Table (3): allowable standard rate for sludge removal



NTU/100 GRAMS	MEDIA CONDITION	ACTION NEEDED
Less than 30	Very clean	Filter sand is too clean need to check wash duration.
30 – 60	Clean	No action needed.
60-120	Slightly dirty	Reschedule a backwash retention analysis soon.
120-300	Dirty	Re-evaluate the operation procedures and backwash.
300 -2000	mud ball problem	Predict media replacement.
Greater than 2000	Extreme mud -ball problem	Media replacement.

* Some example of sludge profile will be present at - figure (7) page 25.at the end of this practices

calibration of instruments and hazard evaluation must be adopting with standard method

2.2. Experiment 1'- Sludge contents:

Purpose:

Refer to the Egyptian code for operation and maintenance for water plants the sludge contents is away to determine and assess the backwash procedures and efficiency.

So that this experiment can be used instead ofthe first one (sludge Retention profile) but I advise to be more accurate use the first experiment as possible.

Equipment Required:

1. Core sampler.
2. Crucible.
3. Scale.
4. Disfilled water.
5. Diluted hydrochloric acid.

Procedure:

1. Conduct the measurement after operation interval 24 hours.
2. Take the first sand sample from filter media surface and the second sample in deep of surface by 40 cm.
3. Transfer the 100-cm^3 sample for the two samples to the Crucible.
4. Dry each sample and weighed by gram.
5. Save the record for sand and turbidity weight.
6. Wash the samples with the Distilled water and diluted hydrochloric acid.
7. Dry each sample and weighed by gram.
8. Save the record just for sand weight.
9. The difference between the two records is the sludge weight in 100-cm3 by gram.
10. Transfer the weight to kilogram.
11. Repeat previous steps before and after back wash cycle.
12. Repeat steps for all filters.

calibration of instruments and hazard evaluation must be adopting with standard method

The result of Meet-khamis WTP:

The result of experiment sludge contents show in table (4) as following:

Table (4): Sludge Removal Result

After wash turbidity clean % backwash efficiency		Before wash turbidity weight kg/m3		filter No.
40 cm depth	filter surface	40 cm depth	filter surface	
99.88	99.68	1.65	4.46	1
99.75	99.78	3.16	2.65	2
99.7	99.76	4.19	3.45	3
99.98	99.76	0.25	2.91	4
99.98	99.91	0.31	1.07	5
99.94	99.88	0.78	1.37	6
99.88	99.87	1.36	1.64	7
99.91	99.78	1.09	2.66	8

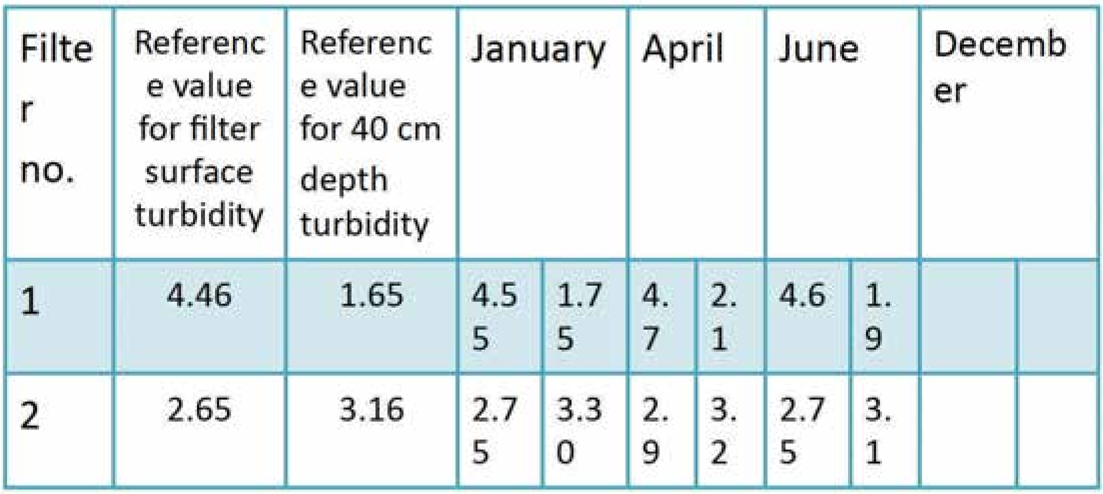
From table (3) filters have high cleaning percentage and seemed to be too clean Backwash duration time we will obtain by applying next step.

2.3. Indicator 1 for assesses backwash cycle:

Monitoring normalized clean bed (starting) head loss over a period of three months is recommended to confirm that backwash is adequate to maintain media in good condition.

Make your record of the sludge contents to be a reference value and use it as indicator for efficiency of the backwash cycle. Use table (5) as following example:

Table (5) Indicator 1 for assesses backwash cycle.



Filter no.	Reference value for filter surface turbidity	Reference value for 40 cm depth turbidity	January		April		June		December	
1	4.46	1.65	4.55	1.75	4.7	2.1	4.6	1.9		
2	2.65	3.16	2.75	3.30	2.9	3.2	2.75	3.1		

As mentioned above for April sample the sludge contents is increase so we review and edit our backwash cycle so that the result of sludge contents is decreasing at June month and so on.

3. Determine how to obtain the filter Backwash standard Duration.

Backwash Water Turbidity Analysis

the core of the good practices is how to obtain the desired backwash durationaccording to international standard procedures.

Purpose

Determine the desirable backwash duration. The desirable backwash duration is defined as the time it takes for the backwash water turbidity to drop to the 10-15 NTU range.

Equipment Required:

1. Stopwatch
2. grab sampler
3. potable or Bench-top turbidity meter
4. Thirty 100-ml sample bottles marked in 1-minute interval.

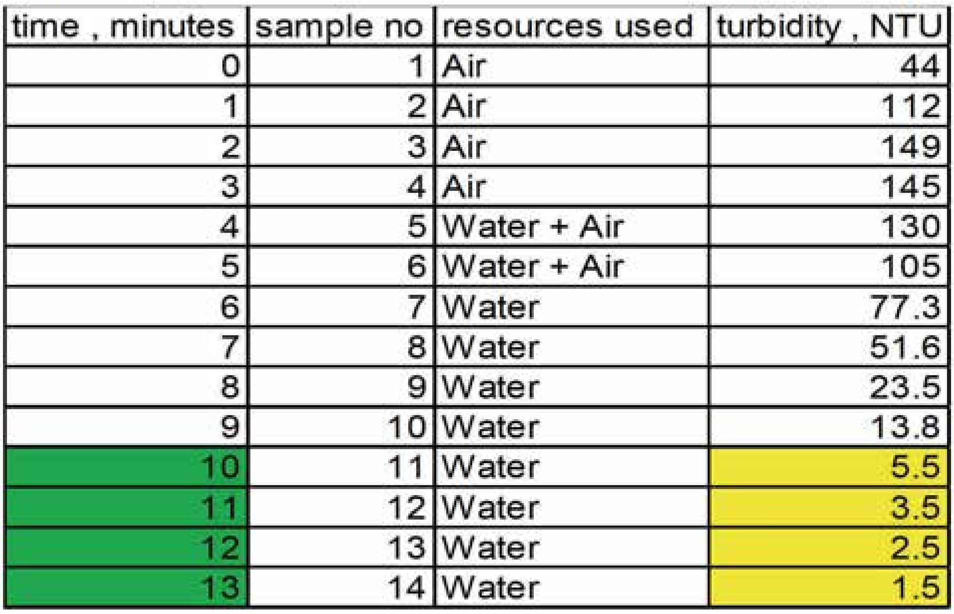
Procedure:

1. Ensure all 100-ml sample bottles are marked in one-minute intervals and in order.
2. Designate one person to keep time during the backwash, and another to sample the backwash water.
3. Start the backwash cycle and the stopwatch.
4. At one-minute intervals sample the backwash water with the bucket.
5. Fill the 100-ml sample bottle to the line with backwash water from the bucket.
6. Dump the remaining backwash water from the bucket into the filter.
7. Repeat this sequence every minute until the normal backwash procedure is completed. It is advisable to extend backwash and sampling for 3 to 5 minutes beyond the normal backwash time.
8. Take the samples to the lab for analysis.
9. Shake each sample thoroughly before analysis.
10. Read the turbidity for each sample and record the results on the form. Use table (6) as example for recorded data.
11. Draw the backwash turbidity profile as figure (6) page 18.

* Calibration of instruments and hazard evaluation must be adopting with standard method

Result of Meet-Khamis WTP:

Table 6



time , minutes	sample no	resources used	turbidity , NTU
0	1	Air	44
1	2	Air	112
2	3	Air	149
3	4	Air	145
4	5	Water + Air	130
5	6	Water + Air	105
6	7	Water	77.3
7	8	Water	51.6
8	9	Water	23.5
9	10	Water	13.8
10	11	Water	5.5
11	12	Water	3.5
12	13	Water	2.5
13	14	Water	1.5

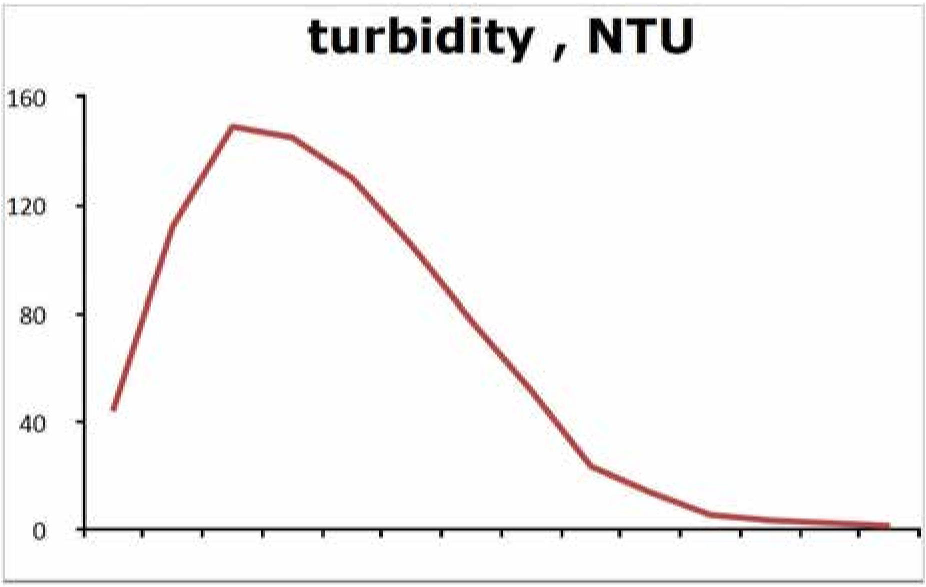


Figure (6). backwash profile.

As we mentioned above that we need about 10:15 NTU still in filter after backwash to rebuild filtration skin (dirty skin) quickly and for economic targets because we consume much amount of resources to reduce small turbidity level.

(Figure no. 11 page 30) shows the turbidity meter record of some previous results.

So that (4 minutes) the time after 10 minutes of backwash cycle seems to be not needed and estimated to save energy and water.

4. Determine energy and water cost.

Purpose:

Determine the energy and water consumption through wash cycle

Equipment Required:

a) Power meter (* in the case of using multi meters for measure volt, current, pf. calculate the power equation).
b) Flow meter.

Procedures:

1. Measure the real power consumed by operating pump and blower during wash cycle.

Calculate power equation. $P = V \times I \times PF \times \sqrt{3}/1000$ (kW)

The energy consumed $E = P^{*}$ hours (kWh)

Where

p: power consumption in KW.
V: voltage in volt.
I: current in ampere.
PF: powerfactor in percentage.
E: energy consumption in kWh.

2. Measure the pump flow (Q in m^3) during wash cycle.
3. Calculate the wash cost in (money, energy, water).

The wash cost (€) = energy cost + water cost

The energy cost = energy consumption for backwash cycle * energy tariff.

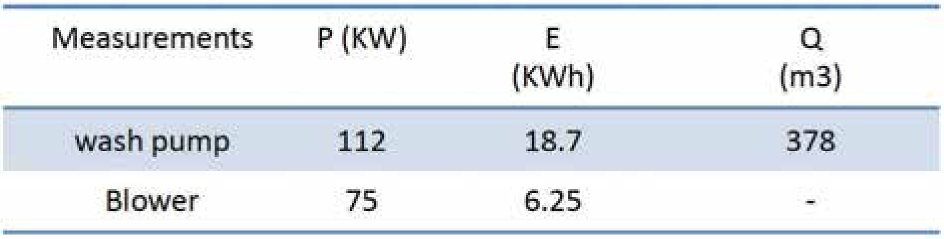
The water cost = water consumption for backwash cycle * water tariff.

4. Calculate the total energy consumption in kwh.

Total energy consumed =

(Energy consume for treated backwash water) + (energy consumed)

Measurements results of Meet- Khamis WTP:



Measurements	P (KW)	E (KWh)	Q (m3)
wash pump	112	18.7	378
Blower	75	6.25	-

* Euro € = 8.80 EGP at 1/1/2015

* Energy tariff = 0.0511 € / kWh

* Water tariff = 0.0454 € / m^3

The results of meet – Khamis WTP:

a) The wash cost (€) = 1.3 + 17.2 = 18.5 € for every wash cycle.

b) The wash energy consumed = 24.95 Kwh

c) The wash cost Water consumed = 378m^3

*This water plant have consume 0,23 Kwh/m^3

d) Total energy consumed = (378*0.23) + 24.9 5= 112 kWh

Advantages/benefits

- We will stop wash after 10 minutes ofbackwash cycle.
- 4 minutes save both of energy and water.

The estimated saving for one wash cycle

= energy 7.5 kWh + water 151 m^3

The rationalization estimated for optimize backwash cycle at Meet – Khamis WTP.

For 1 year operation cycle.

Average back wash rate 24 h.

The time of saving for backwash cycle for one filter is almost equal for the other filter in one water plant because the quality of inlet filter water is the same.

Total Estimated Saving for Meet-Khamis WTP:

Energy = 7.5 * 30 day * 12 month * 8 filters = 21600 kWh per year

Water = 151 * 30 day * 12 month * 8 filters = 434880 m^3 ≈ 100022.4 kWh

So we estimate save for 1 year as following:

Energy : 121622 kWh cost ≈ 6215 €.

Water : 434880 m^3 cost ≈ 19743 €.

Filter efficiency

Filter efficiency = (water filtered – water backwash) / (water filtered) %

Average filter output : 170 l/s ≈ 612 m^3/hours = 612 * 24 hours = 14688 m^3/day

Before optimizing the filter backwash:

Filter efficiency = (14688 – 378) / (14688) = 97.4%

After optimizing the filter backwash:

The new amount of the water backwash ≈ 378 – 151 (water save) = 227 m^3

Filter efficiency = (14688 – 227) / (14688) = 98.5%

Problems

Which came up during the implementation?

- In most cases efficiency for all filters in one plant consider to be the same as the quality of water is fixed to all filters, but for special cases it different. In this case for manual operation I advise to adjust the time duration of all filters according to the result of the wrothest filters in the plant, it's mean the biggest time duration needed for one filters (small saved time) shall be applied for all. To avoid that automatic control should be used.
- The place of take the sample may change the results, so try to collect sample at the filter drain.
- There's no flow meter at backwash pump , in this case an practical solution can obtain the backwash flow or take pump flow nominal rated.
- The amount of energy consumed is small but try to take into your calculation the energy consumed to treat 1 m3 of water will be different.
- For some biological result, save cannot be achieved. The quality control the amount of save the core business is product water with desired quality.

Lessons learnt & Recommendations

- Observation of the surface of the filter before, during and after backwashing will also provide some clues about the state of the media. Lumps and cracks on the surface of the bed prior to backwashing indicate excessive mud accumulation and probable mud balling as do lumps, mud balls, worms and debris on the surface after backwashing Visual inspections should be conducted at least once a month for open gravity filters and at least once every three months for valve less and pressure filters.
- Saving Energy can be achieved by unconsidered actions.
- Optimize the operation cycle may be seem mainly operator responsibility but at all it reflect directly to energy saving.
- Some audit for operation cycle may be helpful to obtain the best decisions.
- You can't start any considerable energy action ifyou have regime maintenance. Any action will not reflect its estimated output through regime maintenance. Also the investment may not be safe.

- Optimize backwash one of Optimize the operation cycle also have many action like optimize the operating plane and like optimize the operating of pump ...etc.
- Optimize backwash action is ranking as direct action with direct save (feedback), it's not cost almost or small budget can invest.
- Auditor should not stop forjust energy audit any other resources consume or effect on the product can be effective for energy save. The main indicator is:
- Energy consumed for unit product I unit product KWH/M3, so if we can increase our production with the same energy consumed we will save energy as it mentioned before.
- Finally our core business is product water with desired quality. Any saving should not effect in production or quality.

Impact

This study is an example of how various water qualifies, media cleanliness, and economic considerations were used in making a decision to make overview for many water plants over many countries in MENA region and encourage the decision maker to install filter automatic system. However the methodologies used in this study can be adopted by other utilities easily.

For general

i. Many countries in MENA region have poor water resources and some of them depend on rivers for water and all of them can't supply and provide they daily needed from water for all services according to national standard (below 700 m^3/day for one person now the situation reach to 300 m^3/day)

ii. Most of countries in MENA region have weak economic make energy saving investment may not be the priority.

So we cant inspect desired investment funded the energy saving actions or achieved real energy saving strategy.

iii. Especially for Egypt the electricity feeding unstable and government decide to increase electricity tariff for constant water tariff. Increasing the gap between water and electricity tariff make apply real energy saving strategy in water companies is more efficient.

For all above situations of countries in MENA region an action save water and energy and not need investment is the answer.

Optimization backwash as one of Optimize the operation cycle is seemed to be the good practices for many countries in MENA region.

Obtain the water and energy saved from this practice will encourage the decision maker to install full filter automatic system.

Small training with routine check for best backwash duration guarantees sustain of this action as good practices.

References

Egyptian codes for operation and maintenance the water plants.

AWWA (American Water Works Association). 2002. *Filter Maintenance and Operations Guidance Manual – chapter (4,5,6). (ref *) is copyfrom guideline.*

The Effect of Backwashing Procedures on Filter Ripening and General Effluent Quality. 2013. For NUS – TUD Double M.Sc. Degree Program

Hydraulics Engineering and Water Resources Management

Standard Methods for the Examination of Water and Wastewater part 1000-3000

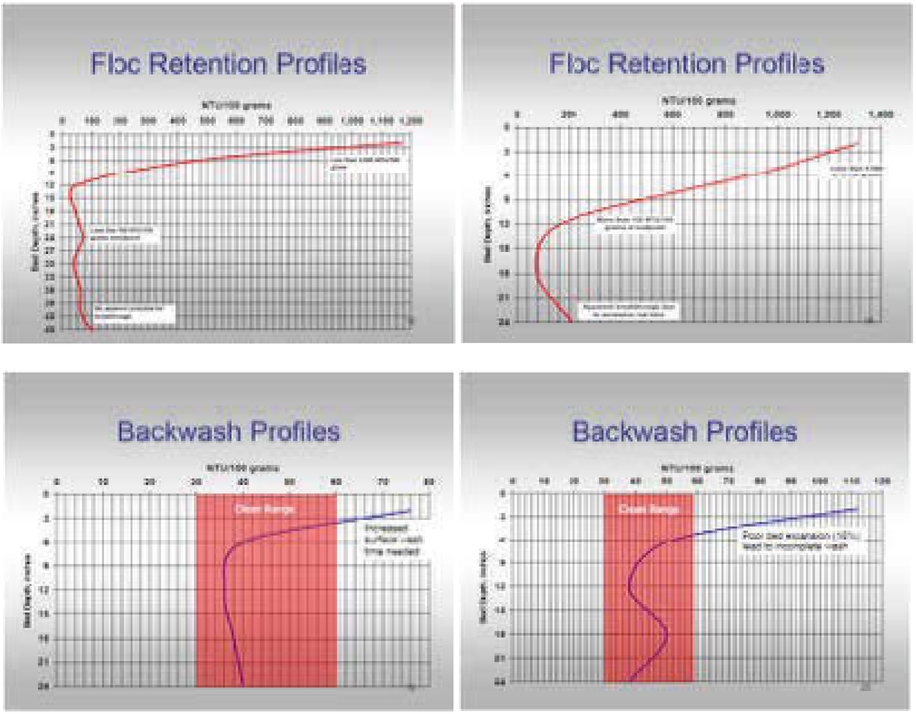


Figure (7): Examples of sludge profile.

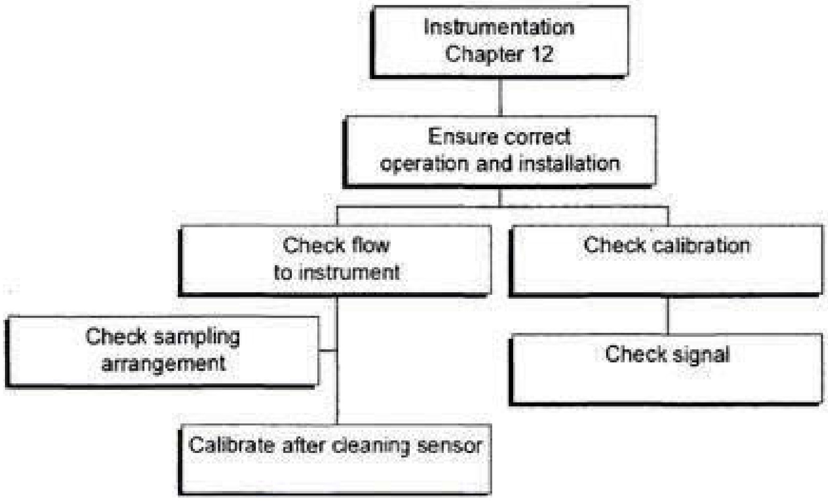


Figure (8): Steps in checking instrumentation

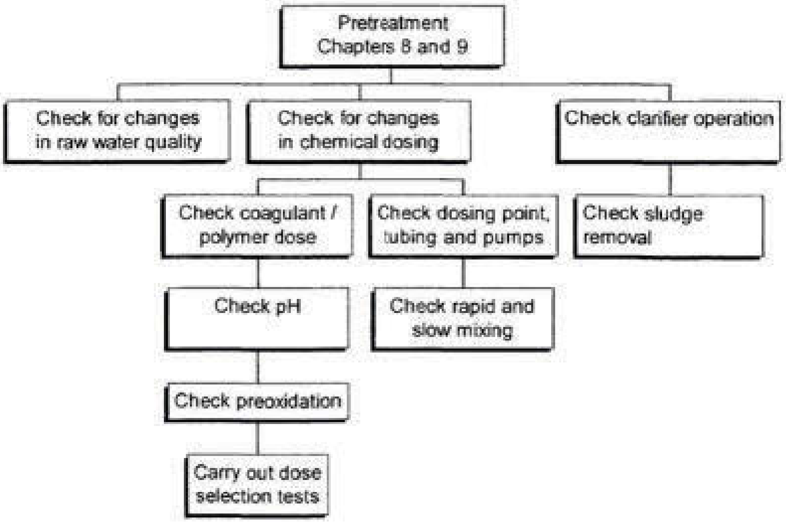


Figure (9): Diagnosis of pretreatment

Filter flow meter

Filter Turbidity mesure (NTU)

Filter headloss mesure (m)

Filter water level mesure (m)

Filter runtime

Filter control panel

SCADA filters data

Plant intake

Plant Sand filter

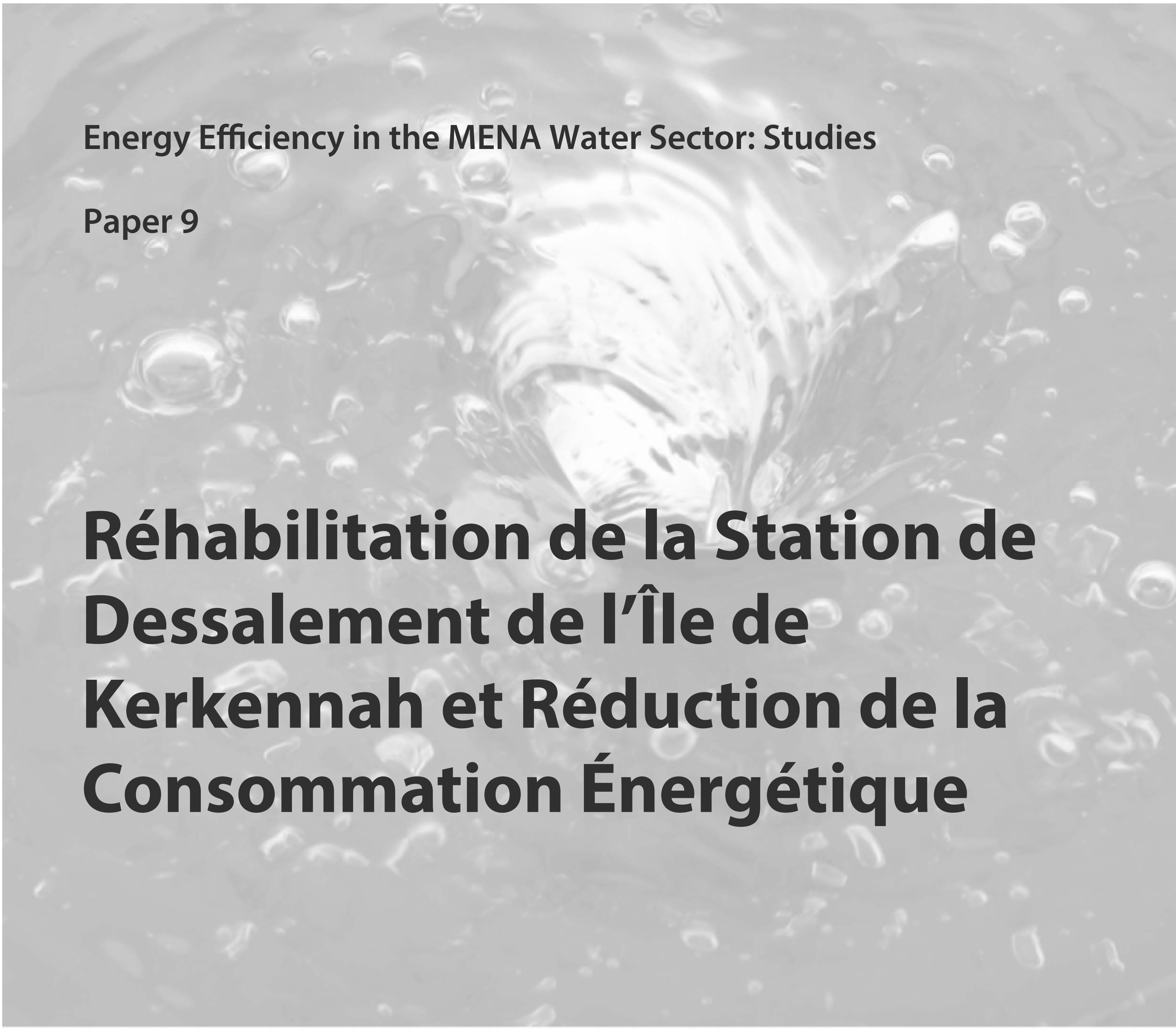
Figure (10) Photos of MEET KHMUS potable water plant.

Minutes 2 sample no. 3 – Maximum value   Minutes 9 sample no. 10 – The desired value

Minutes 11 sample no. 12 – Undesired value   Minutes 13 sample no. 14 – The last sample

(Figures 11) showing the turbidity meter results for Backwash turbidity analysis experiment.

Thank you.



Energy Efficiency in the MENA Water Sector: Studies

Paper 9

Réhabilitation de la Station de Dessalement de l’Île de Kerkennah et Réduction de la Consommation Énergétique

Fait par :
Slim Besbes

ACWUA
Arab Countries Water
Utilities Association

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Abstract

Energy Efficiency: good practices and lessons learned in the optimization of the energy in the water and wastewater sectors in the MENA region

by Slim Besbes

The purpose of this study is the rehabilitation of the desalination plant of Kerkennah and the reduction of energy consumption.

The operation of the brackish water (3.7 g/l) desalination plant of Kerkennah started in 1983 with the capacity of 3300 m^3/day and at this time the desalination process did not take into consideration the energy aspect.

The desalination plant was based on 4 production lines of water using the reverse osmosis process with a recovery of 75% and using cellulose triacetate membranes which required a pressure of 30 bas at the entrance of the membranes to produce the reverse osmosis.

In 2001 a first action was made for the improvement of the desalination process performance. It consisted in the replacement of the cellulose triacetate membranes of two production lines by polyamide membranes wish are characterized by a low pressure at the entrance of the rows of reverse osmosis and a greater resistance to the pH fluctuation and the raw water salinity.

The pressure of pumps decreased from 30 bars to 15 bars for the two lines using the polyamide membranes and the energy consumption decreased by 50% in these two lines.

In 2007 a second action was made for the improvement of the desalination process performance. It consisted in using polyamide membranes in all production lines and the use of speed drives with the high pressure pumps to optimize the energy consumption. Currently the energy consumption is about 1.3 kWh/m^3.

In this paper two options are presented for the rehabilitation of the desalination plant of Kerkennah and the improvement of the energy performance mainly by the use of new reverse osmosis membranes and the implementation of new high pressure pumps coupled to speed drives and the improvement of the total hydraulic diagram of the process.

This study also speaks of the methodology and the approach followed to carry out the diagnosis of the water production process in the desalination plant of Kerkennah.

A great attention has been given to the use of IE2 electric motors which are currently available in Tunisia.

Also, this study shows the impact of the use of new polyamide membranes that require less pressure in the reverse osmosis process and consumes less electrical energy.

This study concludes with recommendations that will open up opportunities to other studies.

Résumé

Le but de cette étude est la réhabilitation de la station de dessalement de Kerkennah et la réduction de la consommation d'énergie.

En effet, l'exploitation de la station de dessalement des eaux saumâtres (3.7 g/l) de l'île de Kerkennah de capacité 3300 m^3/jour a débuté en 1983 avec un processus de dessalement qui ne tenait pas en considérations l'aspect de l'énergie à cette époque.

Cette station comportait, au départ, 4 lignes de production d'eau via le procédé de l'osmose inverse avec un taux de conversion de 75% et utilisant des membranes en acétate de cellulose ce qui nécessitait une pression de 30 bars à l'entrée des membranes pour produire le phénomène d'osmose inverse.

Une première action d'amélioration des performances du processus de dessalement a été faite en 2001. Elle concernait le changeant des anciennes membranes d'osmose inverse en acétate de cellulose de deux lignes de production par des membranes en polyamides caractérisées par une pression à l'entrée des lignes d'osmose inverse plus faible et une résistance plus grande à la fluctuation du pH et la salinité de l'eau brute.

La pression d'entré passait de 30 bars à 15 bars pour les deux lignes utilisant les membranes en polyamides ce qui induit une baisse de la consommation énergétique de 50% dans ces deux lignes.

Une deuxième action d'amélioration des performances du processus de dessalement a été faite en 2007. Elle concernait l'utilisation de membranes d'osmose inverse en polyamides dans toutes les quatre lignes de production et l'installation de variateurs de vitesses sur les groupes électropompes de haute pression pour optimiser la pression d'attaque à l'entrée des tubes de pression du bloc d'osmose inverse et ainsi optimiser la consommation énergétique. Actuellement, la consommation énergétique est de 1,3 kWh/m^3.

Dans cet article, deux variantes sont présentées pour la réhabilitation de la station de dessalement de Kerkennah et l'amélioration des performances énergétiques de la station de dessalement de Kerkennah essentiellement par l'utilisation des membranes d'osmose inverse plus performantes, l'installation de nouveaux groupes électropompes à hauts rendements accouplés à des variateurs de vitesse et l'amélioration du schéma hydraulique de processus de dessalement.

Cette étude parle aussi de la méthodologie et de l'approche suivis pour mener à bien le diagnostic du processus de production d'eau dans la station de dessalement de Kerkennah.

Une grande attention a été accordée à l'utilisation des moteurs électriques triphasés de classe énergétique IE2 qui sont disponibles actuellement dans marché tunisiens.

Aussi, cette étude montre l'impact de l'utilisation des membranes d'osmose inverse qui nécessitent moins de pression d'attaque à l'entrée du bloc d'osmose inverse et donc consomme moins d'énergie électrique.

Cette étude se termine par des recommandations qui ouvriront des opportunités à d'autres études.

Sommaire

1 Situation énergétique en Tunisie et à la SONEDE :

1.1 Situation énergétique en Tunisie :

Le secteur de l'énergie a joué un rôle important dans le développement économique et social de la Tunisie. Le bilan énergétique de la Tunisie a évolué d’une situation excédentaire (1990-1994) vers une situation d’équilibre (1994-2000) puis une situation déficitaire observée depuis l’année 2001.

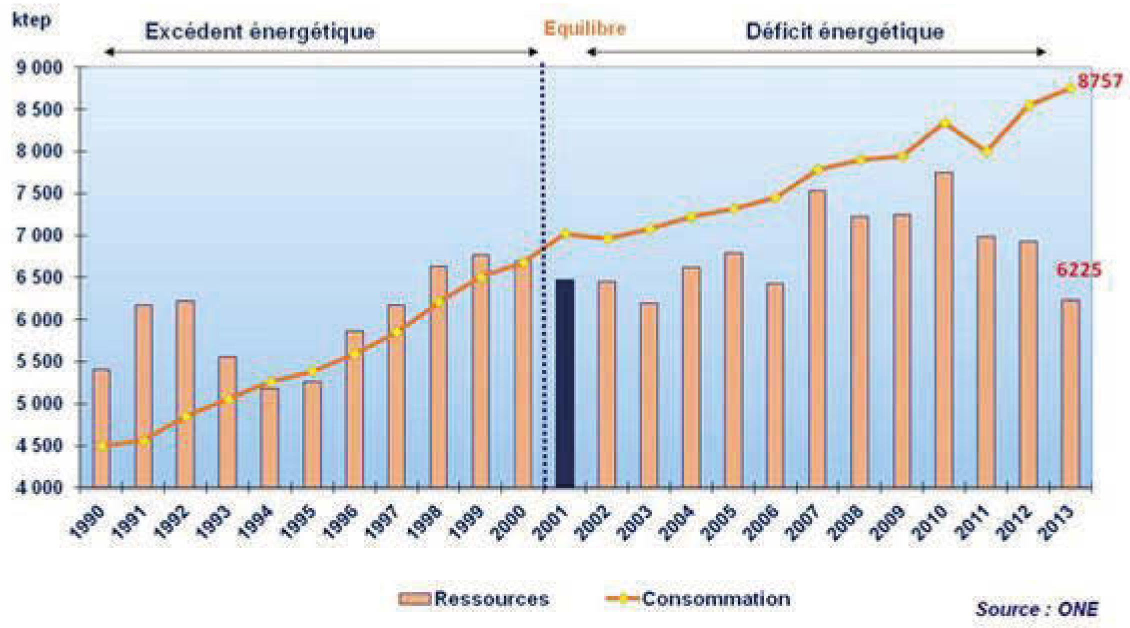


Figure 1 : Evolution rétrospective du bilan énergétique

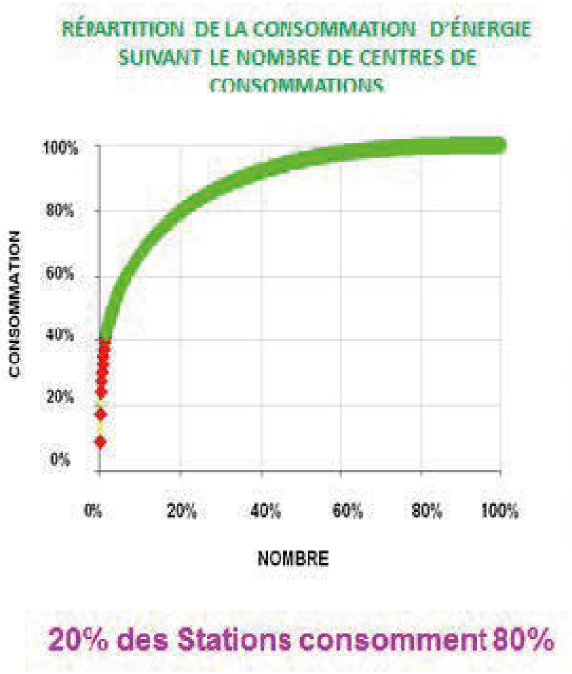
Pour faire face à ces différentes contraintes, la Tunisie est appelée à adopter une stratégie lui permettant de diversifier les ressources énergétiques et investir pleinement dans les secteurs de l’efficacité énergétique et des énergies renouvelables pour assurer sa sécurité énergétique, renforcer son indépendance et réduire les émissions de gaz à effet de serre.

1.2 Situation énergétique à la SONEDE :

La société Nationale d’Exploitation et de Distribution des Eaux (SONEDE) est considéré comme parmi les grandes entreprises consommatrices d’énergie en Tunisie. En effet, elle possède :

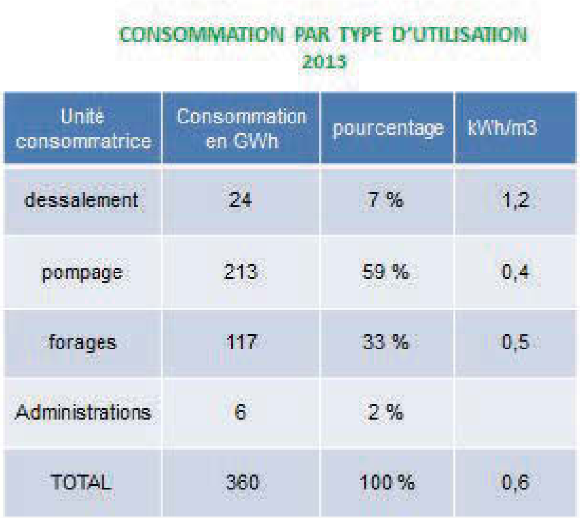
- 2,4 millions d’abonnés,
- plus de 47 500 km de réseau d’’adduction et de distribution de l’eau potable,
- plus de 1050 réservoirs avec une capacité de stockage de 1 million de m3,
- 1300 stations de production d’eau et de pompage.

La consommation d'énergie a atteint en 2013 360 GWh soit l'équivalent de 26 millions d'euros et 20% du chiffre d'affaires de la société répartis comme suit:



RÉPARTITION DE LA CONSOMMATION D'ÉNERGIE SUIVANT LE NOMBRE DE CENTRES DE CONSOMMATIONS

20% des Stations consomment 80%



CONSOMMATION PAR TYPE D'UTILISATION 2013

Unité consommatrice	Consommation en GWh	pourcentage	kWh/m3
dessalement	24	7 %	1,2
pompage	213	59 %	0,4
forages	117	33 %	0,5
Administrations	6	2 %	
TOTAL	360	100 %	0,6

Figure 2 : Répartition de la consommation d'énergie le nombre de centre de consommation et le type d'utilisation

La figure 2 montre que 20% des centres de consommations (stations de pompage ou stations de production d'eau) consomment 80% de la consommation totale en énergie au sein de la SONEDE. Parmi ces stations nous pouvons citer :

- La station de traitement de Ghedir El Golla,
- La station de traitement de Belli,
- La station de pompage de Kerker,
- La station de dessalement de Gabès,
- La station de dessalement de Jerba,
- La station de dessalement de Zarzis

Face à cette situation et aux perspectives de développement des projets d'alimentation en eau potable et construction de station de dessalement d'eau de mer, qui induiront des coûts énergétiques importants et pèseront de plus en plus lourd sur le prix de revient de l'eau, la SONEDE a mis en place en parallèle aux efforts d'amélioration des rendements du réseau, un plan de maîtrise de l'énergie dans les domaines suivants:

- Efficacité énergétique via la réalisation d'audits énergétiques et l'implémentation d'un système de management d'énergie.
- Energies renouvelables via le développement de projets utilisant le photovoltaïque (station de dessalement de Ben Guerdane au sud tunisien) et les éoliènnes

2 Objectif :

La station de dessalement de Kerkennah est située au centre de la ville de Ramla qui se trouve au milieu de l'île. L'exploitation de la station de dessalement des eaux saumâtres (3.7 g/l) de capacité 3300 m^3/jour a débuté en 1983.

Cette station comportait, au départ, 4 lignes de production d'eau via le procédé de l'osmose inverse avec un taux de conversion de 75% et utilisant des membranes en acétate de cellulose ce qui nécessitait une pression de 30 bars à l'entrée des membranes pour produire le phénomène d'osmose inverse.

Une première action d'amélioration des performances du processus de dessalement a été faite en 2001. Elle concernait le changeant des anciennes membranes d'osmose inverse en acétate de cellulose de deux lignes de production par des membranes en polyamides caractérisées par une pression à l'entrée des lignes d'osmose inverse plus faible et une résistance plus grande à la fluctuation du pH et la salinité de l'eau brute.

La pression d'entré passait de 30 bars à 15 bars pour les deux lignes utilisant les membranes en polyamides ce qui induit une baisse de la consommation énergétique de 50% dans ces deux lignes.

Une deuxième action d'amélioration des performances du processus de dessalement a été faite en 2007. Elle concernait l'utilisation de membranes d'osmose inverse en polyamides dans toutes les quatre lignes de production et l'installation de variateurs de vitesses sur les groupes électropompes de haute pression pour optimiser la pression d'attaque à l'entrée des tubes de pression du bloc d'osmose inverse et ainsi optimiser la consommation énergétique. Actuellement, la consommation énergétique est de 1,3 kWh/m^3.

Dans cet article, je présenterais mon étude de réhabilitation et l'amélioration des performances énergétiques de la station de dessalement de Kerkennah essentiellement par l'utilisation des membranes d'osmose inverse plus performantes, l'installation de nouveaux groupes électropompes à hauts rendements accouplés à des variateurs de vitesse et l'amélioration du schéma hydraulique de processus de dessalement.

3 Approche :

Pour la préparation de cette étude pour ACWUA lecture, nous avons suivi l'approche suivante :

3.1 Collecte des données nécessaires à cette étude :

Pour les besoins de la préparation de cette étude, nous avons contacté plusieurs directions au sein de la SONEDE à savoir la Direction Territoriale des Etudes Centre et Sud (DTE2), la Direction Territoriale de Production du Centre et Sfax (DTPCS) et la Direction de Maitrise de l'énergie (DME) pour la collecte des données suivantes :

- Plans du site de la station de dessalement
- Les rapports mensuels sur l'activité de la station de dessalement de Kerkennah : chaque rapport mensuel contient les informations suivantes :
    - Le volume d'eau brute à l'entrée de la station de dessalement,
    - Le volume d'eau produit par la station de dessalement (Perméat),

  - Le volume d'eau pour le mélange,
  - La consommation électrique mensuelle,
  - Les pressions,
- Les fichiers STEG (Société Tunisienne d'Electricité et Gaz) qui comportent le détail de la consommation électrique de la station de dessalement de Kerkennah de chaque mois durant les années 2013 et 2014,
- Les analyses physiquo-chimiques des forages F1, F2, F3 et F4 qui alimentent la station de dessalement de Kerkennah en eaux brutes pour le dessalement et pour le mélange,
- La liste des groupes électropompes installés (forages, transfert, gavage, haute pression, lavage, rinçage, mélange et distribution)
- Les types des membranes d'osmose inverse utilisées pour le processus de dessalement,

3.2 Visite du site de la station de dessalement de Kerkennah :

Nous avons procédé à une visite du site de la station de dessalement de Kerkennah qui a permis de faire :

- Une vérification des équipements et installations existants en suivant le circuit ci-après :
  - Poste de transformation électrique Mt/BT existant (2 x 315 KVA),
  - Groupes électrogènes de secours (2 x 315 KVA),
  - Captage des eaux brutes pour le dessalement (forages F2 et F3),
  - Captage des eaux brutes pour le mélange (forage F1), le forage F4 se trouve à 2 km du site de la station de dessalement de Kerkennah ;
  - Bassin d'oxydation,
  - Filtre à sable,
  - Groupes électropompes de lavage des filtres à sables,
  - Groupes électropompes de transfert des eaux du bassin d'oxydation vers les filtres à sables,
  - Groupes électropompes de gavage (booster) à travers les filtres à cartouches,
  - Groupes électropompes de haute pression,
  - Bloc d'osmose inverse composé par 24 tubes de pression comportant 144 membranes en polyamides,
  - Groupes électropompes de rinçage des membranes d'osmose inverse,
  - Tour de dégazage,
  - Groupes électropompes des eaux de mélange,
  - Groupes électropompes de pompage des eaux mélangées vers le réservoir sur tour de distribution,
  - Salle de commande.
- Un diagnostic des conduites, tuyauterieset vannes motorisées coté circuit haute pression et circuit basse pression,
- Un diagnostic des instruments de mesure de débit, pression différentielle, couple redox, pH, salinité,
- Un diagnostic des armoires électriques, automate programmable et superviseur existant,
- Une discussion avec le staff de la station de dessalement de Kerkennah pour undiagnostic de la problématique liée au sable farineux qui se trouve dans les eaux brutes.

3.3 Interprétation des données collectées :

Après la collecte des données auprès des différentes directions de la SONEDE et la visite du site de la station de dessalement de Kerkennah, nous nous sommesfocalisés sur l'interprétation de ces données et la mise au point d'une solution pour la réhabilitation de la station de dessalement de Kerkennah et la réduction de la consommation énergétique.

3.4 Etude d'une solution pour la réhabilitation de la station de dessalement de Kerkennah et réduction de la consommation énergétique :

La mise au point d'une solution pour la réhabilitation de la station de dessalement de Kerkennah et la réduction de la consommation énergétique se base sur :

- L'étude de la consommation énergétique durant la période Janvier 2013 et Août 2014,
- Etude du circuit hydraulique,
- Identification des groupes électropompes énergivores,
- Comparaison et choix des équipements ayant un bon rendement électrique,
- Comparaison des variantes,
- Bénéfice financier de chaque variante.

4 Activités et résultats :

4.1 Données collectées :

4.1.1 Site de la station de dessalement de Kerkennah et descriptif du processus de dessalement :

Figure 3 : Site de la station de dessalement de Kerkennah

Le site de la station de dessalement de Kerkennah comporte :

- Le forage F1 (artésien),
- Le forage F2,
- Le forage F3,
- La station de dessalement,
- La station de pompage vers le réservoir sur tour,
- Le réservoir semi enterré,
- Le réservoir sur tour.

L'exploitation de la station de dessalement des eaux saumâtres de l'île de Kerkennah de capacité 3300 m^3/jour a débuté en 1983 et exploitant des forages de salinité 3.7 g/l. La station de dessalement comporte :

Un prétraitement composé de :

- bassin d'oxydation,
- filtres à sable,
- microfiltres à cartouches (4 dans la salle des pompes et 4 sur le toit de la station de dessalement),
- pompes de transfert,
- pompes de gavage,
- pompes de lavage des filtres à sable,
- pompe doseuse d'injection de d'hypochlorite de sodium,
- pompe doseuse d'injection de l'acide,
- pompe d'injection d'un antitartre,

Un bloc d'osmose inverse composé de :

- pompes de haute pression,
- quatre lignes (04) d'osmose inverse composées de 144 membranes en polyamides,
- pompe de rinçage,

Un post-traitement composé de :

- une tour de dégazage,
- un ventilateur d'injection d'air,
- pompe doseuse de soude caustique,

Les forages F2 et F3 sont utilisés pour le processus de dessalement :

- Le forage F2 alimente les lignes L1 + L2
- Le forage F3 alimente les lignes L3 + L4,

Les forages F1 et F4 (hors site de la station de dessalement) sont utilisés pour le mélange.

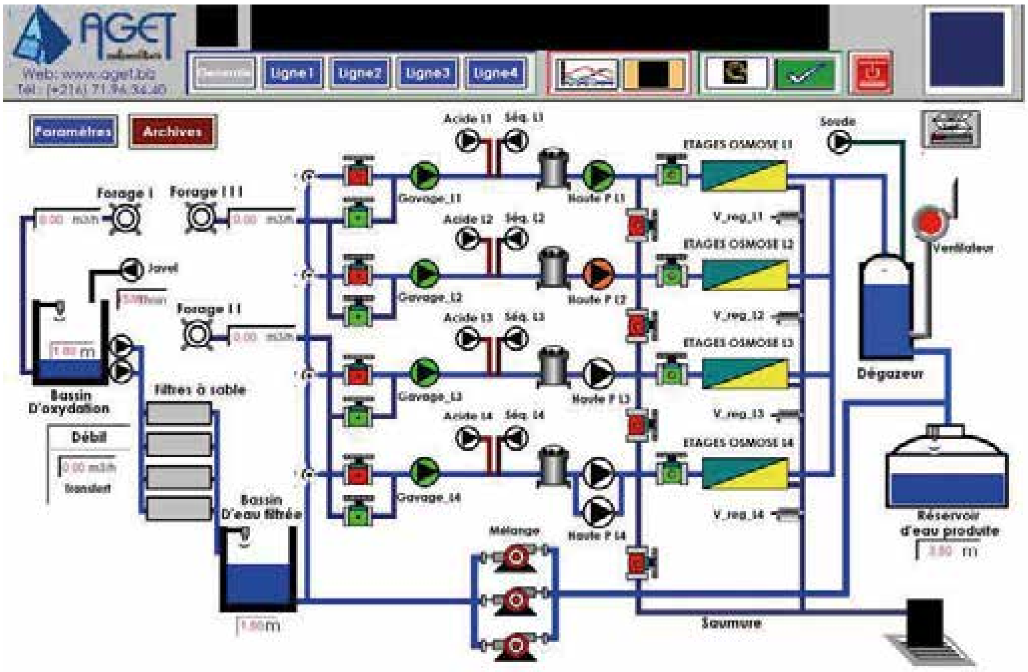


Figure 4 : Schéma de principe de la station de dessalement de Kerkennah

Les eaux brutes provenant des forages F2 et F3 alimentent directement, sans passer par le post de prétraitement (problème de fer), les pompes de gavage (booster) et sont refoulées vers les microfiltres à cartouches pour retenir le sable farineux et les matières en suspension.

La station de dessalement de Kerkennah fait face, depuis la chute de l'artésianismedes forages F2 et F3, à un problème de sable farineux qui se trouve dans les eaux brutes refoulées par les groupes horizontaux de ces deux forages. Les responsables de la station de dessalement de Kerkennah ont été obligés d'installer quatre (04) microfiltres additionnels sur le toit de la station pour retenir ses sables farineux ce qui engendre une perte de charge additionnelle pour les pompe de gavage.

Suite au changement de la totalité des membranes dans les quatre lignes d'osmose inverse en polyamides (en 2008 et 2009), la pression d'attaque à l'entrée des tubes de pression est passée de 30 bars à 15 bars. Les pompes de haute pression, installées depuis 1983, n'ont pas étés modifiées suite au changement du point de fonctionnement. Des variateurs de vitesse ont été installés sur ces pompes pour ajuster la pression de refoulement à l'entrée de chaque ligne d'osmose inverse.

Les eaux brutes provenant des forages F1 et F4 alimentent le post de prétraitement. Ces eaux sont collectées au niveau du bassin d'oxydation de la station de dessalement de Kerkennah. L'opération d'oxydation est réalisée à travers l'injection de l'hypochlorite de sodium et l'air.

Le bassin d'oxydation alimente gravitairement les deux pompes de transfert. Ces pompes refoulent les eaux oxydées vers les filtres à sable (4 compartiments). Les eaux filtrées sont collectées au niveau du bassin des eaux filtrées. Ce bassin alimente trois (03) pompes de mélange.

Le perméat du bloc d'osmose inverse et mélangé avec les eaux de mélange dans la conduite qui alimente le réservoir de stockage semi enterré du site de la station de dessalement de Kerkennah.

Ce réservoir alimente gravitairement la station de reprise vers le réservoir sur tour du site de la station de dessalement. Ce dernier alimente toute l'île de Kerkennah en eau potable.

La station de reprise est composée par trois (03) groupes électropompes horizontaux. En période hivernale, deux groupes électropompes alimentent le réservoir sur tour. En période estivale, tous les groupes électropompes de la station de reprise fonctionnent et alimentent le réservoir sur tour du site de la station de dessalement de Kerkennah.

4.1.2 Données électriques et hydrauliques :

Les données électriques et hydrauliques collectées sont ceux de la période qui s'étale du mois de Janvier 2013 jusqu'au mois de Août 2014. Ces données sont présentées dans le graphique suivant :

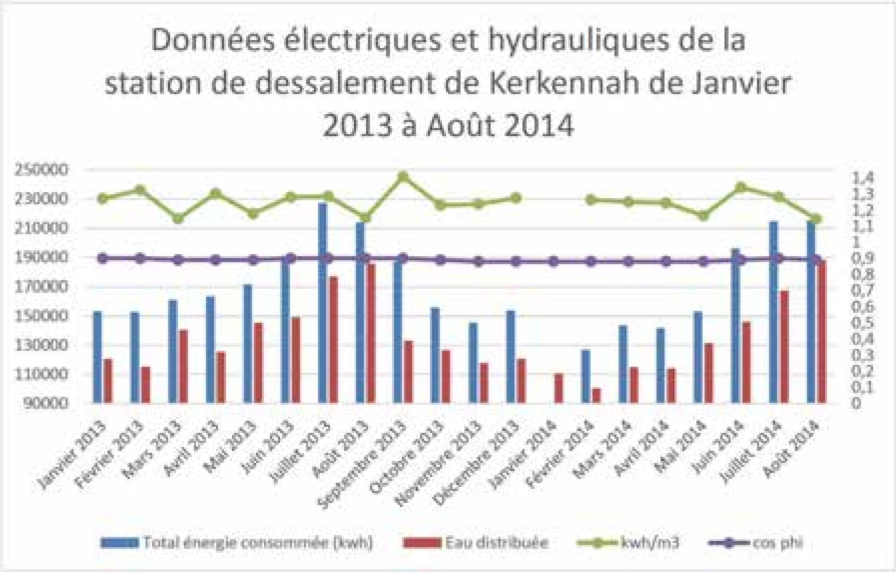


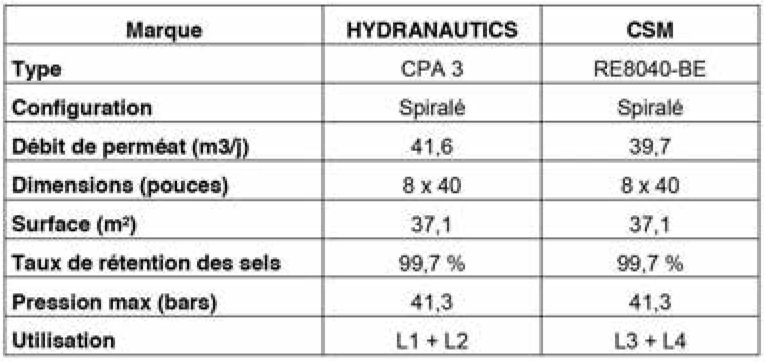
Figure 5 : Données électriques et hydrauliques en 2013

4.1.3 Groupes électropompes installés :

Les groupes électropompes existants datent d'avant l'introduction des anciennes classes d'efficience énergétique EFF1 et EFF2 ni la nouvelle classe IE1, IE2, Ie3 et IE4. Ils sont caractérisés par des rendements classiques et inférieurs à ceux spécifiés dans les nouvelles classe d'efficience énergétiques.

4.1.4 Types des membranes d'osmose inverse utilisées :

Les membranes d'osmose inverse utilisées dans la station de dessalement de Kerkennah sont les suivantes :



Marque	HYDRANAUTICS	CSM
Type	CPA 3	RE8040-BE
Configuration	Spiralé	Spiralé
Débit de perméat (m3/j)	41,6	39,7
Dimensions (pouces)	8 x 40	8 x 40
Surface (m²)	37,1	37,1
Taux de rétention des sels	99,7 %	99,7 %
Pression max (bars)	41,3	41,3
Utilisation	L1 + L2	L3 + L4

4.1.5 Qualité du perméat de chaque ligne d'osmose inverse :

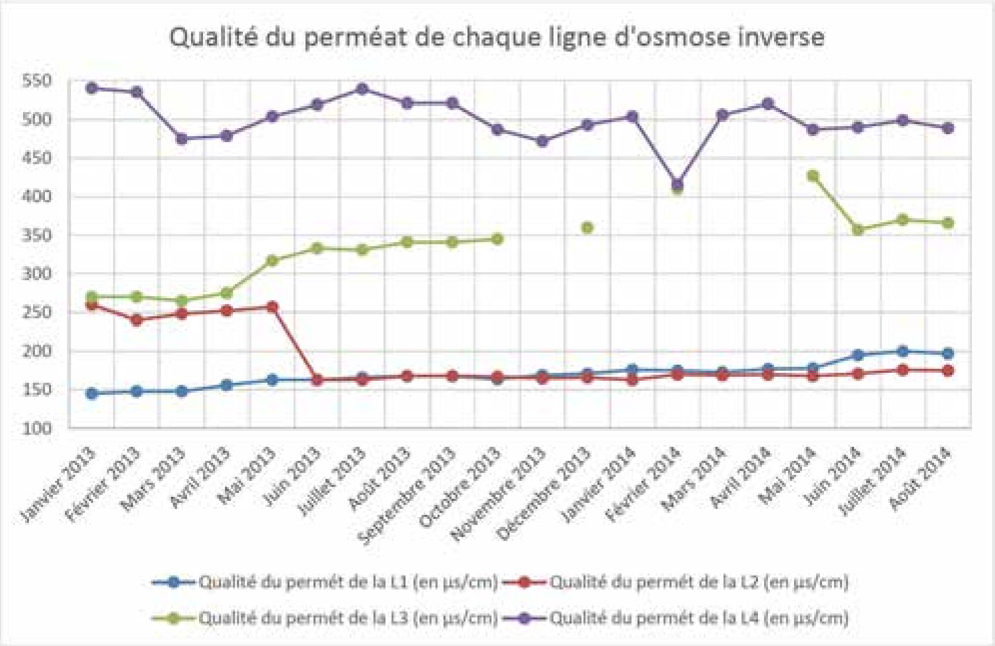


Figure 6 : Qualité du perméat pour chaque ligne d'osmose inverse en 2013

Les membranes CPA 3 des lignes L1 et L2 sont caractérisées par une salinité du perméat meilleure que celle des membranes RE8040-BE.

4.2 Constatation :

4.2.1 Processus de de dessalement :

La station de dessalement de Kerkennah a été construite en 1983 avec un design qui ne prenait pas en considération l'aspect énergétique. Cela se manifeste clairement dans lespoints suivants :

- Les eaux des forages sont refoulées vers le bassin d'oxydation qui se trouve au même niveau que les filtres à sables. On est obligé de pomper en continue ces eaux via les deux pompes de transfert.
- Le mélange se fait à travers trois (03) pompes de mélange qui fonctionnent en continue.
- Les groupes électropompes de haute pression fonctionnent en un point de fonctionnement fixe. A l'époque les variateurs de vitesse n'est pas utilisés.
- Quoi que les membranes en polyamides sont fabriquées depuis 1970, le station de dessalement de Kerkennah utilisait des membranes en acétate de cellulose qui nécessitaient 30 bars de pression d'attaque à l'entrée du bloc d'osmose inverse.

4.2.2 Salle de commande et superviseur :

La salle de commande de la station de dessalement comporte :

- Les armoires électriques,
- Un automate centrale avec les cartes d'entrée sortie,
- Quatre (04) variateurs de vitesse type ABB AC600,
- Un superviseur central.

Malgré la présence d'un automate central et d'un superviseur, la station de dessalement ne fonctionne pas en mode automatique. Les variateurs de vitesse n'agissent pas en mode automatique sur les groupes électropompes de haute pression.

Quelques données de types (ph, débit) sont transmises à l'automate central malgré la présence de moyens de mesures modernes.

4.3 Etude de la solution :

Dans chaque station de dessalement, les groupes électropompes de haute pression sont les groupes les plus énergivores en matière de puissance installée et consommation d'énergie.

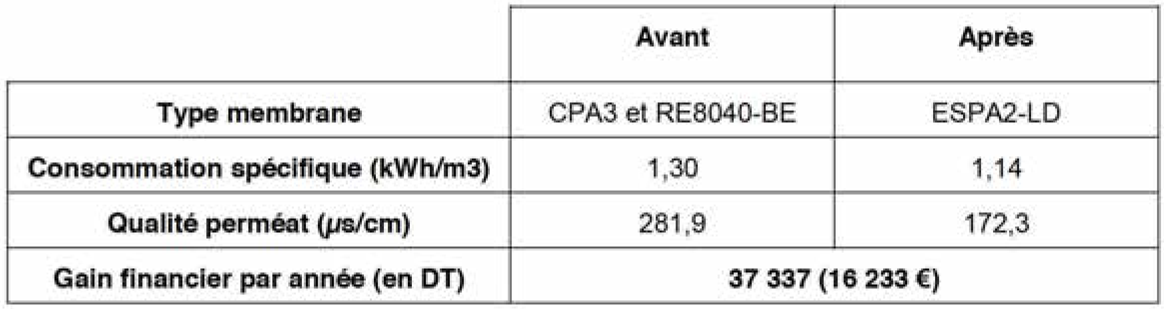
Les membranes CPA 3 sont des membranes énergivores. Actuellement, ils existent de nouvelles membranes s'osmose inverse moins consommatrice d'énergie avec une très bonne qualité du perméat. Le processus de dessalement peut être modifié en partie ou totalité dans

4.3.1 Variante 1 :

La première variante touche uniquement aux membranes d'osmose inverse, aux pompes de haute pression et l'automate central de la station de dessalement. Elle ne modifie pas le profil hydraulique du processus de dessalement. La variante 1 consiste à :

- remplacer les membranes existantes par des membranes moins consommatrice d'énergie tout en gardant une très bonne qualité du perméat (ESPA2-LD),
- modifier les groupes électropompes de haute pression en installant des groupes électropompes conformes à la classe d'efficience énergétique.

Les résultats sont décrits dans le tableau suivant :



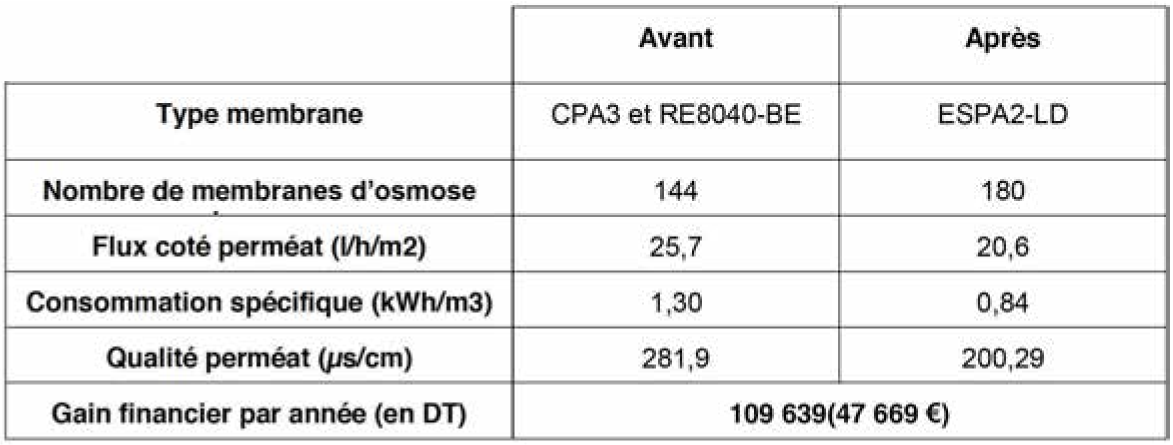
	Avant	**Après**
Type membrane	CPA3 et RE8040-BE	ESPA2-LD
Consommation spécifique (kWh/m3)	1,30	1,14
Qualité perméat (µs/cm)	281,9	172,3
Gain financier par année (en DT)	**37 337 (16 233 €)**	

4.3.2 Variante 2 :

La deuxième variante touche à tout l'aspect de production de la station de dessalement de Kerkennah. Elle modifie toute la conception et le profil hydraulique du processus de dessalement. La variante 2 consiste à :

- Installer deux groupes électropompes immergés dans les forages F2 et F3 au lieu des anciens groupes horizontaux,
- Construire une tour d'oxydation d'une hauteur de 5 m au minimum pour le traitement du fer contenu dans les eaux brutes des forages F2 et F3,
- Installer un bassin de collecte des eaux oxydées au-dessous de la tour d'oxydation,
- Installer quatre (04) nouvelles pompes de gavage avec des moteurs électriques de classe énergétique IE2 au minimum,
- Utiliser uniquement quatre (04) microfiltres à 1µm,
- Augmenter le nombre de membranes d'osmose inverse de 144 à 180 pour diminuer le flux du perméat et ainsi diminuer la Hmt des pompes de haute pression,
- Installer quatre (04) nouvelles pompes de haute pression avec des moteurs électriques de classe énergétique IE2. Ces pompes seront équipées des variateurs de vitesse existants (ABB AC600),
- Utiliser les membranes d'osmose inverse ESPA2-LD,
- Le mélange du perméat avec les eaux de mélange des forages F1 et F4 se fera dans le réservoir semi enterré existant (sans pompage),
- Installer des nouveaux groupes électropompes à la station de reprise vers le réservoir sur tour. Ces groupes seront munis de variateurs de vitesses et les moteurs électriques auront une classe énergétique IE2 au minimum,
- L'automate centrale et le superviseur doivent être opérationnels pour que la station puisse fonctionner en mode automatique avec transmission de tous les paramètres ver le superviseur

Les résultats sont décrits dans le tableau suivant :



	Avant	Après
Type membrane	CPA3 et RE8040-BE	ESPA2-LD
Nombre de membranes d'osmose	144	180
Flux coté perméat (l/h/m2)	25,7	20,6
Consommation spécifique (kWh/m3)	1,30	0,84
Qualité perméat (µs/cm)	281,9	200,29
Gain financier par année (en DT)	**109 639(47 669 €)**	

5 Leçons apprises et recommandations :

5.1 Leçons apprises :

L'élaboration de cet article pour ACWUA Good Practices Reader m'a permis de :

- identifier les différents paramètres et aspects à traiter dans cet article à savoir :
    - la consommation électrique durant la période Janvier 2013 à Août 2014,
    - le principe du processus de dessalement de la station de Kerkennah et le fonctionnement de cette station,
    - les groupes électropompes énergivores,
    - la nature des membranes d'osmose inverse,
    - les indicateurs de performances à suivre durant l'analyse de la consommation électriques,

- identifier les différents responsables pour la collecte des données nécessaires à l'écriture de cet article :
    - le Chef de la Division Maitrise d'Energie pour l'obtention de l'historique de la consommation électrique durant la période Janvier 2013 à Août 2014,
    - le Chef Division de la Division Production Sfax pour l'obtention de informations liées à la station de dessalement de Kerkennah en terme de :
        - volume d'eau brute pour le dessalement (F2 + F3) pour chaque mois,
        - volume d'eau brute pour le mélange (F1 + F4) pour chaque mois,
        - volume d'eau mélangée pour chaque mois,
        - la qualité du perméat par ligne et pour chaque mois,
        - le type des membranes utilisées dans le bloc d'osmose inverse,
        - la liste des équipements de pompage installés dans la station de dessalement,
        - le schéma de principe de la station de dessalement,
        - les différentes analyses physico-chimiques,

- planifier le déplacement et la visite du site de la station de dessalement de Kerkennah :
    - logistique,
    - contacts,
    - locaux à visiter,
    - informations à collecter sur sites,
    - photos à prendre,

- utiliser les différents logiciels de simulations du processus de dessalement :
    - Imsdesign de la société HYDRANAUTICS : ce logiciel permet de simuler le processus d'une station de dessalement en se basant sur l'analyse physico-chimique de l'eau brute et en offrant une multitude de membranes. Ce logiciel permet le calcul d'investissement du projet et le calcul de la consommation énergétique du processus.
    - CSMPro3 : ce logiciel permet de simuler le processus d'une station de dessalement en se basant sur l'analyse physico-chimique de l'eau brute et en offrant une multitude de membranes. Ce logiciel permet le calcul d'investissement du projet et mais pas le calcul de la consommation énergétique du processus.

- s’informer sur la classe énergétique IE2 des moteurs électriques triphasés et la différence des rendements de cette classe énergétique avec les rendements classiques. Le marché tunisien des moteurs électriques commence de plus en plus à avoir des moteurs électriques avec cette classe énergétique en attendant d’avoir la classe IE3 sur le marché.
- Utiliser les applications Web pour le choix des groupes électropompes immergés et horizontaux des différents fabricants de pompes comme :
  - EasySelect de la société KSB : cette application permet de choisir une pompe parmi une multitude de pompe selon :
    - le segment,
    - le domaine d’application,
    - l’application,
    - le débit,
    - la Hmt
  - iPump de la société CAPRARI : cette application permet de choisir une pompe parmi une multitude de pompe selon :
    - type de la pompe,
    - l’installation de la pompe
    - le débit,
    - la Hmt
    - la vitesse de rotation

  Ces applications fournissent des détails techniques sur les pompes tels que les courbes caractéristiques, les puissances, les caractéristiques moteurs, les encombrements et la nature des différents matériaux utilisés dans la fabrication et peuvent aider à la préparation et la conception de projet.
- le calcul de la consommation énergétique selon le processus de dessalement adopter et le choix des équipements les mieux adopter aux deux variantes proposées.

5.2 Recommandations :

Les recommandations qui peuvent être tirées après l’élaboration de cet article se résume comme suit :

- approfondir l’étude de la variante 2 et aboutir à une conception d’un nouveau projet d’une nouvelle station de dessalement à Kerkennah basé sur :
  - La modification totale et l’optimisation du tracé des conduites de refoulement des eaux brutes du site de la station de dessalement de Kerkennah,
  - l’utilisation des groupes électropompes de classe énergétique IE3,
  - la variation de la vitesse,
  - les membranes d’osmose inverse non énergivores,
- réaliser un audit énergétique approfondi de la station de dessalement de Kerkennah,
- réaliser une étude sur le potentiel de l’île de Kerkennah pour les énergies renouvelables tel que les cellules photovoltaïques et les éoliennes afin d’alimenter la station de dessalement en énergie électrique.
- étudier et concevoir une variante 3 basé sur l’utilisation d’un traitement membranaire au poste de prétraitement (ultrafiltration) et calculer la consommation d’énergie qui en résulte tout en la comparant aux résultats tirés par l’étude de la variante 2.

- généraliser l'utilisation des applications Web des fabricants de pompes et tirer avantages des possibilités offertes dans ces applications pour optimiser les cahiers des charges et le choix des pompes.

6 Impact et durabilité :

Cet article aura un fort intérêt pour les études de réhabilitations des stations de pompage et stations de dessalement. En effet, plusieurs aspects ont été abordés dans cet article et qui peuvent être considérés comme un point de départ pour d'autres études de réhabilitations. Ces aspects sont les suivants :

- la collecte des différentes données,
- diagnostic de la situation actuelle,
- identification de la problématique,
- étude des solutions techniques,
- notions énergétique IE2 et IE3 pour les moteurs électriques,
- utilisation des logiciels des fabricants des membranes d'osmose inverse pour la simulation du processus de dessalement en fonction de la nature et la salinité de l'eau brute,
- utilisation des applications web des fabricants de pompes pour l'optimisation du choix d'une pompe selon le débit, la Hmt, la vitesse, la puissance absorbée, le rendement, les matériaux utilisées et l'encombrement,
- le calcul de la consommation énergétique selon les variantes considérées,
- l'impact financier de chaque variante.

L'impact de cet article est de démontrer aux responsables que l'adoption des nouvelles directives en termes d'efficacité énergétique apportera un gain important dans le domaine de maitrise de l'énergie et la rationalisation de la consommation électrique.

L'approche et la méthodologie suivis pour l'élaboration de cet article peuvent faire partie intégrante d'un guidelines pour les bonnes pratiques et l'audit d'énergie dans les stations de pompage d'eau et assainissement.

Aussi cet article servira comme un chapitre dans une formation pour les jeunes ingénieurs pour les initier aux notions de maîtrise d'énergie, les bonnes pratiques et le système de management d'énergie. Ils peuvent s'inspirer de l'approche et la méthodologie adoptées totu en utilisant les nouveautés techniques décrites ci-dessus.

Annexes

Site de la station de dessalement

Site de la station de dessalement de Kerkennah

Station de dessalement de Kerkennah

Forage F2

Forage F3

Forage F1

(le groupe électropompe est en réparation)

Transformateur 1
(315KVA)

Transformateur 2
(315KVA)

Bassin d’oxydation et filtres à sables

Pompes de Gavage
(Booster)

Microfiltres 1
(4 filtres dans la salle des pompes)

Microfiltres 2
(4 filtres sur le toit de la salle des pompes)

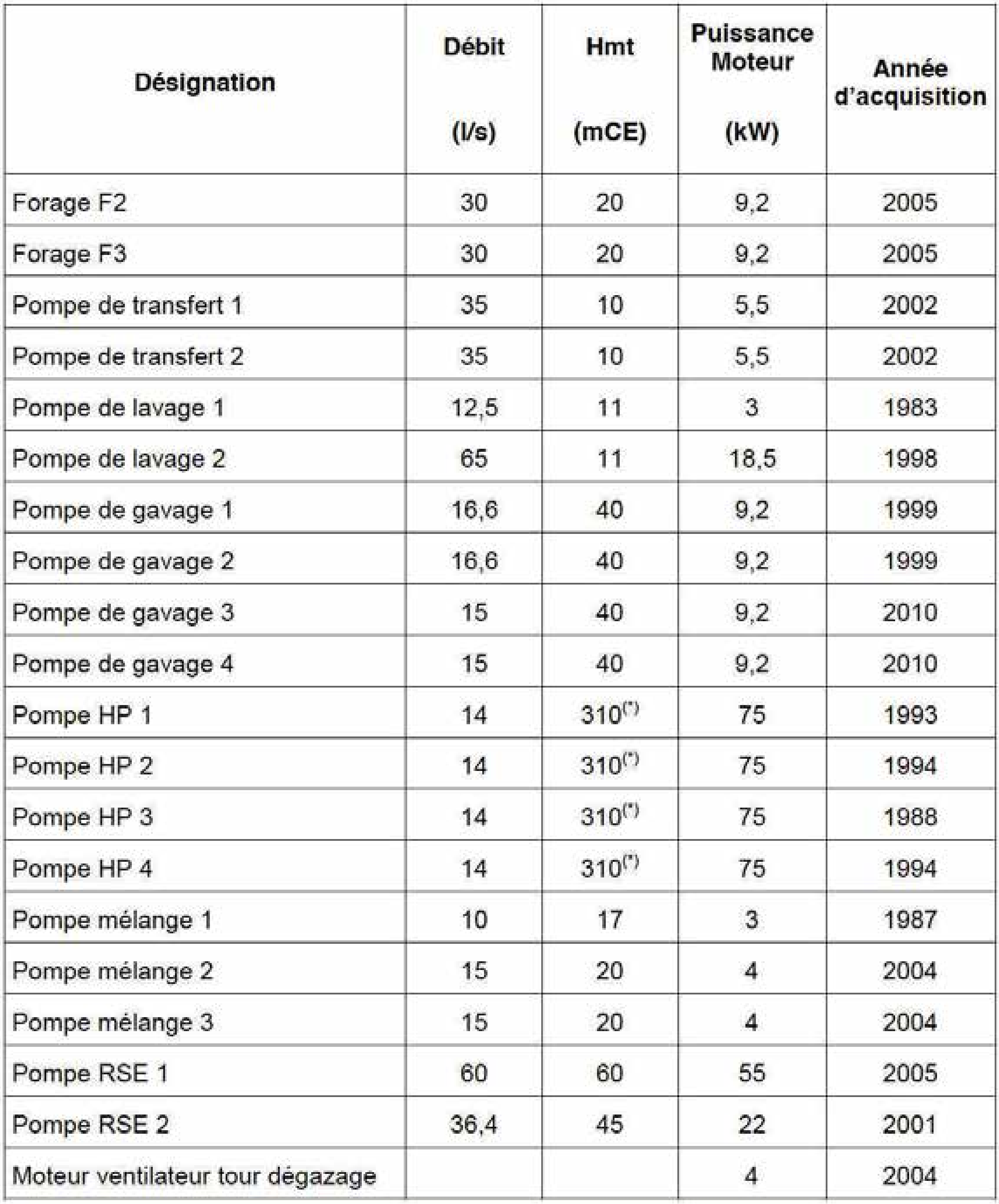
Problème de sable farineux
dans l'eau des forages F2 + F3

Pompes de haute pression

Bloc d'osmose inverse
(L1 + L2 + L3 + L4)

Station de reprise vers réservoir sur tour

Liste des équipements de pompage installés



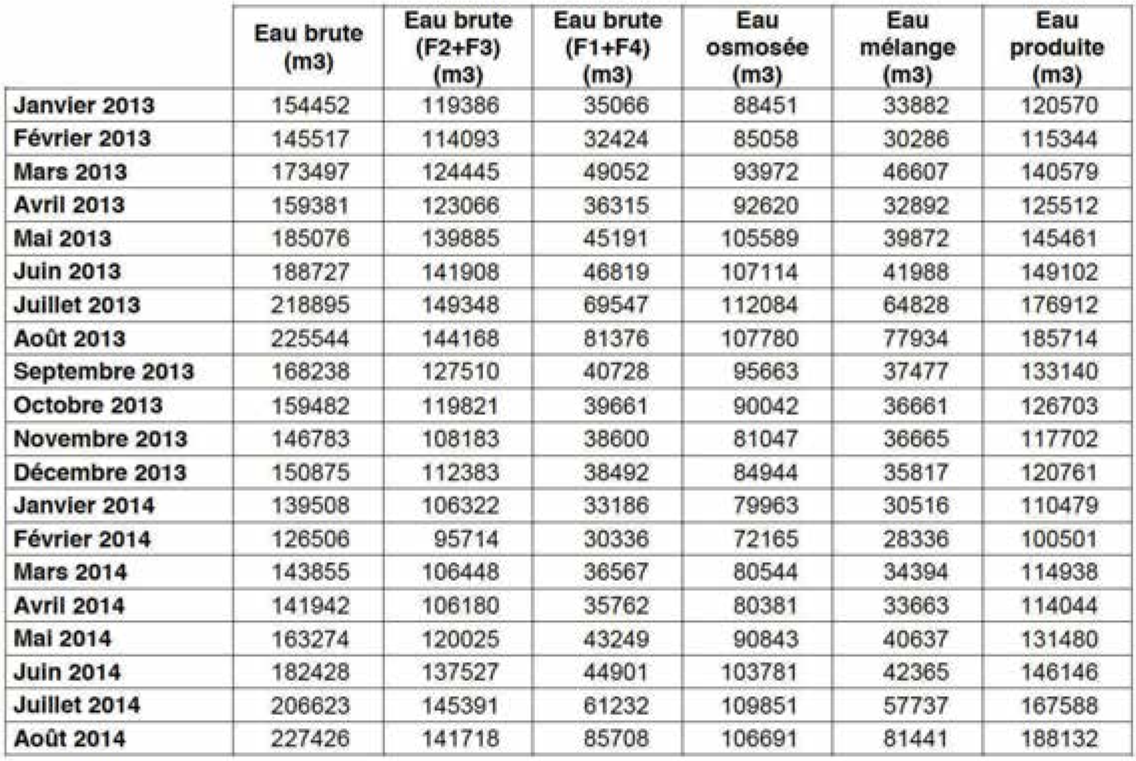
Désignation	Débit (l/s)	Hmt (mCE)	Puissance Moteur (kW)	Année d'acquisition
Forage F2	30	20	9,2	2005
Forage F3	30	20	9,2	2005
Pompe de transfert 1	35	10	5,5	2002
Pompe de transfert 2	35	10	5,5	2002
Pompe de lavage 1	12,5	11	3	1983
Pompe de lavage 2	65	11	18,5	1998
Pompe de gavage 1	16,6	40	9,2	1999
Pompe de gavage 2	16,6	40	9,2	1999
Pompe de gavage 3	15	40	9,2	2010
Pompe de gavage 4	15	40	9,2	2010
Pompe HP 1	14	310(*)	75	1993
Pompe HP 2	14	310(*)	75	1994
Pompe HP 3	14	310(*)	75	1988
Pompe HP 4	14	310(*)	75	1994
Pompe mélange 1	10	17	3	1987
Pompe mélange 2	15	20	4	2004
Pompe mélange 3	15	20	4	2004
Pompe RSE 1	60	60	55	2005
Pompe RSE 2	36,4	45	22	2001
Moteur ventilateur tour dégazage			4	2004

(*) : On utilise des vannes et des variateurs de vitesse pour baisser la Hmt et ajuster la pression d'attaque à l'entrée de chaque ligne d'osmose inverse. La pression moyenne à la sortie de chaque pompe HP est de 175 mCE.

Historique de la consommation électrique durant la période Janvier 2013 à Août 2014

	Jour (kWh)	Pointe (kWh)	Nuit (kWh)	Total Energie consommée (kWh)	Cos phi
Janvier 2013	61996	22368	68892	153256	0,90
Février 2013	60704	21599	70530	152833	0,90
Mars 2013	64523	23981	72630	161134	0,89
Avril 2013	68830	24825	69987	163642	0,89
Mai 2013	70666	24160	76624	171450	0,89
Juin 2013	78445	27901	84547	190893	0,90
Juillet 2013	90724	33412	103260	227396	0,90
Août 2013	87398	32477	94092	213967	0,90
Septembre 2013	76009	26065	85243	187317	0,90
Octobre 2013	59642	19905	76327	155874	0,89
Novembre 2013	60543	21045	64019	145607	0,88
Décembre 2013	59472	22110	72443	154025	0,88
Janvier 2014					
Février 2014	50813	13930	62252	126995	0,88
Mars 2014	57029	15349	71330	143708	0,88
Avril 2014	57570	15969	68377	141916	0,88
Mai 2014	63696	17740	71782	153218	0,88
Juin 2014	58246	41724	96069	196039	0,89
Juillet 2014	55006	75115	84580	214701	0,90
Août 2014	59891	65045	90511	215447	0,89

Historique des volumes d’eau brute, eau de mélange, eau osmosée et eau produite durant la période Janvier 2013 à Août 2014

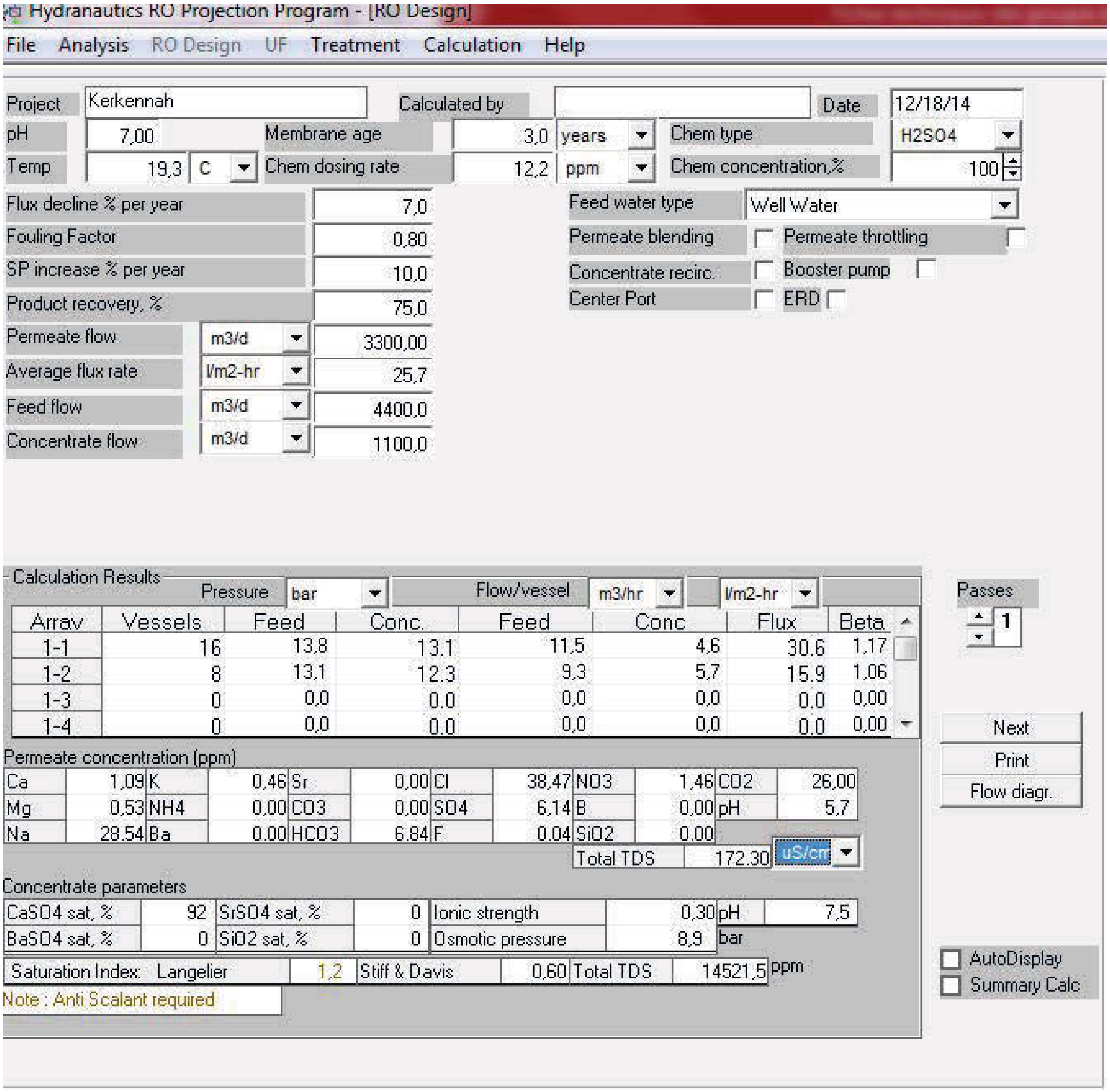


	Eau brute (m3)	Eau brute (F2+F3) (m3)	Eau brute (F1+F4) (m3)	Eau osmosée (m3)	Eau mélange (m3)	Eau produite (m3)
Janvier 2013	154452	119386	35066	88451	33882	120570
Février 2013	145517	114093	32424	85058	30286	115344
Mars 2013	173497	124445	49052	93972	46607	140579
Avril 2013	159381	123066	36315	92620	32892	125512
Mai 2013	185076	139885	45191	105589	39872	145461
Juin 2013	188727	141908	46819	107114	41988	149102
Juillet 2013	218895	149348	69547	112084	64828	176912
Août 2013	225544	144168	81376	107780	77934	185714
Septembre 2013	168238	127510	40728	95663	37477	133140
Octobre 2013	159482	119821	39661	90042	36661	126703
Novembre 2013	146783	108183	38600	81047	36665	117702
Décembre 2013	150875	112383	38492	84944	35817	120761
Janvier 2014	139508	106322	33186	79963	30516	110479
Février 2014	126506	95714	30336	72165	28336	100501
Mars 2014	143855	106448	36567	80544	34394	114938
Avril 2014	141942	106180	35762	80381	33663	114044
Mai 2014	163274	120025	43249	90843	40637	131480
Juin 2014	182428	137527	44901	103781	42365	146146
Juillet 2014	206623	145391	61232	109851	57737	167588
Août 2014	227426	141718	85708	106691	81441	188132

Historique de la qualité du perméat de chaque ligne d'osmose inverse durant la période Janvier 2013 à Août 2014

	Qualité perméat L1 (en µs/cm)	Qualité perméat L2 (en µs/cm)	Qualité perméat L3 (en µs/cm)	Qualité perméat L4 (en µs/cm)
Janvier 2013	145	260	270	540
Février 2013	148	240	270	535
Mars 2013	148	248	265	475
Avril 2013	156	252	275	479
Mai 2013	163	257	317	504
Juin 2013	163	163	333	519
Juillet 2013	166	163	331	539
Août 2013	168	168	341	521
Septembre 2013	168	168	341	521
Octobre 2013	164	167	345	487
Novembre 2013	169	165	Arrêt	472
Décembre 2013	171	166	360	493
Janvier 2014	176	163	Arrêt	504
Février 2014	175	170	410	416
Mars 2014	173	169	Arrêt	506
Avril 2014	177	170	Arrêt	520
Mai 2014	178	168	427	487
Juin 2014	195	171	357	490
Juillet 2014	200	176	370	499
Août 2014	197	175	366	489

Simulation variante 1, calcul de la consommation énergétique et gain



Project: Kerkennah
Calculated by:
Date: 12/18/14
pH: 7,00
Membrane age: 3,0 years
Chem type: H2SO4
Temp: 19,3 C
Chem dosing rate: 12,2 ppm
Chem concentration,%: 100
Flux decline % per year: 7,0
Fouling Factor: 0,80
SP increase % per year: 10,0
Product recovery, %: 75,0
Permeate flow (m3/d): 3300,00
Average flux rate (l/m2-hr): 25,7
Feed flow (m3/d): 4400,0
Concentrate flow (m3/d): 1100,0
Feed water type: Well Water
☐ Permeate blending
☐ Permeate throttling
☐ Concentrate recirc.
☐ Booster pump
☐ Center Port
☐ ERD
Passes: 1

Calculation Results — Pressure: bar; Flow/vessel: m3/hr; l/m2-hr

Arrav	Vessels	Feed	Conc.	Feed	Conc	Flux	Beta
1-1	16	13,8	13.1	11,5	4,6	30.6	1,17
1-2	8	13,1	12.3	9,3	5,7	15.9	1,06
1-3	0	0,0	0.0	0,0	0,0	0.0	0,00
1-4	0	0,0	0.0	0,0	0,0	0.0	0,00

Permeate concentration (ppm)

Ca	1,09	K	0,46	Sr	0,00	Cl	38,47	NO3	1,46	CO2	26,00
Mg	0,53	NH4	0,00	CO3	0,00	SO4	6,14	B	0,00	pH	5,7
Na	28.54	Ba	0.00	HCO3	6.84	F	0.04	SiO2	0.00		

Total TDS: 172.30 uS/cm

Concentrate parameters

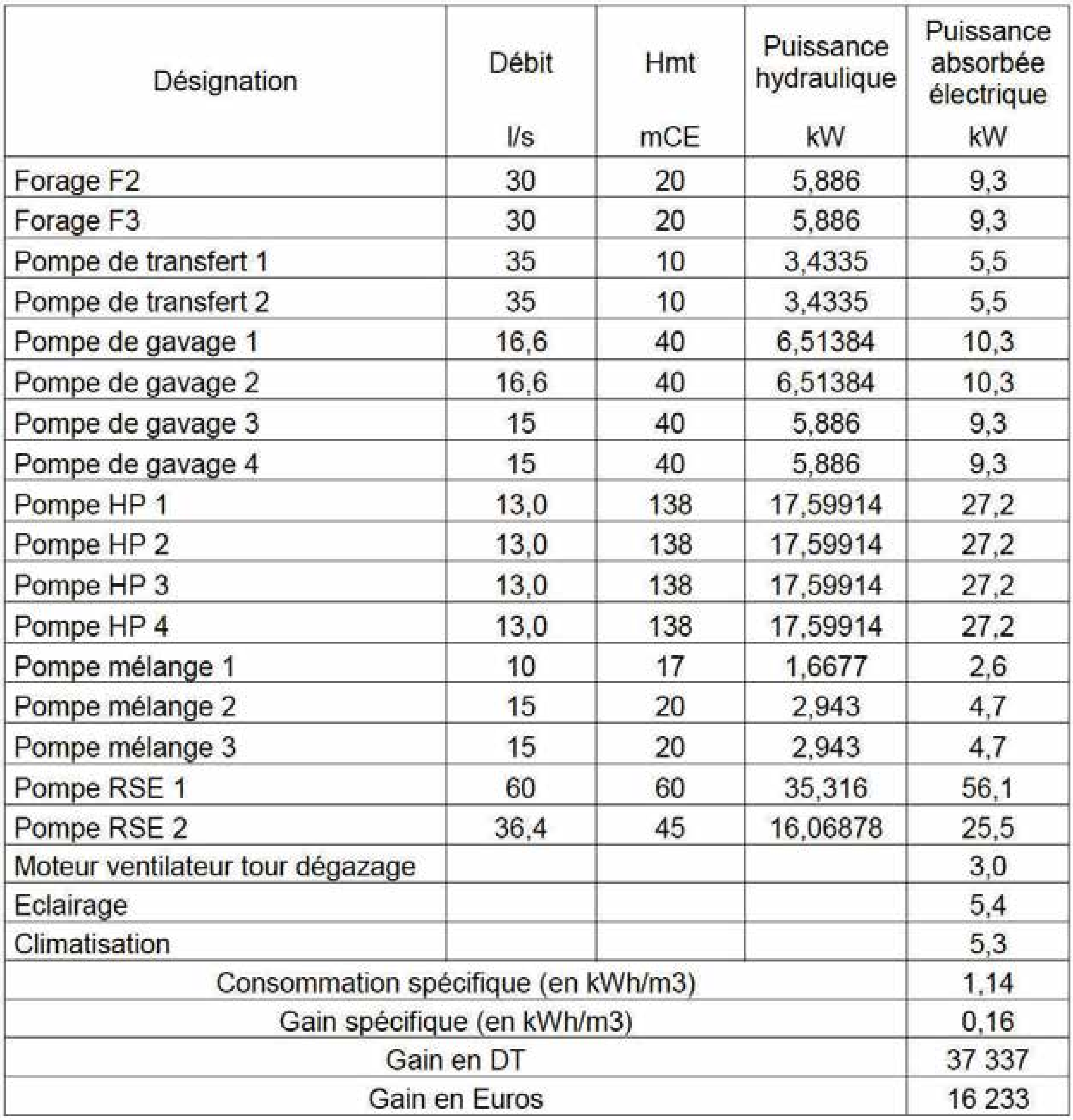
CaSO4 sat, %	92	SrSO4 sat, %	0	Ionic strength	0,30	pH	7,5
BaSO4 sat, %	0	SiO2 sat, %	0	Osmotic pressure	8,9	bar	

Saturation Index: Langelier 1,2 — Stiff & Davis 0,60 — Total TDS 14521,5 ppm

Note : Anti Scalant required

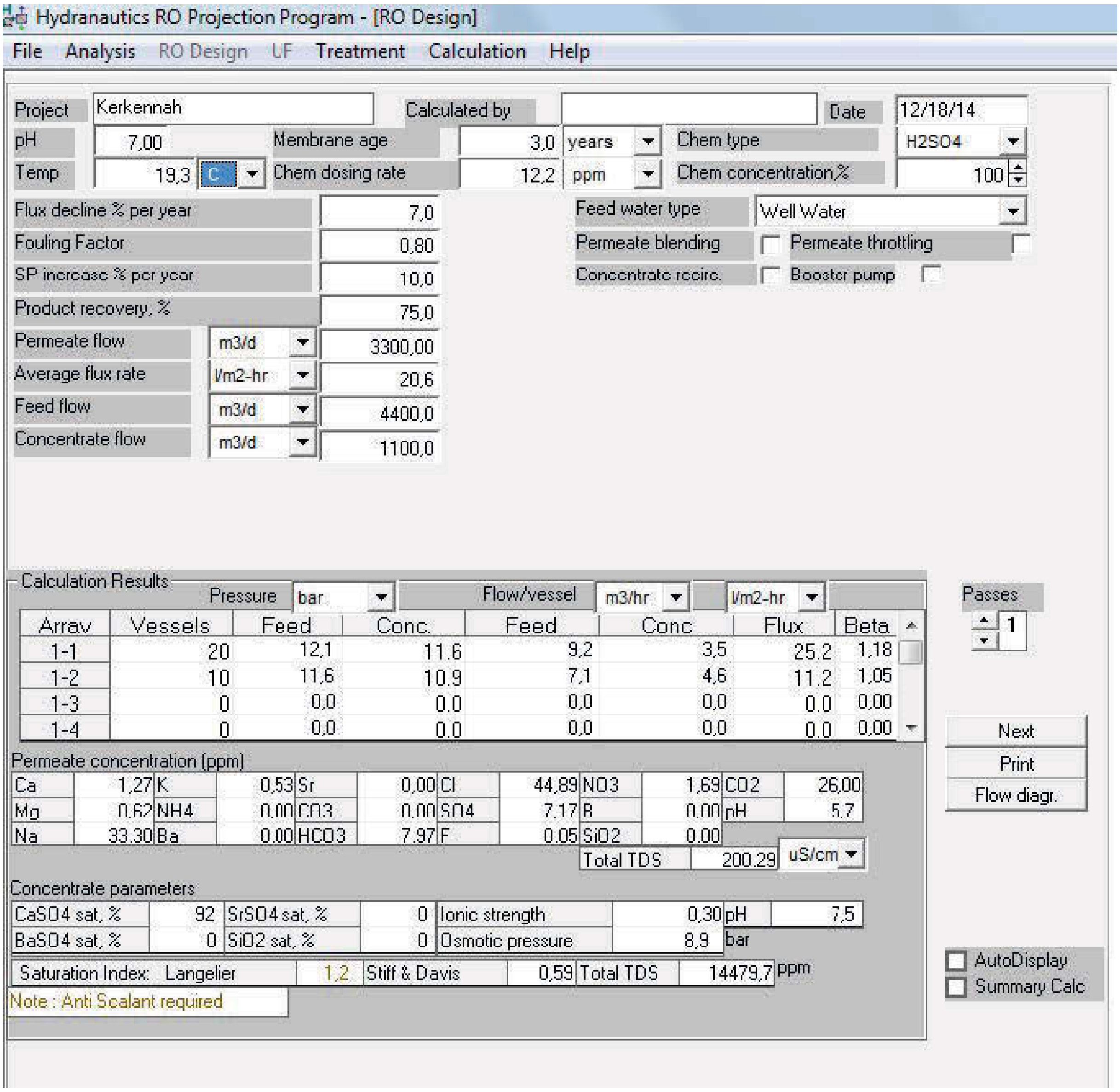
☐ AutoDisplay
☐ Summary Calc

Cette simulation a été faite avec une capacité de la station de dessalement de 3300 m^3/j pour garder le même flux du perméat et ainsi le même nombre des membranes d'osmose inverse.



Désignation	Débit l/s	Hmt mCE	Puissance hydraulique kW	Puissance absorbée électrique kW
Forage F2	30	20	5,886	9,3
Forage F3	30	20	5,886	9,3
Pompe de transfert 1	35	10	3,4335	5,5
Pompe de transfert 2	35	10	3,4335	5,5
Pompe de gavage 1	16,6	40	6,51384	10,3
Pompe de gavage 2	16,6	40	6,51384	10,3
Pompe de gavage 3	15	40	5,886	9,3
Pompe de gavage 4	15	40	5,886	9,3
Pompe HP 1	13,0	138	17,59914	27,2
Pompe HP 2	13,0	138	17,59914	27,2
Pompe HP 3	13,0	138	17,59914	27,2
Pompe HP 4	13,0	138	17,59914	27,2
Pompe mélange 1	10	17	1,6677	2,6
Pompe mélange 2	15	20	2,943	4,7
Pompe mélange 3	15	20	2,943	4,7
Pompe RSE 1	60	60	35,316	56,1
Pompe RSE 2	36,4	45	16,06878	25,5
Moteur ventilateur tour dégazage				3,0
Eclairage				5,4
Climatisation				5,3
Consommation spécifique (en kWh/m3)				1,14
Gain spécifique (en kWh/m3)				0,16
Gain en DT				37 337
Gain en Euros				16 233

Simulation variante 2, calcul de la consommation énergétique et gain



Project: Kerkennah
Calculated by:
Date: 12/18/14
pH: 7,00
Membrane age: 3,0 years
Chem type: H2SO4
Temp: 19,3 C
Chem dosing rate: 12,2 ppm
Chem concentration,%: 100
Flux decline % per year: 7,0
Fouling Factor: 0,80
SP increase % per year: 10,0
Product recovery, %: 75,0
Permeate flow (m3/d): 3300,00
Average flux rate (l/m2-hr): 20,6
Feed flow (m3/d): 4400,0
Concentrate flow (m3/d): 1100,0
Feed water type: Well Water
☐ Permeate blending
☐ Permeate throttling
☐ Concentrate recirc.
☐ Booster pump

Calculation Results
Pressure: bar
Flow/vessel: m3/hr
l/m2-hr
Passes: 1

Array	Vessels	Feed	Conc.	Feed	Conc	Flux	Beta
1-1	20	12,1	11.6	9,2	3,5	25.2	1,18
1-2	10	11,6	10.9	7,1	4,6	11.2	1,05
1-3	0	0,0	0.0	0,0	0,0	0.0	0,00
1-4	0	0,0	0.0	0,0	0,0	0.0	0,00

Permeate concentration (ppm)

Ca	1,27	K	0,53	Sr	0,00	Cl	44,89	NO3	1,69	CO2	26,00
Mg	0,62	NH4	0,00	CO3	0,00	SO4	7,17	B	0,00	pH	5,7
Na	33,30	Ba	0,00	HCO3	7,97	F	0,05	SiO2	0,00		

Total TDS: 200,29 uS/cm

Concentrate parameters

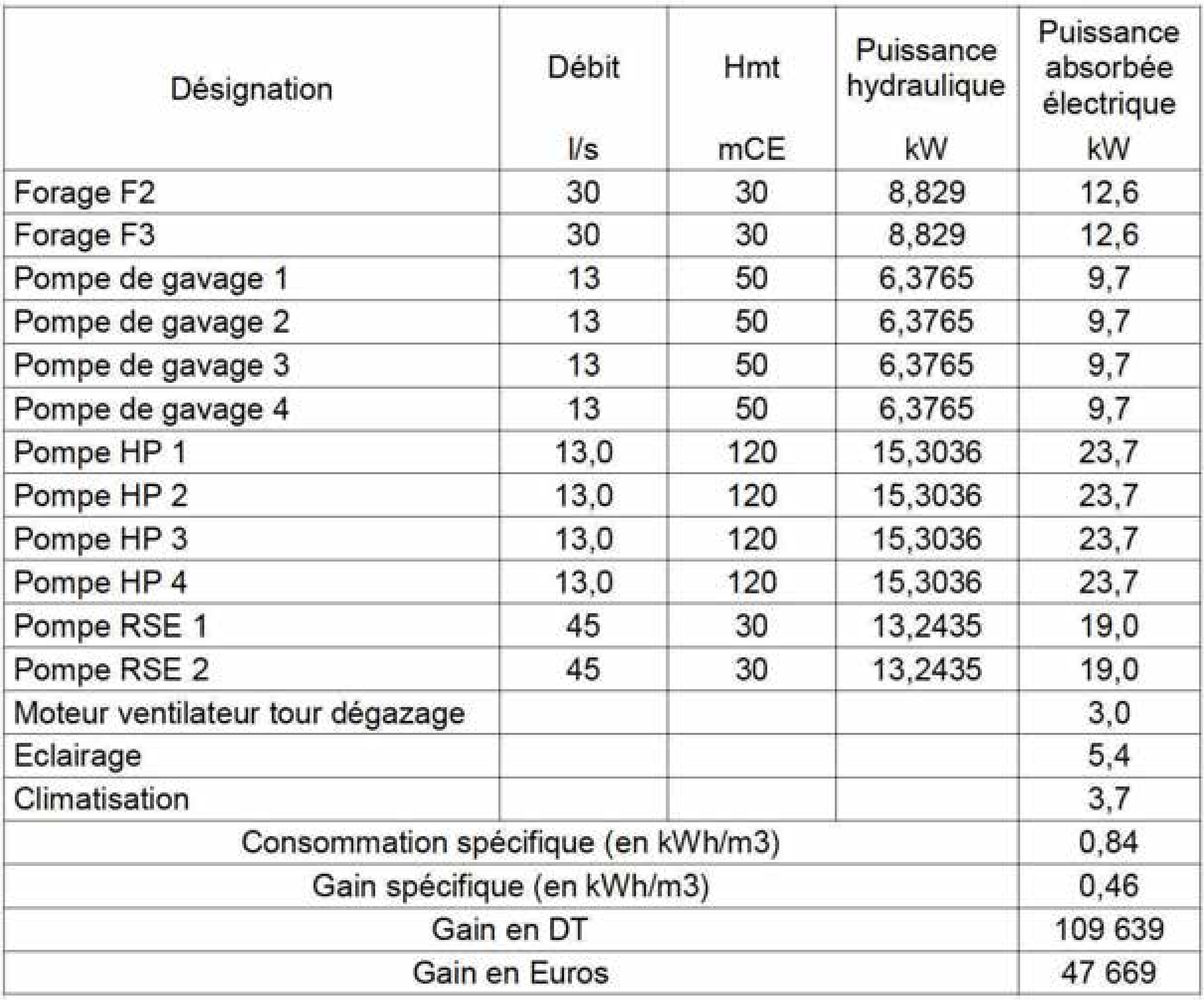
CaSO4 sat, %	92	SrSO4 sat, %	0	Ionic strength	0,30	pH	7,5
BaSO4 sat, %	0	SiO2 sat, %	0	Osmotic pressure	8,9	bar	

Saturation Index: Langelier 1,2 | Stiff & Davis 0,59 | Total TDS 14479,7 ppm

Note : Anti Scalant required

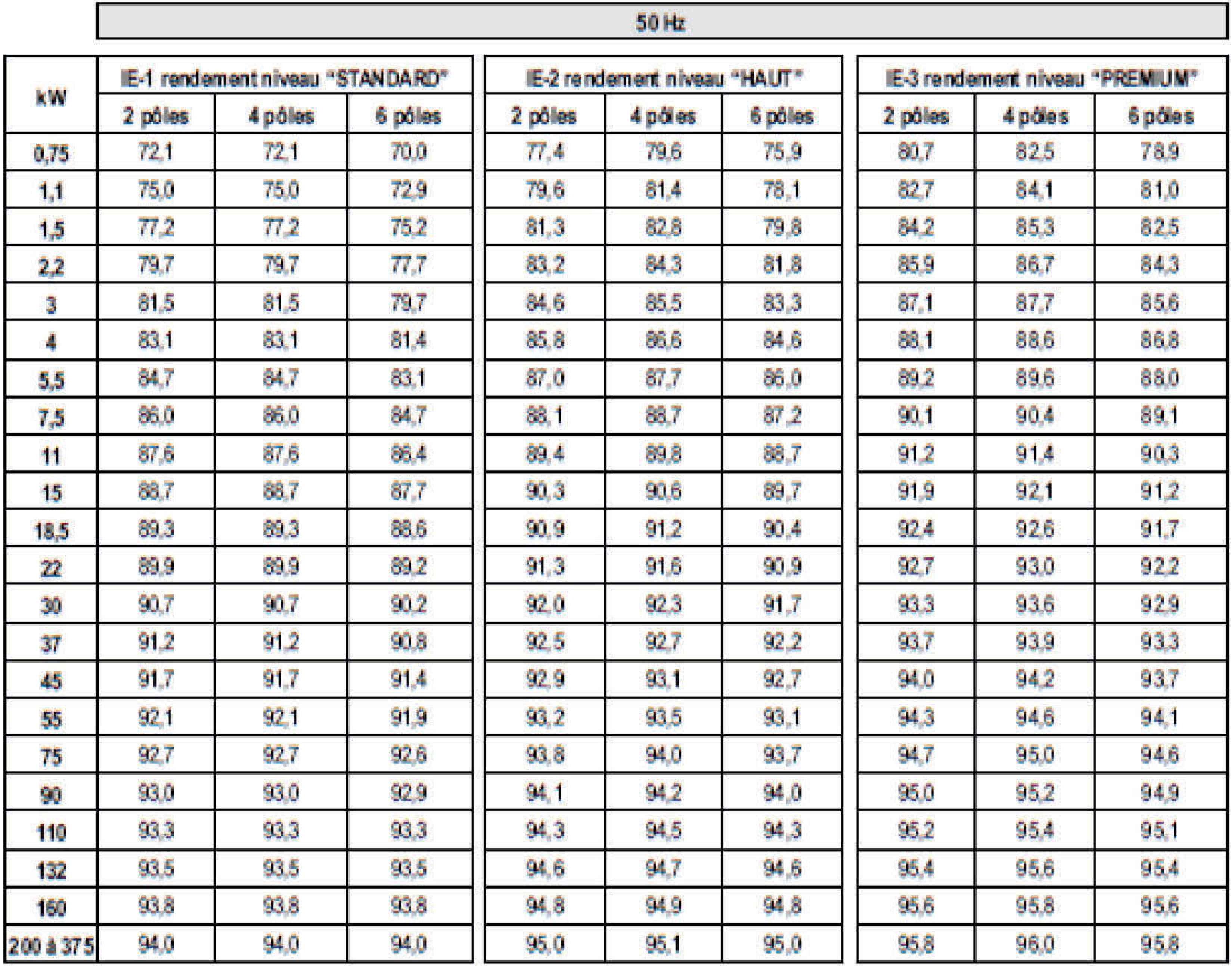
☐ AutoDisplay
☐ Summary Calc

Cette simulation a été faite avec une capacité de la station de dessalement de 3300 m^3/j pour avoir un même flux du perméat de 20,6 l/h/m^2et un nombre des membranes d’osmose inverse de 180.

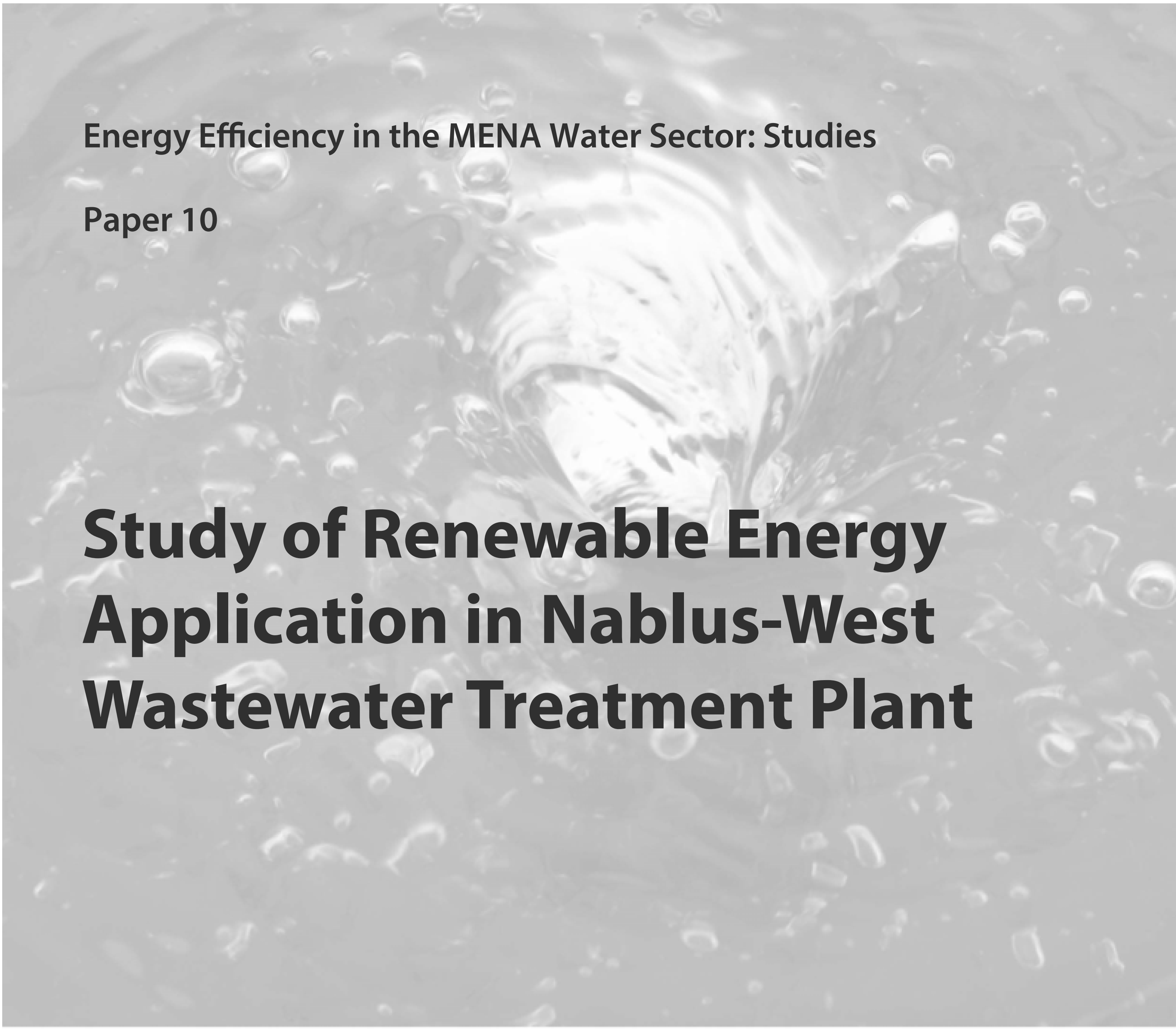


Désignation	Débit l/s	Hmt mCE	Puissance hydraulique kW	Puissance absorbée électrique kW
Forage F2	30	30	8,829	12,6
Forage F3	30	30	8,829	12,6
Pompe de gavage 1	13	50	6,3765	9,7
Pompe de gavage 2	13	50	6,3765	9,7
Pompe de gavage 3	13	50	6,3765	9,7
Pompe de gavage 4	13	50	6,3765	9,7
Pompe HP 1	13,0	120	15,3036	23,7
Pompe HP 2	13,0	120	15,3036	23,7
Pompe HP 3	13,0	120	15,3036	23,7
Pompe HP 4	13,0	120	15,3036	23,7
Pompe RSE 1	45	30	13,2435	19,0
Pompe RSE 2	45	30	13,2435	19,0
Moteur ventilateur tour dégazage				3,0
Eclairage				5,4
Climatisation				3,7
Consommation spécifique (en kWh/m3)				0,84
Gain spécifique (en kWh/m3)				0,46
Gain en DT				109 639
Gain en Euros				47 669

Tableau des rendements des moteurs électriques triphasés standards, IE2 et IE3



kW	50 Hz								
	IE-1 rendement niveau “STANDARD”			IE-2 rendement niveau “HAUT”			IE-3 rendement niveau “PREMIUM”		
	2 pôles	4 pôles	6 pôles	2 pôles	4 pôles	6 pôles	2 pôles	4 pôles	6 pôles
0,75	72,1	72,1	70,0	77,4	79,6	75,9	80,7	82,5	78,9
1,1	75,0	75,0	72,9	79,6	81,4	78,1	82,7	84,1	81,0
1,5	77,2	77,2	75,2	81,3	82,8	79,8	84,2	85,3	82,5
2,2	79,7	79,7	77,7	83,2	84,3	81,8	85,9	86,7	84,3
3	81,5	81,5	79,7	84,6	85,5	83,3	87,1	87,7	85,6
4	83,1	83,1	81,4	85,8	86,6	84,6	88,1	88,6	86,8
5,5	84,7	84,7	83,1	87,0	87,7	86,0	89,2	89,6	88,0
7,5	86,0	86,0	84,7	88,1	88,7	87,2	90,1	90,4	89,1
11	87,6	87,6	86,4	89,4	89,8	88,7	91,2	91,4	90,3
15	88,7	88,7	87,7	90,3	90,6	89,7	91,9	92,1	91,2
18,5	89,3	89,3	88,6	90,9	91,2	90,4	92,4	92,6	91,7
22	89,9	89,9	89,2	91,3	91,6	90,9	92,7	93,0	92,2
30	90,7	90,7	90,2	92,0	92,3	91,7	93,3	93,6	92,9
37	91,2	91,2	90,8	92,5	92,7	92,2	93,7	93,9	93,3
45	91,7	91,7	91,4	92,9	93,1	92,7	94,0	94,2	93,7
55	92,1	92,1	91,9	93,2	93,5	93,1	94,3	94,6	94,1
75	92,7	92,7	92,6	93,8	94,0	93,7	94,7	95,0	94,6
90	93,0	93,0	92,9	94,1	94,2	94,0	95,0	95,2	94,9
110	93,3	93,3	93,3	94,3	94,5	94,3	95,2	95,4	95,1
132	93,5	93,5	93,5	94,6	94,7	94,6	95,4	95,6	95,4
160	93,8	93,8	93,8	94,8	94,9	94,8	95,6	95,8	95,6
200 à 375	94,0	94,0	94,0	95,0	95,1	95,0	95,8	96,0	95,8



Energy Efficiency in the MENA Water Sector: Studies

Paper 10

Study of Renewable Energy Application in Nablus-West Wastewater Treatment Plant

Written by:
Mohammad Homeidan, Hassan Marie and Jaber Hasson

Developed under the guidance of the ACWUA Energy Efficiency Task Force,
with support from GIZ ACWUA WANT program 2013-2015

Abstract

Study of Renewable Energy Application in Nablus-West Wastewater Treatment Plant, Biogas and photovoltaic applications in Nablus West Wastewater Treatment Plant

by Mohammad Homeidan

High power consumption of wastewater treatment plants, in West Bank, is considered as one of the most challenging issues that threats their operational sustainability. Most of treatment plants in West Bank are depending on the public electricity network as a power source. But recently, many municipalities are trying to save energy by thinking to use renewable energy in their plants' operations. The objective of this study is to check feasible application of renewable energy sources in Nablus west wastewater treatment plant. Biogas utilization and photovoltaic cells were used as future green energy scenarios in the plant. The calculation results revealed significant preferability of the hybrid scenario with a capital cost of 3.9 million Shekel and payback period of 4.7 years. The hybrid scenario depends on biogas and photovoltaic cells to recover 100% of the plant energy. Studies to make wastewater treatment plants self sustained by renewable energy will encourage the sustainability of such projects and will enhance their continuity in service.

Keywords-component; Wastewater Treatment Plant; Operational sustainability; Renewable energy; Feasible Application; Biogas, Photovoltaic cells.

I. INTRODUCTION

Power consumption is considered one of the major issues which affect the improvement of wastewater treatment sector in developing countries [1]. In West Bank, wastewater treatment plants (WWTPs) were growing dramatically as same as the questions relating to their sustainable operation. The high power consumption of the plants spotted the light further on the importance of using renewable green energy as power source. Nablus and Jericho municipalities have started to put the base on using green renewable energy as power source in their WWTPs. This paper aims to explore Nablus WWTP as a case study for applying green renewable energy sources. Nablus plant is designed to work as extended aeration with primary settling tank and anaerobic digester. Biogas is produced from the digester and stored in a gas storage tank. This paper studied three scenarios of using green renewable energy in Nablus plant. These scenarios were as the following: 1) using biogas in a combined heat and power (CHP) unit only, 2) using photovoltaic cells without CHP unit, and 3) using photovoltaic cells with combination of CHP as a hybrid system. The baseline information contained in this paper is of importance because of the following reasons: 1) this is the first time that such data have been gathered from one of the leading WWTPs in West Bank, 2) it provides a template around which further investigation on this important topic will be made, 3) despite it is ongoing progressed, officials can use the study results for decision making which achieve good future for wastewater treatment sector.

Background

Nablus WWTP Technology description

Nablus WWTP has an average wastewater flowrate of 10,000 m^3/d. The plant is designed to serve the western part of Nablus city and other five villages. It is located in Deir Sharaf village between Nablus and Tulkarem cities. Activated sludge treatment process used as a technology of treatment. Wastewater flows continuously into preliminary treatment units that consist of coarse and fine screening units in addition of grit and grease removal unit. After preliminary treatment, the flow enters to a primary settling tank to collect the primary sludge. The primary sludge settles down in the tank and the clarified flow continues to a biological unit equipped by surface aerators. Surface aerators supply oxygen to make aerobic oxidation of biodegradable organics matter using microorganisms. After retention time of 24 hours, the aerated solution in the biological unit is leaving the unit to separate the activated sludge (which contains microorganism) and clarified water through final settling tanks. Most of settled sludge is returned to the biological unit to keep the concentration of activated sludge between 2 to 3 g/L. The daily excess quantity of activated sludge due to its biological growth should be sending to sludge treatment units. Main sources of sludge in the plant are primary sludge and activated sludge. The primary sludge enters to a gravity thickener tank which increases the dry matter concentration from 2.5% to 5%. The excess of activated sludge enters to a drainage belt thickener which increases the dry matter concentration from 0.7% to 6-8%. These two sources of sludge are mixed together to be homogenized in a blending tank. The blended sludge enters anaerobic biological tank called digester. The sludge is anaerobically degraded and produces biogas within approximately 20 days retention time. The biogas contains approximately 65% methane and 35% carbon dioxide. Nablus plant uses the biogas in special boiler for heating up the temperature of the digester at 36 ºC under mesophilic conditions. Digested sludge has two options for drying. The first option is in summer season where areas are used for drying and called drying beds. Drying beds depends on solar energy and special drainage channels. The second option is in the winter season, where mechanical thickener press is used and consumes a lot of polymer in its drying operations. Fig. 1 depicts general scheme of Nablus WWTP.

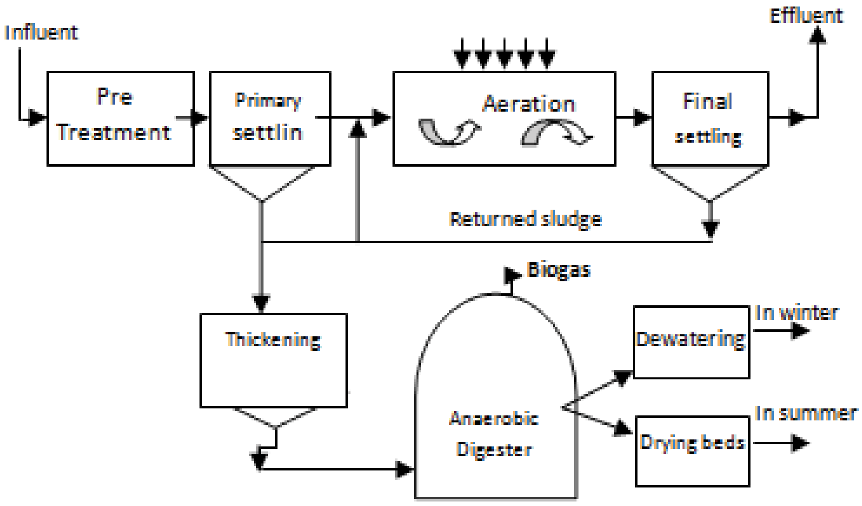


Figure 1. Nablus WWTP's unit scheme

Power consumption of Nablus WWTP

Treatment units in the plant are controlled and supplied by energy from special motorized control centers. All MCCs are fed by energy from main distribution panels (MDP). Five MCCs are distributed in the plant and feeding their treatment units by energy. Table I summarizes MCCs and their related treatment units.

TABLE I. MCCS' TREATMENT UNITS

MCC Number	Related Treatment Units
MCC1	Screens, Septage station, Grit chamber, Primary Settling unit
MCC2	Biological aeration unit (two tanks)
MCC3	Primary thickener, Mechanical thickener, Secondary thickener, Mechanical dewatering
MCC4	Digester tank, Heating & recirculation room, Gas balloon, Gas flare, Blending tank
MCC5	Return activated sludge station, Booster station, Final settling unit, Streets lights and buildings

Power consumptions of the MCCs were monitored in daily and monthly bases. Average power consumption for each MCC was calculated. The average annual power consumption of the plant was 2,261,762 kWh. It is calculated by taking the average consumption from January until the end of July 2014. As shown in Fig. 2, most of the plant's power is consumed in the biological unit. The high power consumption is relating to surface aerators which consume a lot of energy (68 kilowatt/aerator). Each tank in the unit has eight surface aerators, four mixers, and one motorized gate.

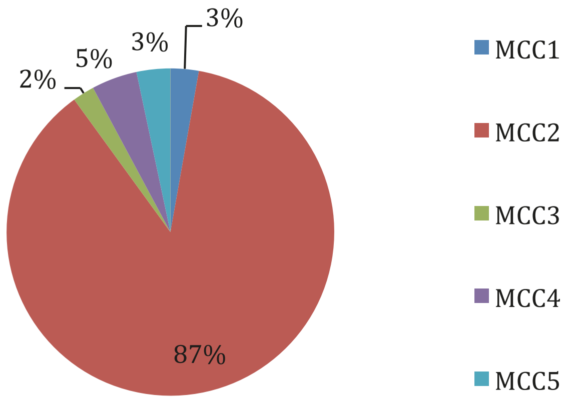


Figure 2. Percentage of MCCs' power consumption

GREEN ENERGY SCENARIOUS AND RESULTS

Main renewable energy sources in Palestine are solar energy, biomass, and wind energy. Palestine is one of the leading countries on using solar energy. The daily average solar radiation in Palestine was determined in comparable with long term measurements in Jordan to be 5.4 kWh/m2/d [2]. Jericho WWTP has started to use photovoltaic cells as green energy source. Jericho photovoltaic cells are producing 1200 kWh/d. Palestinian people are using Jift (solid waste of olive mills) in household for heating in winter season. There are many examples of using fecal solids of animals as a source of energy in some agricultural activities. But till now, no clear studies had been done to assess its potential production of biogas. Regarding to wind energy, Palestine has moderate wind speeds which inhabit the application of using wind mills. Nablus has an average wind speed reached to 4 m/s. It is not feasible to use wind energy for electric generation if the wind speed is not in the range of 6 to 20 m/s [3].

Finally, the proposed green energy sources for Nablus plant will depend on biogas utilization and solar energy. In the following, the study will explore the application of these green energies on Nablus WWTP.

Biogas utilization scenario

In Nablus WWTP, biogas is utilized to supply the anaerobic treatment by thermal energy which needed to raise the process temperature at 36 ºC. By using special filters of stones and ceramic, biogas is pretreated and then burned in a boiler. Pretreatment is necessary to get rid of undesired humidity and hydrogen sulfide gases. The future scenario which could be done is utilizing the biogas through a CHP unit. In CHP unit, biogas is burned in an engine generator and generates electricity. In the internal combustion engine of the generator, there is a jacket of water that produces thermal energy for anaerobic process. The average daily production of biogas in Nablus plant is 3080 normal cubic meter per day (Nm^3/d). Table II shows the parameters and values which used and resulted in the calculations of needed thermal energy for digestion process. The results depend on real data of temperature from the plant readings.

Table ii. Current utilization of biogas

Table Head	Values and Results
Daily Sludge feed to the digester	180 m^3/d
Average temperature in the last year sludge	20.8 ºC
Average weather temperature in the last year in the plant site	18.2 ºC
Thermal energy losses from tank surface and piping losses respectively	(836)+(1975) kWh/d
Thermal energy for sludge heating of feed	4115 kWh/d
Total thermal energy consumed per day	6926 kWh/d
Equivalents of digester gas quantity	**787** Nm^3/d

The current strategy of utilizing the biogas of the plant is wasting a lot of biogas quantity which not used and sent to the gas flare. Installing of CHP unit will utilize the plant biogas to generate electricity and supply thermal energy. If the CHP unit is not enough to produce needed thermal energy for the process, Boiler can utilize the biogas to substitute the deficit in thermal energy which produced by CHP. Calculations' results for CHP scenario are depicted in Table III.

Table iii. Chp scenario for utilizing the plant biogas

Technical information	Value and Results
Produced amount of biogas	3080 Nm^3/d
Utilized amount of biogas in CHP unit	2200 Nm^3/d
Possible CHP module size for available biogas	229 kWel
Selected module size	220 kWel
Availability of the CHP in operation/year	78 %
Electrical efficiency	41 %
Thermal efficiency	43 %
Overall efficiency	84 %
Own use electrical energy	15 kWel
Average electricity production	1,401,000 kWhel/y
Average heat production	1,462,507 kWhth/y

CHP scenario results showed no full recovery of electrical and thermal energy which needed by the plant. The electrical and thermal energy deficits were 860,762 and 1,112,200 kWh/y respectively. On this scenario, biogas quantity is considered as a limiting reagent to recover whole energy consumption of the plant.

Photovoltaic cells scenario

Photovoltaic scenario has no limitation as CHP unit and it can recover the whole electrical consumption of the plant. The location of cells could be in the same location of the sludge drying beds unit. The plant has eleven constructed beds, each one with an area of 1035 m2. This scenario will use the beds as a location for the calculated cells. Digested sludge will dry by mechanical dewatering machines instead of the beds for whole the year. This scenario will depend on the current strategy of biogas utilization for supplying the digester by thermal energy.

Table iv. Photovoltic solar cells scenario

Characteristics	**Value and Results**
Average yearly power consumption	2,261,762 kWh/y
Average daily power consumption	6197 kWh/d
Sun hours per day in Nablus	5.4 hr/d [3]
Theoretical daily power generation	1147 kW/hr
Derate ratio	77%
Real daily power generation	1490 kW/hr
Solar cells (found in local market)	0.250 kW/cell
No. of cells needed	5962
Cell dimensions (length×width)	1.64×0.99= 1.62 m^2
Area Needed for installation	9656 m^2
Drying Beds needed for cells	10 beds from 11
Needed inverters (30 kW)	50

Hybrid scenario (Biogas and Photovoltaic cells)

This scenario will treat the electrical deficits of CHP scenario by installing of photovoltaic cells. Thermal energy deficit will be covered by burning unutilized biogas in the special boiler of the plant. This boiler can work by biogas or diesel. The quantity of biogas which used in CHP scenario was 2200 Nm^3/d from 3080 Nm^3/d. The biogas difference can be utilized in the boiler instead of sending it to the gas flare. The quantity of biogas which is not utilized in the CHP unit is more than the quantity of biogas needed by the boiler for thermal energy supplying.

Table v. Photovoltaic solar cells to cover the deficit

Characteristics	Value and Results
Average yearly electrical deficit	860,762 kWh/y
Average daily electrical deficit	2358 kWh/d
Sun hours per day in Nablus	5.4 hr/d
Theoretical daily power generation	437 kWh/hr
Derate ratio	77 %
Real daily power generation	567 kW/hr
Solar cell	0.250 kW/cell
No. of cells needed	2269 cells
Area of one cell	1.62 m^2
Area needed for installation plus safety for cells clearance 43 m^2	3718 m^2
Drying Beds needed for cells	≈3.5 beds from 11
Needed inverters (30 kW)	19

Table vi. Biogas needed for covering thermal energy deficit

Characteristics	Value and Results
Volume of biogas needed	521 Nm^3/d
Calorific value of digester gas	6.5 kWh/m^3 [4]
Theoretical thermal energy	3386 kWh/d
Theoretical thermal energy	1,236,073 kWh/y
Efficiency of boiler	90 % [5]
Real thermal energy produced	1,112,465 kWh/y
Thermal energy deficit by CHP was	**1,112,200** kWh/y

This scenario satisfies full energy recovery for the plant and more redundancy. Also, it takes into consideration an excess quantity of biogas as a safety factor to overcome operation variables. Around 360 Nm^3/d of biogas will be the contingency quantity for CHP and boiler during low biogas production days. The location of photovoltaic cells will occupy 3.5 drying beds (3675 m^2) and will keep other drying beds in operation. Also it is possible to use the roof of units' buildings as an area of installation.

Scenarios Results Analysis

Cost calculations have been done for each scenario and results showed in Table VII. Capital cost was calculated for photovoltaic cells according to the Palestinian local market. The capital cost of photovoltaic cells includes cells, invertors, and installation prices. The capital cost of the CHP unit includes generator machine, building construction, and mechatronics & civil planning prices. The price (including taxes) for the installed 250 watt cell and 30 kW inverter are 952, 16936 NIS respectively. The CHP capital and operation cost was taken from German supplier [6].

Table vii. Cost and scenarios comparison

SCENARIOS	CHP	PV	HYBRID (CHP & PV)
Recovery %	38%	100%	CHP =38%, PV=62%
Capital Cost (NIS)	1,400,000	6,523,000	1,400,000+2,482,000= **3,882,000**
Maintenance Cost (NIS/25y)	5,075,000	500,000	5,325,000
Electricity cost savings (NIS/25y)	11,602,840	30,534,000	30,534,000
Salvage value (NIS) (CHP=20, PV=15)%	280,000	980,000	280,000 + 372,300 = **652,300**
Net profit per 25 y	4,847,840	22,530,000	20,675,000
Annual Profit (NIS)	193,913	901,000	827,000
Payback period (y)	7.2	7.2	4.7
Area needed(m^2)	0	10,300	3,630

The comparisons show hybrid scenario as the best scenario in terms of payback period, beds used and redundancy. With a total capital cost of 3.9 million NIS, Nablus plant will satisfy full energy recovery. Yearly operation cost of the scenario contains the maintenance, operators, insurance and management of the CHP unit. Operation cost was calculated (as lump sum) 20000 NIS/y for the photovoltaic scenario and 10000 NIS/y for the cells in the hybrid system. The difference in operation cost was related to the number of cells in the different scenarios. Knowing that local suppliers of the cells are offering 25 years of insurance and no batteries needed when they are connected as on grid system.

CONCLUSIONS

- Nablus WWTP has anaerobic digester which produces biogas. Biogas can be utilized in a CHP generator and decrease the electrical consumption by 38% and achieve full recovery of thermal demand for the process with operating of biogas boiler.
- Hybrid energy scenario is the most preferable scenario to achieve full energy recovery with payback period of 4.7 years. It provides more reliability and will increase the redundancy in terms of energy sources in the plant.
- Photovoltaic cells scenario will occupy 10 drying beds from 11, and will affect drying operation process cost.

RECOMMENDATIONS

- Conduct campaigns to raise the importance of renewable energy in WWTP's among the municipalities.
- Collect Blood of Nablus slaughter houses and feed it to the plant digester after screening will enhance biogas production and save energy.

ACKNOWLEDGMENT

Warm thanks go to Nablus Municipality represented by its Mayor Mr. Ghassan Al-Shakaa for their support and guidance which allow us to be inventive and find ways for saving environment. Authors would also like to thank Eng. Hani Shraideh, and Mr. Christensen for their truthful support.

REFERENCES

[1] C. H. Laugesten, O. Fryd, T. Koottatep and H. Brix, Sustainable Wastewater Management in Developing Countries: new paradigms and case studies from the field, American Society of Civil Engineers, 2010, pp. 147-153.

[2] I. Ibrik, Initial Assessment of the Contribution of Renewable Energy Technologies in Arab Mediterranean Countries, Published paper at the advanced seminar on Solar and Wind Power Energy, Pamplona, Spain, 2006.

[3] M. Mason and A. Mor, Renewable Energy in the Middle East, London: Springer, 2009, pp. 82-87.

[4] M. Gareth, Evans, C. Furlong, Environmental Biotechnology, Wiely, 2011, pp. 239-240.

[5] F. Peter and S. Gilkinson, 27 Months Performance Summary for Anaerobic Digestion of Dairy Cow Slury at AFBI Hillsborough, Agri-Food and Biosceinces Institute, 2011, pp. 3-4.

[6] Passavant-Roediger GmbH is a German-Based Subsidiary of Drake & Scull International PJSC, International Company, Germany, 2014

السادة / الجمعية العربية لمرافق المياه (أكوا)

تحية طيبة وبعد،

أرجو إعلامكم بأن المصنف بعنوان " **Reader Energy Efficiency in the MENA region Good Practices from ACWUA Members**"، إعداد: **Arab Countries Utilities Association (ACWUA)**

قد تم منحه رقم إيداع في مركز الإيداع في دائرة المكتبة الوطنية تحت رقم الإيداع المبين أدناه.

يرجى العمل على تثبيت هذا الرقم كما هو مدون أدناه، في أي مكان ظاهر من المصنف، وتسليم مركز الإيداع ثلاث نسخ على سبيل الإيداع وبحيث تكون النسخ المودعة مطابقة للمصنف من جميع الوجوه ومن أجود النسخ المنتجة، وذلك استنادا لأحكام المواد (38، 39، 40، 41) من قانون حماية حق المؤلف رقم (22) لسنة 1992 وتعديلاته، وأحكام نظام إيداع المصنفات رقم (4) لسنة 1994 م.

واقبلوا فائق الاحترام،،،

The Hashemite Kingdom of Jordan
The Deposit Number at The National Library
(2016/4/1861)
يتحمل المؤلف كامل المسؤولية القانونية عن محتوى مصنفه ولا يعبّر هذا المصنف عن رأي دائرة المكتبة الوطنية أو أي جهة حكومية أخرى.

ACWUA
Arab Countries Water
Utilities Association

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH