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Project title: "Opportunities and barriers to implementing energy efficiency in selected pumping installations in Kenya"

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Mechanical Engineering (Industrial Engineering option) in the University of Nairobi, Department of Mechanical and Manufacturing Engineering.

By

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Declaration

This is my original work and has not been presented for a degree in any other university.

Approval

This thesis has been submitted for examination with our approval as university supervisors.

Dr. Alex A. Aganda	Signature alex aganda
Dr. Julius O. Ogola	Signature....................

DEDICATION

To my daughter Becky , my sons Brannon and Bradshore.

ACKNOWLEDGEMENTS

I am grateful to my supervisors Dr. Alex Aganda and Dr. Julius Ogola whose ideas and insight provided the clarity in choosing my research topic and more so for their guidance throughout the research period.

I am indebted to the management and employees of Kenya Pipeline Company limited and Nairobi water and sewerage services for the support they gave during the time I was in the field collecting data. To my various friends and contacts in the various organizations that I paid short visits throughout the whole country and to my beloved wife Miriam for the continual encouragement as one deadline after another passed by.

ABSTRACT

This project was aimed at evaluating opportunities and barriers to implementing energy efficiency in 5 selected pumping installations-viz Kenya Pipeline Company, Nairobi Water and Sewerage Company, Nzoia Sugar Company, Davis and Shirtliff, and SpinKnit Diary. This would give insight into energy utilization, efficiency and provide information as to the barriers encountered in implementing energy efficiency measures in the pumping systems. In this study, energy efficiency refers to the ratio of the energy imparted to the fluid to electrical energy or oil energy supplied.

The study involved surveying of selected pumping installations in the country to identify energy saving opportunities and to investigate the nature of barriers to implementing energy efficiency. The study was conducted by identifying installations in Kenya whose core business involved mainly pump systems. Data collection was by the use of interviews, observation and questionnaires. Data was analyzed and recommendations were made on the measures to minimize the effects of barriers to realizing effective energy efficiency.

In four out of the five installations surveyed it was not possible to determine at what efficiency the pumps were being run. This was due to lack instrumentation and manufacturers performance data of the pumps. However, in one of the installations (Kenya Pipeline Company) there was adequate instrumentation to enable quantification of energy saving potential. Except for one pump in one installation (Nairobi Water and Sewerage Company) all pumps were driven by electric motors. Indeed most of the motors were 10 years more old and some had been rewound. In all installations motors were directly coupled to the pumps except in one major system where gearboxes were used to vary the speed between the motor and the pump and fluid coupling was employed. Also evident were poor pump and motor matching in one of the installations as well as wide spread valve throttling method of pump control. Preventive maintenance was also poor as shown by fluid leakages in the pipe networks.

Tackling all these opportunities will lead to improved energy efficiency of the systems. However a number of obstacles and barriers existed in these installations that had made it difficult to realize the energy saving opportunities. One of the problems encountered in all the five installations is lack of

technological knowhow of the performance parameters of pumping systems. Secondly lack of information on existing more efficient equipment. Thirdly company policy and management structure had not put energy efficiency as a major concern. Management of all the companies seemed to be concerned more on product output than on energy used and cost and hence energy efficient measures were never taken as an immediate priority.

To improve energy efficiency and therefore reduce energy use and cost in pumping installations, up to six measures could be implemented and this would require overcoming at least four existing barriers.

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NOMENCLATURE

AGO-Automobile Gas Oil

ASDs- Adjustable Speed Drives

BEP- Best Efficiency Point

BHp- Brake Horsepower

CDM-Clean Development Mechanism

CIPEC-Canadian Industry Program for Energy conservation

EE- Energy Efficiency

EEMOD- Energy Efficiency in Motor Driven systems

EMCAT- Energy Management Consultation and Training project

GPM- Gallons per minute

H. I. –Hydraulic Institute

HEM- High efficiency motors

Hp- Horsepower

IEA- International Energy Agency

IK-illuminating kerosene

JIG-joint international group

KIPPRA-Kenya Institute for Public Policy Research and Analysis

KOSF-Kenya Oil Storage Facility

KPC- Kenya Pipeline Company

KPRL- Kenya Petroleum Refineries Limited

kW- Kilowatt

MEPS- Minimum Energy Performance Standards

MSP- motor spirit premium

MSR-motor spirit regular

NEMA-National Electrical Manufacturers Association

NPSHr-Net positive suction head required

NRCan- Office of Energy Efficiency of Natural Resources

OEE- Office of Energy Efficiency- America

OIT-office of industrial technologies

PFD-process flow diagram

PS-pump station

RMS-root mean square

RPM- Revolutions per minute

SF- service factor

TDH-total discharge head

U.S. DOE- United States Department of Energy

VFD- Variable frequency drive

VSD-Variable Speed Drive

WHp-Water Horse power

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

The energy policy in Kenya has evolved through sessional papers, regulations and Acts of Parliament. The focus was on the electricity and petroleum sub-sectors. The sessional Paper No. 10 of 1965 dwelt on the Electric Power Act (CAP 314) that was used to regulate the sector. This was followed by the sessional Paper No. 1 of 1986, which however, did not focus much on the power sector. The sessional paper called for the establishment of the Department of Price and Monopoly Control (DPMC) within the Ministry of Finance. Under new legislation, the department was to monitor action in restraint of trade and to enforce pricing in the various sectors. This also included the petroleum sub-sector. All this did not address energy efficiency [2].

With increased cost of energy, for instance the sharp increase in Kenya's energy price (e.g. price per liter of premium petrol varied from Kshs. 58 to kshs.116 between 2007 and 2012) and scarcity of energy, policy makers have had to intervene in the management of the available energy that has led to the need of efficient energy utilization and hence the cost of energy. The high cost of energy adversely affects industry profitability, competitiveness and general economic growth which results into loss of jobs and increase in poverty. Efficient utilization of available energy especially by industry is one means of reducing the overall cost of energy and therefore increases profitability and competitiveness. In 2004, the Ministry of Energy developed the sessional Paper No. 4 of 2004 which considered energy efficiency for the first time [2].

Energy efficiency also results from ongoing technological progress, competitive forces pressuring businesses to cut all types of costs including energy costs and from government by implementing wide range policies and programs such as funding research and development (R&D), energy efficiency standards, educational efforts, obligations on market actors and financial incentives to accelerate the development and adoption of energy efficiency measures [3].

Energy efficiency is considered as an alternative to energy supply options such as conventional power plants that produce electricity from fossil or nuclear fuels. It is emerging as a key policy solution to address high energy costs and the threat of climate change [2, 4].

The two main advantages of promoting energy efficiency therefore are to preserve natural resources and to minimize damage to the environment. Environmental damage can occur from emissions produced during the manufacturing of products, the generation of power needed for processing, the disposal of wastes and the disruption of the natural environment [1].

Industry uses nearly 40 percent of worldwide energy to produce materials and products on a daily basis. In the process it contributes to CO_2 emissions and almost 37 percent of global greenhouse gas emissions (GHG). At the same time, substantial inefficiency in the production and consumption of energy impedes economic growth and development [5, 6, and 7].

Industry must therefore make energy management a key factor in the whole production process because efficient utilization of available energy by industry is one means of reducing the overall cost of energy thereby increasing profitability, competitiveness and reductions on environmental degradation through the reduction of CO_2 emissions and Green House effect. Energy efficiency management encompasses taking advantage of opportunities and overcoming barriers to these opportunities [7].

Like any other organizational function, the success of energy efficiency management system depends on four factors; technical and managerial capacity, top management support and monitoring of energy implementation plans [8].

Major technical and managerial capacity opportunities exist for improvements in energy efficiency through end-use technologies. These opportunities for performance improvements and reduction in energy cost can be achieved in a number of ways; firstly, the proper system design. Proper system design implies designing the system to meet the required needs. Secondly, proper selection and operation of system equipment is essential. The selection considers use of high efficiency equipment that has the potential of significant energy savings and finally effective maintenance [1].

Studies of existing systems provide a greater opportunity for savings than do new systems for two reasons. First, there are at least 20 times as many systems in the installed base as are build each year. Secondly, many of the existing local systems have equipment and controls that were designed long time ago when the recent consideration of energy costs and efficiency was not important. Rapid changes in technology have also brought about changes in operations and maintenance of equipment [7].

Despite energy efficiency being often the least expensive way for businesses to reduce GHG emissions which also comes with added benefits of reduced operational costs and risks, there remains a gap between the available energy efficiency measures and those actually undertaken by companies creating enormous opportunities for improving the energy efficiency. This gap exists due barriers in implementing energy efficiency measures in organizations [9].

It is argued that although the operational, design and maintenance interventions required to tackle the efficiency problem are rather simple from the technical sense, lack of awareness, poor technical capacity and organizational structure and bad finances are impeding their implementation [10]. These barriers have been a hindrance in the implementation of energy efficiency measures leading to use of huge quantities of energy by end use technologies. One such end use technology is the pump systems.

Pump systems represent about one quarter of the total electricity consumption of all motor systems in the United States of America. In Europe, they account for about 20 percent of industrial electricity demand [12]. The situation for Africa and Kenya in particular is not clear. There is no sufficient information documented to quantify the sectors' contribution to the total energy consumed. Therefore in view of the worldwide increase in energy costs, more attention pertaining opportunities and barriers must be given to the energy economics of pumping installations as a whole [11, 12].

There exists opportunity to achieve 20 to 60 percent improvements in energy costs of already installed pumping systems while improving pump and process reliability. This is because already installed systems have either old inefficient equipment, poor system design and could have even had a change in the pumping need. Hence an assessment of pumping system performance is an opportunity to qualify and quantify best energy efficient measures for overall system's low cost [13].

In this project, an attempt was made to identify opportunities and barriers to implementation of energy efficient measures in pumping systems. Opportunities to energy efficiency were mainly technical in the nature in relation to the installations operations while the barriers were mainly as a result of the managerial aspects of the installations operations. Identification of the opportunities and implementation of those opportunities by overcoming the barriers to their implementation is important because optimization of the installations energy use may result in significant energy savings and hence cost savings. The assessment focused on large installations whose purposes were mainly pumping.

1.2. STATEMENT OF THE PROBLEM

The high cost of energy is one of the significant constraints to economic growth in Kenya and other countries in the region. The cost of energy is a major challenge to the manufacturing sector and other industries. One means of reducing energy costs is to ensure that the available energy is used in the most efficient manner. To this end, industrial processes and equipment must be designed, operated and maintained such that minimum energy is wasted. However due to existence of barriers, the opportunities existing in improved design, operation and maintenance of industrial equipment are not always implemented leading to wastage of energy.

In large installations, pumping systems are known to waste a significant amount of energy. This is because these installations are old, poorly designed, operated and maintained. They also have efficiency which is not clear. In Kenya, statistics of various sector contributions to the total energy consumed by the manufacturing sector is not clearly documented. This state is the same for pumping systems. However, energy now accounts for up to 50% of the sector’s production costs in industrialized nations [14, 15, and 16].

This project aimed at surveying 5 pumping installations with the view of determining the opportunities and barriers to implementing energy efficiency so as to provide information on the energy use in pumping systems in the country. This information could assist in improving the systems’ energy performance resulting in major savings in energy and therefore cost. It was therefore important to look at the performance of existing systems and identify opportunities and barriers for improved system designs, operations and maintenance and organizational energy management practices.

1.3. JUSTIFICATION

The study aimed at identifying opportunities and barriers to implementing energy efficiency in selected pumping installations. The identified opportunities and barriers could assist in putting in place management strategies, policies and regulations for improving energy efficiency and planning for energy (generation and utilization) in Kenya.

Greater energy efficiency in pumping systems could save consumers and businesses money while reducing the adverse environmental impacts associated with energy production, conversion and use [17]. In particular, good preventive maintenance programs could help reduction of leakages along the pipe networks for Nairobi Water and Sewerage Company. This could minimize the energy wasted in pumping the water not delivered to the consumers while conserving the same resource by minimizing wastages arising from leakages. Removing long couplings between motor and pump could reduce the energy wasted at every stage of the long coupling; this could also reduce the maintenance problems encountered in aligning the long couplings to reduce vibrations. Improving pump motor match could also save energy as motors perform well at 75 percent of the rated load below and above this the performance drops significantly. At the same time use of new equipment that have been manufactured considering energy efficiency characteristics like high efficiency motors could also save energy. Finally, installation of metering instruments could assist in monitoring the energy performance of the pump system equipment and provide information for real time corrective actions when required. This could minimize energy wastages and enhance energy efficiency which could not be the case without proper instrumentation.

However the above actions could not be possible if the barriers to implementing these opportunities were not overcome. Installations could train staff on the operating parameters of the pumping equipment in use at the installations as per the recommendations of the manufacturers. This could help staff to be aware of the of the best efficiency points of pumping systems either in terms of individual equipment(component approach) or a system as a whole(system approach). All equipment in the installations could be labeled clearly with the manufacturers operating parameters. This could enable proper equipment matching e.g. pump and motor match. At the same time this could assist in maintenance personnel ensuring that the recommended manufactures operating parameters are maintained after repairs for energy efficiency and also facilitate in the identification of the energy efficient equipment from those that are not energy efficient. Thirdly company policy and management structure could put energy efficiency as a major concern for example energy efficiency departments could be developed to facilitate the implementation of energy efficiency measures. Finally the Management of all the companies could give the same focus on energy used and cost as was given to the products produced. This will strengthen energy efficiency measures.

1.4. OBJECTIVES

The overall objective of the study was to identify and quantify where possible energy efficiency opportunities and the barriers to implementing the identified opportunities.

The specific objectives are the following;

1. To determine factors affecting energy efficiency of selected pumping installations.
2. To establish the opportunities for increasing energy efficiency in the selected pumping installations.
3. To establish the barriers to implementing effective energy savings.
4. To determine measures to minimize the effects of barriers to realizing expected energy efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1. ENERGY EFFICIENCY IN PUMPING SYSTEMS

Kenya is making strenuous efforts to find indigenous alternatives to petroleum oil besides the endless search for oil itself. However, this can only be viewed as a long-term solution to the energy problem. There is still a short-term need to secure additional energy resources to assist the industrialization process. A possible solution that has been successfully demonstrated is the concept of conservation through improvements in the efficiencies and utilization of energy resources [18, 19].

It has been demonstrated [20] that through a combination of technological innovation in process and equipment and a systematic monitoring of actual consumption, energy savings up to 80% could be achieved. Indeed this can be achieved by technological innovation in process design, operations management and equipment and system maintenance.

There is considerable technical potential for improving industrial energy efficiency and the economics appear favorable, even without putting a price on carbon emissions [21]. Such improvements frequently involve the adoption of established technologies whose performance is well proven and which involve relatively little technical risk. Many studies [22], suggest that these technologies are highly cost-effective, with risk-adjusted rates of return greatly exceeding the anticipated cost of capital. Even greater savings can be realized in developing countries where old, inefficient technologies are commonly used. Savings may also be made through optimizing system design and improving operational and maintenance procedures while many technologies have productivity benefits that extend well beyond energy-saving [6].

Energy efficiency varies dramatically across industries and manufacturing processes, and even between plants manufacturing the same products. Efficiency can be limited by mechanical, chemical, or other physical parameters, or by the age and design of equipment. In some cases, operating, maintenance practices and overall management practices, policies and organizations' culture contribute to lower than optimum efficiency [23].

The following is a comparison of typical energy efficiencies of selected energy systems and industrial equipment; power generation 25-44%, steam boilers (natural gas) 80%, steam boilers (coal and oil) 84-85%, waste heat boilers 60-70%, thermal cracking (refineries) 58-61%, EAF Steelmaking 56%, paper drying 48%, graft pulping 60-69%, distillation, column 25-40%, cement calciner 30-70%, compressors 10-20%, pumps and fans 55-65%, motors 90-95% .It can be seen that pump systems which is a combination of a pump and motor provide one of the highest combined efficiencies and also are among the most used equipment in industry [23].

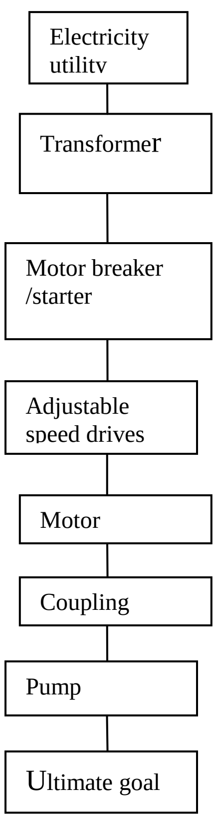
Pumping systems are wide spread and are applied in areas such as food and chemical. A typical process plant can have a pump population of up to 2,000 units [24]. Pumps are the largest single application of electric motors and therefore according to the Hydraulic Institute [25], optimizing pumping system efficiency has the potential to achieve up to a 50% improvement in energy costs while improving pump and overall process reliability. Pumping systems account for nearly 20 percent of the world's electrical energy demand and account for 25-50 percent of the energy usage in many industrial operations [24]. The study conducted by the United States Department of Energy [26] states that 16% of a typical facility's electricity costs are for its pumping systems.

Plant-wide energy assessments of pumping systems identify the best opportunities to improve overall operations and the efficiency of pumping installations. Losses inside the pumping installations are substantial and companies can realize significant energy efficiency gains from improvements in the designs, operations and maintenance of pumping systems [26].

2.2. EFFECTS OF SYSTEM DESIGN AND SELECTION TO ENERGY EFFICIENCY

Pump system design is the process of defining the architecture, components, modules and interfaces for a pump to satisfy specified pumping requirements. Proper pumping system design is an important element in minimizing the energy costs [7]. A typical pumping system comprises of a pump, a driver, pipe installation, and operating controls and each of these elements should be considered individually. The design phase of a pumping system involves, starting with the end use (head and discharge) and working backwards by appropriately sizing the piping, pump and matching it with the motor and associate couplings [27].

Pump system components are chain links considered working as a single unit hence the system approach. Typically comprise of the following; pump, motor, couplings and gear boxes, control system and delivery system as illustrated in flow chart 2.1



Flow chart 2.1: shows typical pump system equipment layout linked and working together as a single unit –system approach.

Some links are primary and produce kinetic energy for movement and include pumps, motors, couplings and gearboxes. The control system and delivery system are secondary links [28]. This is the system approach which views the all the components of the pumping system as a unit and considers the effects of the poor design of one component on the other components.

Comparing the component approach and the system approach, the system approach provides greater potential for energy efficiency. The system approach accurately matches system flow and pressure output to process requirements. This approach can obtain energy savings of 20% to 50% compared with savings of 3% to 15% with component efficiency improvements [29].

Pumps are typically purchased as individual components; they provide a service only when operating as part of the system. The energy and materials used by a system depend on the design of the pump, the design of the installation and the way the system is operated [30].

Pumps are categorized into two main categories; Rotodynamic (centrifugal) and Positive Displacement. Rotodynamic pumps represent 73% of the pump population and hence the greatest energy savings opportunity [10]. Centrifugal pumps are widely used because of their relatively simple operation and low cost and they offer the most opportunity for efficiency improvements. Pump efficiency is a function of volumetric efficiency, mechanical efficiency and hydraulic efficiency [31].

The overall savings of energy with rotodynamic pumps can be as high as 40% with the break down as follows: selecting a higher efficiency pump- 3%, selecting a better sized pump- 4%, better system design -10%. This statement emphasizes the fact that proper knowledge and information at the design stage of the system provides good opportunity for energy efficiency.

Several factors need to be considered when designing a pumping system as a whole starting with the general process demand estimates, population and fluid consumption estimates. These are the basis for determining the flow demand of a fluid supply and distribution system.

Flow and pressure demands at any point of the system are determined by hydraulic network analysis of the supply, storage, pumping, and distribution system as a whole. Supply point locations and storage reservoirs are normally known based on a given source of supply or available space for a storage facility [32].

The selection of pumps involves the computation of total head against the discharge, normally called as the duty of pumps. The total head incorporates the static head, frictional head in the pipe, velocity head and other head losses in the valves, pipe specials etc. Static and pressure heads remain constant in most systems. It is the friction head that varies with the pump's capacity that is friction loss varies by approximately the square of the resistance. Twice as much flow produces almost four times the friction loss [33].

Other head losses in the valves, pipe fittings are normally taken as 10% of the static head and friction head. However it has been found that the other losses computed at 10% are always on the higher side, making the system total head lesser than the design total head arrived at. This deviation result in the change of duty point, shifting the operating point to lesser efficiency, consuming more power (often over loading) and pumping more discharge. Therefore, it is imperative that the other losses calculated should be precise [33].

A survey of popular pump brands demonstrates that pump efficiencies range from 15% to over 90%. The question then arises, "Is this very wide range due to poor selection, poor design, or some other variable which would interfere with good performance?" The best available evidence suggests that pump efficiency is directly related to the specific speed number with efficiencies dropping dramatically below a number of 1000. Testing also shows that smaller capacity pumps exhibit lower efficiencies than higher capacity designs [34].

Computations of total head against discharge are important factors when selecting a pump hence flow and head are much more important variables in determining pump horsepower drawn than pump efficiency alone in a fluid pumping system. The fact that flow varies approximately with the square root of head change provides a safety factor in terms of head estimation in piping systems. A flow tolerance of ±10 percent provides a head tolerance of about ±20 percent [35].

The head (h) in meters generated by a centrifugal pump can be expressed as:

$h = AN^2 + BNQ + CQ^2$. -- (2.1)

Where h is head, N is rotational speed, Q is flow rate, and A, B and C are constants for a given pump and impeller. This equation was used in the plotting of the pump characteristic curve for Kenya pipeline as shown in Appendix 6.3.2.2 (sample calculations). For the typical case of a pump operating at constant speed, this head-vs.-capacity equation can be rewritten as:

$h = a + bQ + cQ^2$. -- (2.2)

The constants a, b and C are for a given speed.

This equation compares favorably with a much simplified equation i.e.

$H = h + aQ^2$. -- (2.3)

Where, H is the total head (m).

h is the static head(m).

a is a constant which is the function of the flow.

Q is the flow rate (m^3/s)

This equation was used to determine the friction factor as in Appendix 6.3.1.4.

Power consumed to overcome the static head in a pumping system varies linearly with flow and very little can be done to reduce the static component of the system requirement [37].

Several energy and money-saving opportunities exist to reduce the power required to overcome the friction component of the pumping system. The frictional power required is dependent on rate of flow, pipe size (diameter), overall length of the pipe, pipe characteristics (surface roughness, material, etc.) and properties of the liquid being pumped [38].

In order to minimize energy consumption within the pumping system, a pump should be selected that has a system curve which intersects the pump curve within 20% of its BEP; then select a midrange impeller that can be easily replaced to meet higher or lower flow rate requirements [39]. This is as illustrated in figure 2.1 for single size impeller and figure 2.2 for different sizes of pump impeller.

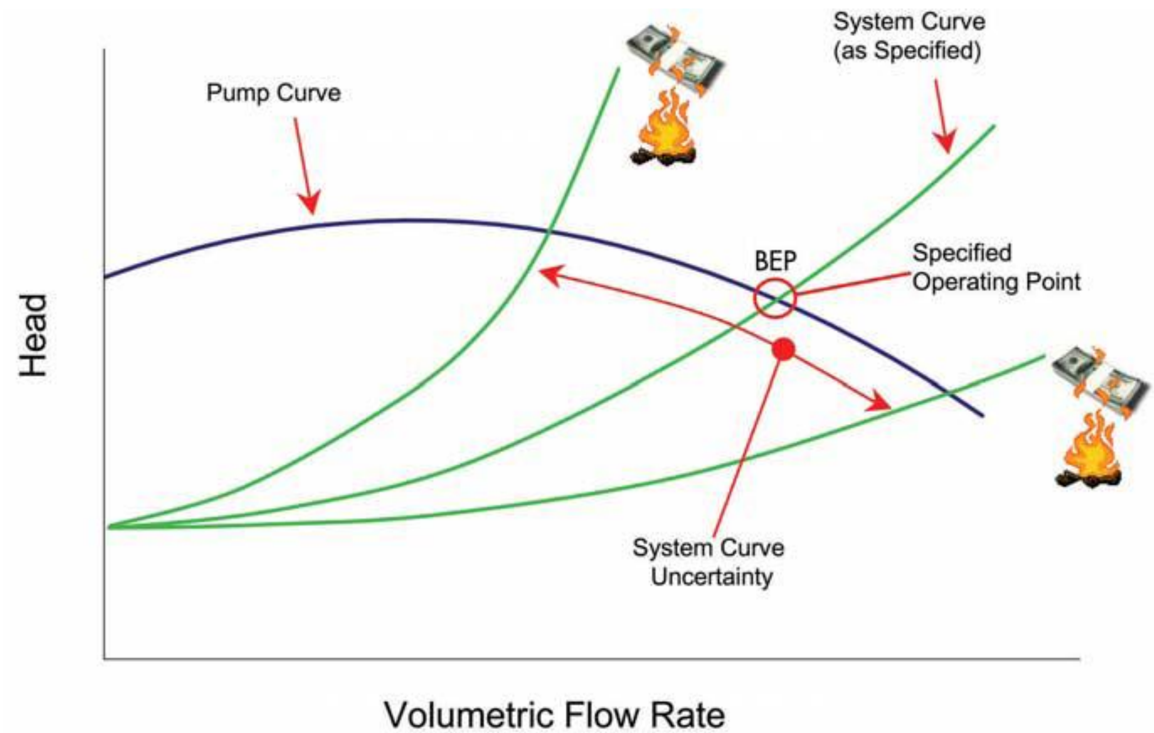


Figure 2.1: pump system B.E.P and system uncertainty due to change in pumping need.

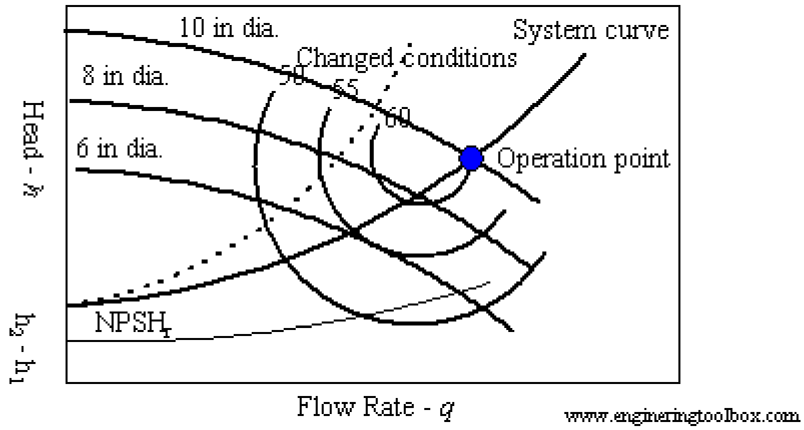


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Figure 2.2: pump system operating point and system uncertainty for different impeller sizes.

The system curve is a plot of the Total Head vs. the flow for a given system. The higher the flow, the greater the head required .The shape of the system curve depends on the type of system being considered. The system curve equation for a typical single outlet system is [40]:

$\Delta H_{P\,(q)} = \Delta H_{F\,(q)} + \Delta H_{EQ\,(q)} + \Delta H_{V\,(q)} + \Delta H_{TS}$. -- (2.4)

Where;

$\Delta H_{p\,(q)}$ = Total head

$\Delta H_{F\,(Q)}$ = Frictional head

$\Delta H_{EQ\,(q)}$ = Equivalent head of the pipe fittings

$\Delta H_{V\,(q)}$ = Velocity head due to fluid flow

ΔH_{TS}= Total static head

This equation was used to determine pressure drop as shown in Appendix 6. 3.1.2.

The system generating dynamic head comprises of the pipeline with the associated fittings. Pipes, elbows, valves, check valves, filters, sprinklers, bubblers, and a host of other special purpose components deliver the fluid to the desired use point. Overlooking efficiency for these components can waste a lot of energy. The money saved by installing undersized pipe and inefficient components may be far overshadowed by the energy waste over the lifetime of your system. System performance will normally be poorer as well [41].

For a particular desired flow, the flow velocity will be dependent on the pipe size. For normal liquid (water) service applications, the acceptable velocity in pipes is 2.1 ± 0.9 m/s at piping discharge points including pump suction lines and drains. As stated, this velocity range is considered reasonable for normal applications. However, other limiting criteria such as potential for erosion or pressure transient conditions may overrule. In addition, other applications may allow greater velocities based on general industry practices; e.g., boiler feed water and petroleum liquids. Pressure drops throughout the piping network are designed to provide an optimum balance between the installed cost of the piping system and operating costs of the system pumps. Primary factors that will impact these costs and system operating performance are internal pipe diameter (and the resulting fluid velocity), materials of construction and pipe routing [42].

The frictional power required is dependent on rate of flow, pipe size (diameter), overall length of the pipe, pipe characteristics (surface roughness, material, etc.) and properties of the liquid being pumped [65]. One of the properties of the fluid flow is the Reynolds number (Re). If the Reynolds number is below 2,000 the flow regime may be assumed to be laminar. If Re is above 4,000 it can be assumed to be turbulent. Between these values the flow is in some intermediate regime that at one end may be laminar and at the other end may be full turbulent [43].

The friction loss in a fitting can be estimated by a technique called "equivalent length of steel pipe." To do so, the friction loss through the fitting is equated to the friction loss in an equivalent length of straight steel pipe of the same diameter as the fitting. Appendix 6.1 table 6.1.3 provides factors needed to calculate equivalent lengths of several types of fittings and valves. It is best to select fittings and valves of the same size as the main pipeline [44].

The system curve is superimposed on the pump performance chart. The Total Static head is constant and the friction head, equipment head and velocity head are flow dependent.

The calculation of total head at different flow rates produces a plot of total head vs. flow that is called the system curve. Equation 2.4 agrees with the argument put forward by Scherer [45] which also defines the total dynamic head of a pump as the sum of the total static head, the pressure head, the friction head, and the velocity head.

This curve is plotted for a constant speed (rpm) and a given impeller diameter (or series of diameters). It is generated by tests performed by the pump manufacturer. Pump curves are based on a specific gravity of 1.0. The user must consider other specific gravities.

The pump curve can also be determined by entering the two extreme points on the curve - head when capacity is zero and capacity when head is zero as indicated in equation 2.6. Then, a parabola with a negative curvature can be fitted through the two points. This parabola can be used since it is a good approximation of a typical pump curve and does not require users to enter a multitude of data points. Pump catalogs only give the two extreme points on the curve rather than a graph showing the complete curve [47].

$$H = H_{\max}\left[1-\left(\frac{Q}{Q_{\max}}\right)^2\right] \quad \text{(2.6)}$$

Where;

H is the operating head

H_{max} is the maximum head

Q is the discharge

Q_{max} is the maximum discharge.

Most pump curves can be described mathematically through use of a polynomial equation. The second-degree polynomial is commonly used, although a fourth degree is found to be the best model for some systems. Higher order polynomials might be used to describe some unusual characteristic curves although care must be taken as higher degree polynomials can wiggle between data points [48]. Figure 2.3 shows a typical pump performance curve generated from Kenya pipeline PS 21. This pump curve is a plot of head in meters against flow in cubic meters per hour using the equation 2.1 and shown in Appendix 6.3.2.2 of the sample calculations.

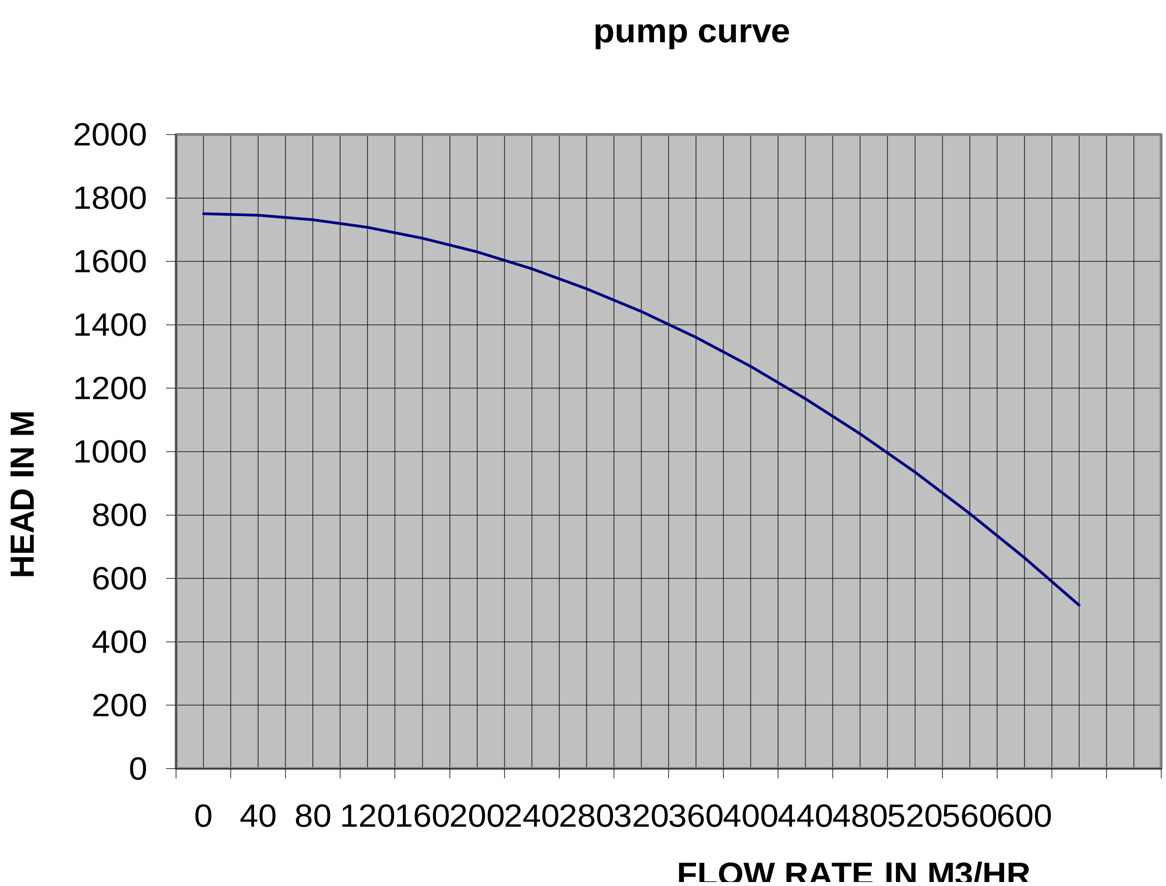


Figure 2. 3:Typical pump performance curve

An alternative equation to describe pump characteristic curves is the cubic spline where the use of splines in place of the fourth degree polynomial was attempted [49].

Pumps are normally selected to match the hydraulic requirements dictated by distribution geometry and hydraulic variability. Many hydraulic systems operate over a dynamic range of flow conditions due to changes in demand, reservoir elevations, position of laterals, friction and local losses caused by valve operation, or by the aging process (leaks). In such cases pumps are oversized in industrial and commercial installations. A major reason for HVAC pump over sizing and the resulting power waste is a fear of flow unbalance (short circuiting) and a consequent lack of flow for some terminal units. However, because Pump power drawn will increase directly with increases in either head or flow. Oversized pumps generally increase flow and head over that needed by the system, thus increasing system-operating power draw over that actually required [46]. Besides use of oversized pumps in some situations it may be desirable to use multiple pumps that are combined in series and/or in parallel [50].

To handle wide variations in flow, multiple pumps are often used in a parallel configuration. This arrangement allows pumps to be energized and de-energized to meet system needs [51].

Pumps in parallel are used whenever a flat type of characteristic curve is required. That is, the pump discharge head decreases gently with an increase in flow rate. A situation like this might occur when the water demand changes with time, such as during the day in a town, along a season in crop land farm when laterals are turned on and off within an irrigation system. Also, pumps may be connected in parallel for safety or to simplify maintenance. In municipalities, it is common to use three pumps in parallel, each one having the capacity for supplying 50% of the required design flow rate while the third pump on standby. Another option is to have four pumps in parallel, each one capable of supplying 33% of the normal flow requirement and the fourth pump on standby [52].

When selecting parallel pumps, one should always look at the pump and system curves to ensure the system curve crosses the single pump curve. In some cases it will not. In these cases, the performance of the system may be jeopardized during one-pump operation. Since the system can only operate where the pump curve crosses the system curve, hence if the published curve ends before it crosses the system curve, no one will know how the system will operate under these circumstances. Proper pump selection for parallel operation and pump performance monitoring are the best tools in avoiding load-sharing problems and maintaining a well operating parallel pump installation for energy efficiency as pumps operating in parallel will consume twice the energy of the single pump. [53].

Mackay [54] recognizes the role of piping design in parallel pump operation. Multiple pump arrangements present a great temptation for system designers to ignore the rules of piping with serious energy wastages as a result of increased friction. Poor piping arrangements are almost the norm in packaged systems where multiple pumps are used. It is imperative that proper piping practices be maintained for each pump in a multiple pump arrangement. These include: no elbows on the suction nozzle of the pump, zero pipe strain on the pump, a straight run of 5 to 10 times the pipe diameter to the suction nozzle, both sets of piping to be, at least, one size larger than the pump nozzle and use of an eccentric reducer on the suction side, with the flat side up.

Inlet and discharge piping configurations and lengths are also important in parallel pumping. The lengths should be comparable between the pump and the suction and discharge headers. Proper piping configuration for pumps operating in parallel should include suction and discharge headers of larger diameter than the lines leading to and from the individual pumps. Differences in suction or /discharge piping configuration will always lead to a disparity in pump flow rates hence wasting energy as a result of poor harmonization of the parallel pump system.

When an inefficient driver is installed, higher energy costs and premature equipment failure will result. Pump system components are tightly dependent on each other to produce the lowest installation and operating cost hence the importance of system design in optimizing operation and maintenance costs. It actually gives us the link between the three elements of the pump system hence the system approach [28].

From plant and works engineering magazine, [39], energy costs can represent up to 99% of the lifecycle costs of electrical motors. In some large motor applications, the use of reciprocating engines or gas turbines coupled directly to the load can provide significant benefits. These applications can be successful when there is a constraint on the electrical supply. These engines can also offer variable speed and over-speed capability for peaking loads of short duration. Engine packages offer a wide range of sizes, high-efficiency options and low emissions [31]. However motors will always be preferred over the reciprocating engines in terms of energy efficiency.

2.2.1. Effects of motor design and selection on energy efficiency

Motor systems are involved in a number of systems. In every facility a number of these systems can be identified, one of such facility is the pump system [55].

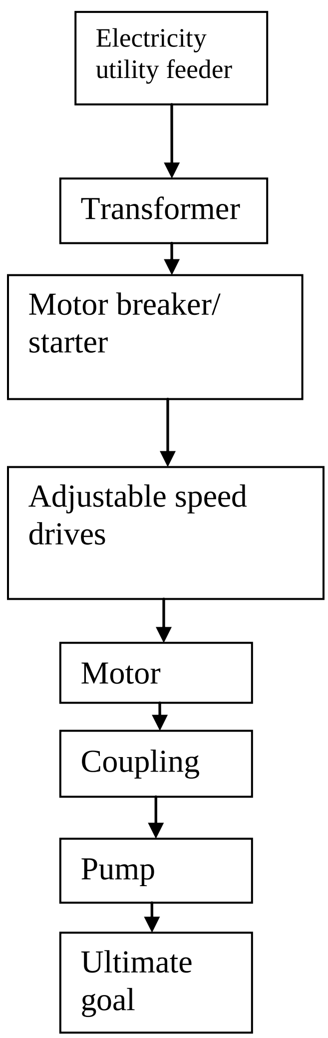
Motor systems consume more than 60% of a plant’s electricity and about 15% of the final energy use in industry worldwide [56]. Motors operate all types of process equipment and have a direct effect on operation’s productivity and product quality. Improved energy efficiency helps business lower operating costs, be more productive and reduce greenhouse gas emissions that contribute to climate change [57].

From the AB Journal [58] motor systems consume approximately 63 percent of all electricity. It is therefore estimated that implementation of efficiency improvement options in motor systems could reduce worldwide electricity demand by about 7% [1]. Therefore optimizing motor performance in pump systems will contribute in the enhancing the energy efficiency of pump systems as a whole.

Half the world's electrical energy goes through electric motors, so it is likely that motors are consuming a lot of energy used by most organizations. Hence, the key to improving efficiency is to consider the efficiency of the actual motor and its suitability for a particular task [59].

Motor systems can be split into a number of segments, each with their own efficiency referred to as the component approach as indicated in flow chart 2.2 below. A potential for 20-30% efficiency gains for complete systems is widely quoted [60]. This compares poorly with the system approach in flow chart 2.1 where we had a saving of 20-50percent when used in pump systems.

Studies recommend that the best way to maximize energy savings is to work backwards from the task to be performed to the power input of the motor, because large savings are the aggregation of many small savings made.



Copyright Arnie Sdano- American water works association annual conference (2003). Flow chart 2.2: shows typical pump systems equipment layout- component approach.

Energy costs over the life of a motor or system are often many times the initial incremental cost of purchasing high-efficiency equipment [31]. The initial purchase price of a motor represents only two percent of its total lifetime cost. The cost of power used represents almost all of the remaining 98 percent [61].

Selecting the right motor and drive combination can save energy and improve performance. Between 30 to 40 percent of all fossil fuels burned are used to generate electricity, and two-thirds of that electricity is converted by motors into mechanical energy [62].

Accurate selection of the pump drive and calculation of operating cost or feasibility studies require the knowledge of the drive power required for the pump to operate at the required Duty Point [63]. Indeed the selection of pump drivers is limited as electric motors and reciprocating engines are the most commonly used drivers for pumps.

Findings by the U.S. Department of Energy [64] show that most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load and that far too often motors are mismatched or oversized for the load they are intended to serve, or have been rewound multiple times. Care should be exercised in leaving an adequate but not excessive safety margin. The motor should be sized for the peak load expected. Oversized motors can significantly increase costs since all electrical components must be sized to the motor rating [31].This leads to energy waste.

Motors are oversized just as it is a common practice to oversize pumps. Motors are oversized in an attempt to insure against unexpected peak loads or to allow for process expansion in the future. Leading to hundreds of motors used in industry being grossly oversized [65].

In practice there is always the danger of the duty point having shifted. It must be recommended to select the motor to drive a pump with power reserve of approximately 5 to 20% above that theoretically required. However the upper limit in the above range does contradict the principle of not over sizing motors. In fact it increases the cost of energy but does not vary the efficiency so much because Motor efficiency is fairly constant down to approximately 50% of rated load, below which it drops off quickly [66].

Many motor manufacturers have two lines of motors; standard efficiency and high (premium) efficiency. "High Efficiency Motors" (HEM) are about 2-4% more efficient and offer lower operating costs and reduced energy consumption when compared to standard motors. For example, a 10 kW HEM may have an efficiency of 93 percent, compared with the standard electric motor's 88 percent, a saving of 5 percent in both energy and greenhouse gas emissions. The reduction in electricity costs will usually recoup the extra money paid for a HEM in about two years [59].

HEM design enhancements include: 20% to 60% more copper and up to 35% more high-quality electrical steel laminations, lower loss rotor bar design, optimized manufacturing methods and production techniques that reduce losses [29].

The use of HEM creates an energy saving from 1% to 4% than standard motors. They are generally more reliable, last longer and result in lower transformer loading. Other benefits from HEMs include a cooler running temperature, thus reducing space cooling costs, and increasing grease life. They also maintain high efficiency over a wider range of loads and have a greater thermal tolerance (i.e. don’t heat up so quickly when overloaded) [29].

It is important to match the HEM to the application because it operates at a slightly higher full-load speed than standard motors. This means that centrifugal loads, such as pumps, can be affected by this higher speed, delivering more fluid and consuming more energy [59].

Energy-efficient motors offer other benefits. Because they are constructed with improved manufacturing techniques and superior materials, energy-efficient motors usually have higher service factors, longer insulation and bearing lives, lower waste heat output, and less vibration, all of which increase reliability [67].

The rated motor horsepower must be greater than the brake horsepower at the operating point. Unless specifically requested, pump manufacturers attach a motor that is rated at least as large as the highest brake horsepower demand point across the whole pump curve. Motors rated less than the maximum pump brake horsepower are occasionally specified to reduce installation cost. This occurs when the pump operates at a sufficiently low enough flow to decrease the required motor size

Brake Horsepower is determined with help of efficiency, head, flow, specific gravity and viscosity. It is the pump shaft horsepower required to drive the pump at the operating point that determines the motor size.

If the specified duty point of a pump is located on the left hand portion of the duty curve (page 14 figure 2.1) with a corresponding lower power input it is feasible to select a smaller size motor. In such case however there exists the hazard of overloading the motor if the actual duty point allows a higher flow rate than that calculated (a more flat system curve) [63].

When “direct-read” power measurements are available, they can be used to estimate motor part-load. With measured parameters taken from hand-held instruments, equations such as equation 2.7 and 2.8 can be used to calculate the three-phase and single phase input power to the loaded motor. Motor’s part-load can then be quantified by comparing the measured input power under load to the power required when the motor operates at rated capacity [67].

$$P_i = \frac{V.I.PF.\sqrt{3}}{100} \quad \text{---} \quad (2.7)$$

Where:

P_i = Three-phase power in kW

V = RMS voltage, mean line-to-line of 3 phases

I = RMS current, mean of 3 phases

PF = Power factor as a decimal

$$1\ \text{Phase HP} = \frac{E \times I \times \%Eff \times Pf}{746} \qquad \text{--------------------------------2.8}$$

Where:

E is the voltage, I is the amperage, Pf is the power factor, Eff is the efficiency and 746 is a constant for converting from kW to Hp

Every motor has a metal nameplate or data plate listing the manufacturer, motor type and electrical requirements for the motor. Some of the information contained on the nameplate includes: voltage, full load current, efficiency, power factor and service factor [68].

The two very important pieces of information on the motor plate are; Horsepower (HP), which is the horsepower rating of the motor, and the Service Factor (SF), which is a multiplier factor. Horsepower multiply by the Service Factor = Total Brake Horsepower. The total brake horsepower of the motor is real power rating of that pump or motor.

Three phase motors use the same calculation as is used on single-phase motors with one addition to the formula. Three phase motors have three separate voltages each 120 degrees out of phase from one another. This is what gives the three phase motor its superior starting and running power and eliminates the need for start capacitors and start relays to remove a starting winding as is often necessary on single phase motors. The three-phase motor is 73% more powerful than an equivalent motor using single phase. The number 1.73 is added to the wattage side of the calculation to reflect this increase for 3 phases Energy [64].

To avoid negating the energy savings, the motor's operating speed must be matched with the load requirements. This may mean replacing an existing motor with a smaller one, trimming impellers on pumps or changing gear or pulley. Motors are most efficient when operating at full load. By installing a smaller motor, which operates at full load, the operating efficiency will be greatly improved ratio [59].

Operating in the service factor is normally done to reduce the motor size for reduced installation cost. Some applications require that the pump do not operate in the safety factor. Efficiency normally drops off at service factors above 1.00.

Many companies buy the motor with the lowest initial capital cost, but ignore its operating costs and energy efficiency. It is important to look at the entire life costs of the motor - including purchase price, installation costs and operating costs. By investing in a more efficient motor, the reduced operating costs achieved will far exceed the additional capital cost needed to buy one.

If there is any possibility that the high consumption point could be reached, the full size motor should be specified. Overloading the motor may damage it and will cause downtime when the protection circuit turns off the motor.

When improvements are made in motor or pump efficiency, equation 2.9 can be used to estimate energy savings.

$kWh_{savings}$=BHP X 0.746 [1/MEFF1 – 1/MEFF2].Annual working hours-------------- (2.9)

Where:

BHP = Brake horsepower at pump driveshaft

MEFF1 = old motor efficiency

MEFF2 = new motor efficiency

Combining premium efficiency motors with highly efficient gearing can save substantial energy and operating costs. Efficiency gains of 8 to 35 percent are possible by upgrading to more efficient or properly sized gearboxes and energy-matched gear components (e.g. helical, cycloid, bevel, or planetary) [61].

2.2.2. Effects of Pump system mechanical component design and selection on energy efficiency.

Energy efficiency is more than just high efficiency motors; couplings must also be considered [69]. In as much as motors spend most of the energy in the pumping system set, account should also be taken of the instances where high efficiency motors are routinely fitted as part of a larger power transmission chain with gearboxes to drive pumps. Indeed there is a significant loss of power at each stage of transfer in the transmission chain.

Mechanical components as transmission gear and bearings generates a mechanical loss that reduces the power transferred from the motor shaft to the pump. The mechanical efficiency can be expressed as in the equation 3.0 [70].

$$\eta_m = \frac{\left(p - p_l\right)}{p} \text{--} \quad (3.0)$$

Where;

η_m = Mechanical efficiency

P = power transferred from the motor to the shaft

p_l = Power lost in the transmission

Coupling designs may be divided into four principal categories, each having several specific designs. Solid and magnetic couplings are among the four couplings. They do not require lubrication. Solid couplings are fundamentally rigid structures that do not compensate for misalignment, but do allow two shafts to be joined for the purpose of transmitting torque. Magnetic couplings allow shafts not in direct contact to be driven together using powerful permanent or electrical magnets. A seal less magnetic drive pump is a common example [71].

Other coupling types are flexible couplings and fluid couplings. Many flexible couplings use fixed position flexible metallic, rubber or plastic elements, such as discs or bushings, which rotate with the shafts and absorb misalignment. Designs of this type do not require lubrication. Others such as geared, chain, grid and universal joints do require lubrication for proper performance and longevity. Fluid couplings include torque converters and torque multipliers as well as comparatively simple fluid couplings, which are couplings filled with lubricating fluids that rely on the fluid itself to transmit torque [71]. Each of the mentioned type of coupling has specific maintenance requirements that if not considered carefully will contribute to poor maintenance leading to energy wastage.

Greater percentage of the energy used for pumping is consumed in the transportation of the fluid in the pipeline, hence careful consideration should be given in the design of the piping system and the associated fittings.

2.2.3. Effects of piping system and fitting design and selection on energy efficiency

W. Trimmer and H. Hansen, [31] states that when designing or retrofitting a pumping system, one of the key decisions is picking the proper size of pipes and fittings for the system. The best pipe size or fitting is not always the one with the lowest initial cost. The important consideration is the lowest cost of ownership. The objective is to minimize the sum of capital, pumping, maintenance, and energy costs during the life of the system.

However according to [72] the sizing for any piping system consists of two basic requirements: components fluid flow design and pressure integrity design. Fluid flow design determines the minimum flow rates acceptable to meet the demand. Pressure integrity design determines the minimum pipe wall thickness necessary to safely handle the expected internal and external pressure and loads.

The primary elements in determining the minimum acceptable diameter of any pipe network are system design flow rates and pressure drops. The design flow rates are based on system demands that are normally established in the process design phase of a project. Before the determination of the minimum inside diameter can be made, operating conditions must be reviewed and used to determine the minimum inside diameter of the pipe for the network.

2.3. EFFECTS OF PUMP SYSTEM OPERATIONS ON ENERGY EFFICIENCY

Pumping system operation is the daily management of the system to meet the need. Because of the diverse needs that the system has to fulfill, it is operated in various ways including the use of throttle valves, variable speed drives, multi stage pumping, capacitors and computerized control systems for monitoring pump efficiency. Regular observation of how a pumping system is functioning can alert operators on potential losses in system performance. Performance indicators include changes in vibration, shock pulse signature, temperature, noise, power consumption, flow rates, and pressure. Each of these operational elements is geared towards ensuring that the energy costs are kept to a minimum as possible. However depending on the need some operational devices are more preferred [24].

Peak efficiency is possible only at a particular flow and pressure. Putting a pump into a system where it is forced to operate at a different condition will reduce efficiency [29]. Operations of a pumping system are as important as the design and none of these aspects should be overlooked for efficient energy utilization.

Many systems use constant speed motors and mechanically regulate process flow using throttling valves, dampers, fluid couplings or variable inlet vanes. These devices generally do not regulate the pump system efficiently because energy is dissipated across the throttling device. Hence the use of electronic Adjustable speed drives (ASDs) to provide a cost-effective means of matching system performance to the requirements of the process while saving significant amounts of energy [69].

2.3.1. Effects of Pump control systems on energy efficiency; Variable speed drives

A variable-frequency drive is an electronic controller that adjusts the speed of an electric motor by modulating the power being delivered. Variable-frequency drives provide continuous control, matching motor speed to the specific demands of the work being performed. According to PG&E [73], these drives are an excellent choice for adjustable-speed drive users because they allow operators to fine-tune processes while reducing costs for energy and equipment maintenance.

Variable-frequency drives help cut costs in pump applications by controlling motor speeds, providing users with improved energy efficiency and power quality. When pump speed is reduced by 20 percent from 100 percent, motor horsepower is reduced by nearly 50 percent, as is brake horsepower (Bhp) the indicator of how much energy a pump motor is using [74].

Further to the above, energy savings can be significant when pump systems are designed to respond to varying demand systems and that systems operating with constant speed pumps and pressure regulator valves waste energy. Affinity laws for centrifugal pumps also bring out the fact that even a small reduction in motor speed will highly leverage your energy savings.

Variable-frequency drives can reduce a pump’s energy use by as much as 50%. A variable frequency drive controlling a pump motor that usually runs less than full speed can substantially reduce energy consumption over a motor running at constant speed for the same period. Because this benefit varies depending on system variables such as pump size, load profile, amount of static head, and friction, it is important to calculate benefits for each application before specifying a variable-frequency drive. [75].

Single-speed drives start motors abruptly, subjecting the motor to high torque and current surges up to 10 times the full-load current. In contrast, variable-frequency drives offer a "soft start" capability, gradually ramping up a motor to operating speed. This lessens mechanical and Electrical stress on the motor system and can reduce maintenance and repair costs and extend motor life [76].

Variable-frequency drives allow more precise control of processes such as water distribution, aeration and chemical feed. Pressure in water distribution systems can be maintained to closer tolerances. Wastewater treatment plants can consistently maintain desired dissolved oxygen concentrations over a wide range of flow and biological loading conditions by using automated controls to link dissolved oxygen sensors to variable-frequency drives on the aeration blowers [77].

Not all systems with widely varying flow requirements are good candidates for ASDs. Many systems require constant pressure over a wide range of flows or have a minimum head requirement. Even though flow may be substantially reduced, it may be necessary to keep the turbo machine near full speed to meet the system's pressure requirements [29, 78].

The decision to use a VFD should be based on economics i.e. does the savings in energy offset the cost of the VFD? This depends on the ability to correctly identify the load profile of the pumping plant. The load profile describes the various required operating conditions and the percentage of time that the pump operates at those conditions. From this statement, it is not true that the use of variable speed drives will be necessary in all pumping systems. In order to apply variable speed drives it will be important that the system operating conditions are keenly considered [78].

First costs for variable-frequency drives are relatively expensive. This is emphasized by the fact that VSDs can be 2-5 times the cost of the motor.

Peterson, [79] states that Installed drives range from about $3,000 for a 5 horsepower motor to almost $45,000 for a custom-engineered 300 horsepower motor, and more for larger versions. Variable-frequency drive installation can take from 10 to over 70 labor-hours, depending on system size and complexity. However, payback period for these drives can range from just a few months to less than three years for 25- to 250 horsepower models. Because each variable-frequency drive can drive more than one motor, some costs can be consolidated. In addition, savings from reduced maintenance and longer equipment life contribute significantly to achieving a rapid payback and long-term savings. Many electric utilities offer financial incentives that can reduce the installed costs of variable-frequency drive. Energy savings for variable speed systems can produce up to 40 percent for single pump systems and 30 percent for multiple pump systems.

If variable speed is justifiable, what system should be used? It has been shown that even in today's electronically driven world the advantages of the fluid coupling should still be considered. This statement by the Energy Efficient Environmentally Friendly Drive Systems Principles, [80] shows that not all variable frequency drives are appropriate for use in pumping systems. Among other factors, environmental impact of this drives should be considered while selecting the most suitable ones.

To determine the costs of driving and controlling a pump it must be principally distinguished between the shaft power requirement [kW] of the pump, often equal to the installed rated motor power and the actual power input to the drive motor [kW]. The latter is the basis for determining the operating costs [81]. It is important for a consideration to be given on the number of power transfers to minimize on the power losses at the interface of systems. Long chains of couplings should be discouraged.

2.3.2. Effects of Fluid flow control operations on energy efficiency

The system resistance or system head curve is the change in flow with respect to head of the system. The user based upon the conditions of service must develop it. These conditions include physical layout, process conditions, and fluid characteristics. It represents the relationship between flow and hydraulic losses in a system in a graphic form and, since friction losses vary as a square of the flow rate, equation 3.1 below shows that the system curve is parabolic in shape [82]. Hence to minimize the hydraulic losses for a particular desired flow, proper selection of the pipe size and fittings should be done.

$$hf_2 = hf_1 \left(\frac{Q_2}{Q_1} \right)^2 \text{ --- } (3.1)$$

Hydraulic losses in piping systems are composed of pipe friction losses, valves, elbows and other fittings, entrance and exit losses, and losses from changes in pipe size by enlargement or reduction in diameter [83].

The operating point is the point on the system curve corresponding to the flow and head required. It is also the point where the system curve intersects the performance curve. The design system curve is usually calculated with extra flow capacity in mind. It is good practice to plot the system curve for higher flow rates than the design flow rate, since flow demand may change and extra capacity may be required. The required pumping head in a branchless pipeline is determined from Bernoulli's equation for one-dimensional, stationary flow of incompressible fluids as indicated in equation 3.2 [84].

$$H_A = \frac{p_a - p_e}{\rho \cdot g} + H_{geo} + H_{v,ges} + \frac{v_a^2 - v_e^2}{2g} \quad \text{---} \ (3.2)$$

p_a, p_e = pressures on suction or delivery liquid levels respectively, p = fluid density g=gravity9.81m/s2)

H_{geo} = Static height difference between suction and delivery liquid levels respectively. $H_{vges.}$=Total friction loss between inlet and outlet areas.
$v^2{}_a$,$v^2{}_e$, = Mean flow velocities at inlet and outlet areas.

When capacity requirements call for an unrealistically large pump and motor, using parallel pumps can also reduce current surge during motor startup by staging two or more smaller pumps. This is a problem, which may otherwise require expensive equipment such as electronic soft starters or part winding type motors. However one of the most notable benefits of parallel pumps is the redundancy built into the system. If one pump were to fail in a two pump system, the second pump would not only continue to operate, but would also increase its output [35].

In process industries such as petrochemicals and semiconductors, there is often a need to operate several pumps of the same capacity in parallel to cater to changing load requirements. The desired performance attributes for such a pump system include, but are not limited to: low energy consumption at high loads, low energy consumption at low loads, ease of maintainability, quick response to disturbances such as pressure fluctuation and power glitches, expandability [85].

Applying parallel or series pumps in a system can be a cost-effective solution to various system problems. However the fact that these comes with its own challenges cannot be overlooked [50]. One of the challenges that pump users face quite frequently comes into play when more than one pump is required to operate at the same time on the same system. parallel operation may be required to meet variable demands, such as flood control, or to satisfy a temporary condition that occurs such as when changing over pumps in an uninterruptible process. Pumps may be connected in parallel to increase station discharge for a given pressure head, for safety or to simplify maintenance. In municipalities, it is common to use three pumps in parallel, each one having the capacity for supplying 50% of the required design flow rate [85].

2.3.2.1. Parallel pump operation and energy efficiency

Significant problem may be encountered when running two differently sized pumps together in parallel. If not carefully selected, one pump can overpower the other and force its check valve to close, causing a potentially dangerous situation. Inasmuch as the practice is to select pumps that are comparerable; with as close shut-off heads as possible (not more than 2% or 3% recommended), however all pumps do not work like this; not all Pumps are Equal. This shows that pumps operating in parallel have to be studied and understood so that if there is a substantial variation, a proper starting procedure is determined depending on the strengths of these pumps [46].If proper starting procedure is not adhered to, there will be energy loses.

Other problems associated with parallel pump operation. Load sharing problems, between pumps operating in parallel, may increase wear, reduce seal and bearing life, lower operating efficiencies can limit process operations. In the absence of any flow measurement capability, an uneven performance distribution, between pumps operating in parallel, is easier to avoid than to detect [46].

While developing the combined pump curves for parallel pumps, the flow rates rather than heads are added for a common total head. Because of the slope of the system curve, the pumps in parallel arrangement will each operate at a lower flow rate when operating together, than they would if they operate alone on the same system. This is particularly relevant on multi-pump arrangements, and it requires careful selection to ensure the most efficient and stable operation [50].This therefore means that in practice, it will not be possible to achieve the theoretical flow of pumps operating in parallel resulting to loss of energy.

Because pumps with flat curves (operates over a narrow range of head) are very sensitive to relatively small head changes, there are significant flow shifts when adjacent pumps are turned on and off, or when the station total dynamic head (TDH) changes because of changes at either the suction or discharge side of the station. The interplay among pumps is increasingly dynamic when the curve slopes of adjacent pumps are not the same. Identifying the performance of a single pump operating in a family of parallel pumps, with changing pump station TDH requirement, and dynamic pump station friction and turbulence losses is difficult [46].

Much of the effort devoted to careful selection and sizing of pump and pumping system components may be wasted if the unit is not maintained properly.

2.4. EFFECTS OF PUMP SYSTEM MAINTENANCE ON ENERGY EFFICIENCY.

Maintenance and repair is a significant component of pumping system life cycle costs as illustrated in the visual figure 2.4. An effective maintenance program can minimize these costs. Obtaining optimum working life from a pumping system requires regular and efficient servicing of the various system components [86].

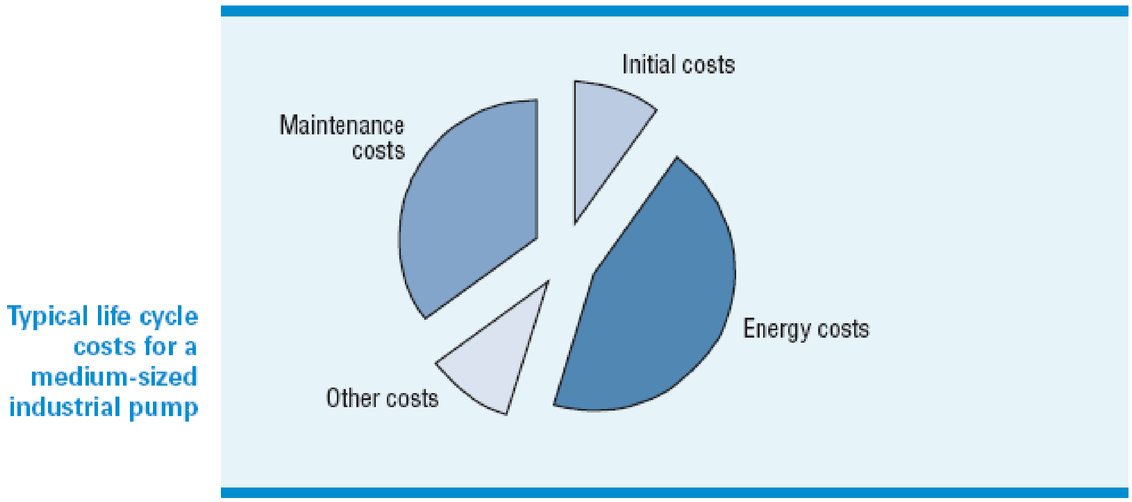


Figure 2.4: Pie chart; visual presentation of typical life cycle costs for medium sized industrial pump.

Other than keeping a pump system in an energy efficient state as exhibits it lower frictional losses and decreased operating temperatures an effective maintenance program also enhances reliability, performance and productivity. Out of the 40 % energy consumed by pump systems that could be saved, proper installation and maintenance could account for 3 % [31].

Particular consideration of the individual pump system components according to the manufacturers' recommendation is important in achieving high energy savings for the pump system as a whole. Efficiency can be further enhanced through proper motor maintenance. A basic motor maintenance program requires periodic inspection and correction of unsatisfactory conditions [61].

Many users choose to rewind or repair motors when they fail as part of the maintenance program, a practice that is more common with motors greater than 50 horsepower. Even though rewinding a motor costs less than buying a new one, rewound motors are less energy efficient even after using the best rewinding technician. For most applications with high annual hours of operation it is cost-effective to replace a standard motor with a new Premium one. In many cases, it may be cost-effective to replace a standard motor even prior to failure with a NEMA Premium motor [87].

Couplings and gearboxes are part of the pump system maintenance evaluation. Important items for the couplings are alignment and balance. Alignment and balance minimize vibration and friction losses consequently energy as well as reduce operating maintenance cost [88].

Fluid couplings transfer momentum from the input shaft to a fluid and then to the output shaft when transmitting torque. Misalignment is accommodated solely by clearances between the moving parts. The small clearances don't provide much room for error in alignment. However, it is possible to effectively compensate for shock loading and high torque starting loads, as there is no solid connection between input and output shafts [89]. While maintaining the fluid couplings coupled with the pump care should be taken to ensure proper alignment to minimize friction, shock in the bearings and balance in the whole system. These elements are important in minimizing energy losses.

Gearboxes must be aligned to reduce energy loss and equipment damage. Gearbox lubrication is also critical. Proper lubrication schedules, amount of lubrication and correct type of lubrication reduces energy consumption through reduced heat loss [73]. In terms of alignment, Adam M. Davis, 2007 puts it that Gear coupling compensate for misalignment via the clearance between gear teeth.

Technical consideration of pump system design, operations and maintenance brings out opportunities for energy efficiency improvements, however without proper monitoring, controlling, and conserving energy the technical energy audits are fruitless. Energy should be viewed as any other valuable resource as raw material required for running a business – not as mere overhead and part of business maintenance. They need to be managed well in order to increase the business' profitability and competitiveness and to mitigate the seriousness of these impacts [90].

2.5. ENERGY EFFICIENCY MANAGEMENT STRATEGIES IN PUMPING SYSTEMS

Like any other organizational function, the success of energy management system depends on four factors; top management support, technical & managerial capacity, monitoring and strategic plan. All organizations can save energy by applying the same sound management principles and techniques they use elsewhere in the business for key resources such as raw materials and labour. These management practices must include full managerial accountability for energy use. The management of energy consumption and costs eliminates waste and brings in ongoing, cumulative savings [91].

The support of top management is starting point for any successful energy management strategy and is essential for long term improvements. The support of top management can be measured or indicated in terms of how much of organizational resources, a firm would earmark for the function such as appointing an energy manager, building a dedicated energy efficiency (EE) team, financial allocation and its overall policy towards energy efficiency and conservation [8].

Many organizations realized that building capacities within the organization helps to lower the operating and capital cost, since an informed employee takes better decisions in operations of the equipment, selection of the equipment. Enhancing capacity building also includes up-gradating of measuring and monitoring instruments and data management, so that quality data/information and human skills are used in managing energy resources.

Monitoring of energy use forms the key element in many situations, since it helps to address few simple improvements through behavioral change or maintenance practices. In general, industry uses different performance metrics such as pump efficiency, specific energy consumption, % of leakage, un-accounted water, etc to track its system performance by comparing and benchmarking with their own operations (intra-day, monthly or yearly), with an industry norm (national, international or best practice) or with equipment standard. Monitoring of energy efficiency metrics indicate the performance gaps, thereby help to set energy efficiency goals for the system or organization [91].

2.5.1. Barriers to implementation of energy efficiency strategies

The energy efficiency improvement projects are never realized because of the existence of several barriers, these barriers could be from within the organization or from external sources [92].

Although the operational interventions required to tackle the efficiency problems are rather simple from technical sense, lack of awareness, technical capacity and organizational structure and bad finances are impeding their implementation [8].

Barriers can be categorized differently. Some of the barriers are very prevalent for electric motor systems. Among these categories are principal agent problems, lack of information, transaction costs or organizational structure [93].

Industry, barriers may exist at various points in the decision making process, and in the implementation and management of measures to improve energy efficiency. Barriers may take many forms, and are determined by the business environment and include decision-making processes, energy prices, lack of information, lack of confidence in the information, or high transaction costs for obtaining reliable information, as well as limited capital availability. Other barriers are the "invisibility" of energy efficiency measures and the difficulty of quantifying the impacts, and slow diffusion of innovative technology into markets while firms typically under-invest in R&D, despite the high pay-backs [94].

Absence of corporate energy policy, lack of awareness on energy efficiency strategies, insufficient skills and knowledge on energy efficiency matters, competing corporate priorities and insufficient financial resources to fund measures are listed as some of the barriers to implementing energy efficiency measures common to most pumping installations [8].

Decision-making processes in firms are a function of its rules of procedure, business climate, corporate culture, managers' personalities and perception of the firm's energy efficiency [95].

Lack of skilled personnel makes it difficult to select and install new energy efficient equipment. In many firms (especially with the current development toward lean firms) there is often a shortage of trained technical personnel, as most personnel are busy maintaining production [96]. Therefore training programs for pumping installations should be designed with a component of energy efficiency and should not only focus on improving product quantity and quality.

The position within the company hierarchy of energy or environmental managers may lead to less attention to energy efficiency, and reduced availability of human resources to evaluate and implement new measures. Energy managers are supposed to be at the same level as other first line managers in production, operations, finance, safety and human resource.

In many developing countries especially for small and medium sized enterprises (SMEs) capital availability may be a major hurdle in investing in energy efficiency improvement technologies due to limited access to banking and financing mechanisms.

In some organizations, EE is not always implemented due to lack of awareness, information and capacity regarding EE opportunities. Organizational culture can be a key factor to lack of awareness to information and capacity regarding energy efficiency opportunities. Internal competition for scarce resources may make managers to look inward and fail to realize training opportunities and other interactive mechanisms for information and awareness campaigns in the market [8].

Further to this the requirement for managers to act as public interface with larger population (or customers) also takes efforts and time of managers and most of the time, managers are preoccupied with just delivering and meeting service and quality requirements. There is any hardly effort and capacity to do any EE improvements in the installations.

The real and perceived insignificance of energy efficiency is another barrier to implementing EE opportunities. The EE potential though seems large pumping installations, can be achieved only by implementing large number of smaller projects. The total energy and cost savings potential would be visible after implementing these small projects. Since this requires effort, time and other resources (administrative, technical, engineering and financial), managers are not too interested in implementing EE. Even the cost savings projections of present energy cost, when seen in comparison with total O&M cost and capital budget of the overall installation, is miniscule. The main reason for this perception (or reality) is the lack of institutionalization of EE in Pumping systems. Each EE project activity requires identification and implementation, requiring multi-disciplinary skills. Lack of institutionalization of EE put greater demand for these skills and pumping installations are not geared for this. Also most of the discussion and arguments for EE in industries are centered on technical and financial aspects of the projects. The environmental, social benefits along with larger economic benefits to the society or country are never taken into account [8].

The absence of a substantive energy management function in the installations is another important barrier to implementing energy efficiency measures in organizations. In fact this is twofold; technical (metering, monitoring of energy consumption) and management (structure, accountability, reporting) aspects. For technical aspects**,** the existing metering and measurement of energy and other operational performance parameters are not comprehensive. The level of instrumentation and monitoring required for any diagnosis is minimal. In management aspects, organization energy objectives are not always integrated into operating, maintenance or purchasing procedures [8].

EE measures may not be implemented in installations because the existing practices of Operations and maintenance do not factor energy efficiency. Maintenance is always a case of “firefighting” i.e. maintenance is done when pump fails to operate. Hence all maintenance efforts are to make the system to work somehow, but not how efficiently. There are also no performance related parameters such as energy efficiency or specific energy consumption (kWh/m^3) as deliverables which could be the basis for instituting EE measures [8].

Finances act as catalysts in implementing EE measures. Hence lack of this important factor inhibits the consideration of the other barriers in the process of implementing EE. The main reasons for this are lack of proper pricing, revenue/tax recovery systems in installations which are mostly public together with political interferences. However there are many technical and administrative aspects which can be improved to minimize the problem of finances i.e. the policy options adopted by the organization.

Lack of minimum standards and labeling and energy audits is another barrier to implementing energy efficiency. For over a decade, many countries have begun implementing labeling and minimum energy performance standard (MEPS) schemes to improve the efficiency of motors on the market. MEPS aim at phasing out the least efficient motor classes by setting minimum standards for the efficiency of motors being sold in a country. By labeling motors, policymakers seek to overcome the information barrier that made it impossible for company managers to invest in high efficiency motors. Labeling provides the needed information in a transparent way and facilitates comparisons of motor efficiencies among producers. Thus, it reduces transaction costs and contributes to the transformation of the motor market towards high efficiency motors. Therefore, MEPS and labeling often go hand in hand. While MEPS reduce the market share of least efficient motors, labeling promotes the use of very efficient motors, most likely in applications where they are most cost-effective [97].

However, the largest savings can be gained by optimizing the entire motor system. Yet from a policy point of view, this is also more difficult to tackle because motor systems and their integration into the production process vary among processes as well as plants, and their optimization requires substantial knowledge about the relevant process. Consequently, the required policies are also more diverse and the involvement of experts is necessary. Other possible approaches are energy audits and information and capacity building programs for system optimization [97].

While there is a general consensus that energy efficiency ‘gap’ exists, and that policy options to overcome this gap need to be identified and acted upon, there is debate over the most effective approach [50].

CHAPTER 3

RESEARCH METHODOLOGY

While carrying out this study, 5 pumping installations were selected and surveyed. The installations were selected from across the country. These installations had pumping as one of the major functions. The survey was carried out using face to face interviews, personal observations of the systems and with the use of questionnaires. The installation personnel targeted for interviews were technical staff in charge of the pump systems and the technical staff in managerial positions.

The following procedure was used to meet the objectives of the study.

1. Literature review was conducted to develop an understanding on factors affecting energy efficiency in pumping systems i.e. technical capacity- (design, operations, and maintenance), managerial capacity, top management support and monitoring of energy efficiency implementation plans. The contribution of these factors to industrial energy bill was also got from the literature review.

2. A list of 15 major manufacturing firms was developed from the yellow pages of the Kenya telephone directory 2006. From the list, 10 firms whose operations were thought to involve pump systems were identified and letters seeking access to the firms were written and send. Five firms responded positively. These firms were; Kenya Pipeline Company Limited; Kenya pipeline company is an installation dealing with transporting of petroleum products through a pipeline, Nairobi water and Sewerage Company Limited; deals with domestic water distribution and waste water management in the city of Nairobi, Spin Knit diary limited; deals with raw milk processing and packaging, Davis and Shirtliff Company limited, is a major dealer in pump and pump systems and was selected as a bench mark to the pump system technology and a after sales service for the pump systems and Nzioa Sugar Company is a sugarcane processing company. Access to pumping systems was sought.

During the study of the installations, the following information was obtained, the number and size of pumps, power consumption of the pumps, the operations schedule, maintenance procedures and energy management practices. This information was obtained via interviews of the technical personnel in charge of the design, operations and maintenance of the various pump systems. At Kenya Pipeline Company, the information was obtained from the chief engineers, senior engineers and engineers 1 and 2 in charge of electrical, mechanical, instrumentation and control. Design drawings were obtained from draftsman 1. The information from Nzoia Sugar Company was obtained with assistance from the process engineer's office. At Nairobi water and Sewerage Company, the information was obtained from the operations managers' office together with a mechanical operator who took me round the installations pumping stations. For Davis and Shirtliff, the information was obtained from the marketing managers' office while at spin knit diary, the information was obtained from the process supervisor.

Also obtained from the technical staff were cases of leakages, mismatch of pump and motor sizes, type of motor weather energy saving or not and the year of manufacture.

3. Opportunities were identified by reviewing the technical aspects in pumping systems with emphasis on new technologies in design, operations and maintenance that enhance energy efficiency as brought out in 2 above. Management practices were also evaluated to establish barriers to implementing the identified energy efficiency opportunities. Measures to address the barriers were also suggested.

4. Technical staff in managerial positions explained why; leakages were not stopped, there was poor match of pump and motor sizes and energy efficient modern equipment were not procured. Pump systems operation procedures were noted and compared to manufacturers' recommendations. The management structure

was sought in order to establish the position of energy department if it existed. Operational and maintenance priorities were sought to indicate the importance of energy management. A filled sample questionnaire used to collect some of the information is in Appendix 6.4.1.This was used to identify the barriers and measures to minimize the effects of these barriers recommended.

5. At Kenya Pipeline Company limited because of available instrumentation it was possible to obtain the system layout, pipe sizes and lengths, operations schedules, head, flow rates, power consumption for the pumps, operating pressures, temperature and vibration levels. At Nairobi Water and Sewerage Company the information obtained was; a layout of pump systems, head, discharge, nature of motors (energy efficient or not), maintenance plans, pipe sizes and lengths, procedures as well as energy consumption. For Davis and Shirtliff, information on the pump systems and their maintenance was obtained. Nzoia Sugar Company provided process layout for sugar production and a list of pump and motors used in the processing of sugar and at Spinknit Dairy; a list of pumps and motors, the manufacturers' data was provided.

Data collected from Kenya pipeline was processed and analyzed. This involved tabulating the data, converting the units into S.I. determining the mean pressures, temperature, current, flow rate, plotting graphs, and determining the energy required to transport one cubic meter of fuel per meter. The data was used to estimate the potential savings. . The other four installations did not have instrumentation to use in obtaining the required data for estimating potential savings. Installing measuring instruments to be able to obtain the operating parameters could not be allowed as could interfere with the operations of the installations.

3.1. LIMITATIONS

There were a number of limitations and these were;

1. There was limited cooperation from the management of one of the installations (Spin Knit diary) during the premises visit sitting reasons such as confidentiality. Some of the information such as the company management structure and power consumption could not be obtained.
2. The spin knit diary, Nzioa Sugar Company and Nairobi water and sewerage did not have up to date records of the pump system in all the departments.
3. The investigator had limited budget, time due to work related duties and logistical resources like metering instruments for full data collection.

CHAPTER 4

RESEARCH FINDINGS AND DISCUSSION

This chapter describes the pump system survey findings and discussion in the following installations; Kenya pipeline, Nairobi water and sewerage services, Davis and shirtlif, Nzioa Sugar Company and Spin knit Dairy.

It was found out that technical (the design of the pump systems, operations, maintenance schedules), management support, energy management practices and monitoring of energy implementation plans were the most important factors affecting the energy efficiency of pump systems. Each firm was considered separately.

4.1. DESIGN, OPERATIONS AND MAINTENANCE PRACTICES AT NAIROBI CITY WATER AND SEWERAGE COMPANY LIMITED

The Nairobi city water and sewerage company limited supplies Nairobi city with water. There are various sources of water to the city i.e. Kikuyu springs, Sasumua dam, Ndakaini dam, Ngethu and Ruiru dam. Water from these sources flow to the main pumping and treatment stations by gravity. The main pumping and treatment stations are; Gigiri and Kabete. However, there are other booster stations that assist in supplying water to the various consuming zones that are located in high areas around the city. These booster stations include; Kenyatta University booster station, Kamiti prisons booster station, Gigiri pumping station, kabete booster station, Kenyatta (Serena) booster station, Loresho booster station, Lower Kabete pumping station and Gatina booster station.

4.1.1. Kenyatta University Booster Station

This station receives water from Kasarani reservoir which is located at an altitude of 1549m.The station is serviced by five pumps, two of which feeds the Kamiti Prisons pumping station located 3087m away. The other three were operating as follows; one to the storage tank, another to Kahawa Garrison and the other as a standby. The specifications for the motors of the first two pumps were; 1450 rpm and 14.9 kW while for the other three were; 1440 RPM and 14.9 kW. The corresponding specifications for the pumps could not be established as there were no nameplates on the pumps. The two pumps operated one at a time for 12 hours alternately.

The flow rates could not be established as there were no flow meters installed. Neither could the individual power consumption of the systems be established. The changed flow rate and power consumption could not be measured as installation of the metering equipment could interfere with the operations of the installation. Pumps were coupled directly to motors (not energy efficient) which were very old and likely rewound several times. It was evident that the demand for water had changed due to growth in population. As such it was likely that the system was being operated off the best efficiency point as a result of the additional connections hence change in the total head and therefore a shift in the system curve while maintaining the same pump curve.

4.1.2. Kamiti Booster Station

Kamiti booster station is at an approximate altitude of 1576 m at a distance of 3087 m from Kenyatta University pumping station which is the source of its water. The water from Kenyatta is feed directly into the pumps at kamiti by a commercial steel pipe of 150mm diameter. The flow rates to the station could not be determined as there were no flow meters installed neither at inlet nor outlet of the pumps. This water is pumped to a storage tank located 200m away and 10m high by three pumps, two being run by motors while the third pump was run by a diesel engine. Each pump works alone at a time, changing over after twelve hours. However the one fitted with a diesel engine works only when there is a power outage.

The motor speed and power for both pumps were; 1445 RPM and 3.7kW. The specifications for the pumps could not be identified as the name plate for the pumps did not have the details. Similarly, the power consumed by each pump could not be ascertained as the metering instruments were not fitted.

The maintenance schedules were available and are as shown in Appendix 6.6. There was no evidence of compliance with the planned maintenance schedules. Pumps were coupled directly to motors which were very old, not energy efficient and likely rewound several times. Just as in the case of Kamiti booster station, the demand for the water had changed due to growth in population. The changed flow rate and power consumption could not be measured as installation of the metering equipment could interfere with the operations of the installation. As such it was unlikely that the system was being operated efficiently as a result of the additional connections hence change in the total head and therefore a shift in the system curve while maintaining the same pump curve.

4.1.3. Gigiri Pumping Station

This station receives water from Ngethu water works and stores the water in three ground storage tanks. The water comes to the station by gravity. The station is at an altitude of 1711m above sea level. The water at Gigiri is received via three 36000 meter long pipes. Two of these pipes are 0.7m and one 1.2m in diameter.

The station supplies 43,000 m^3 of water to Kabete station through a 0.7m diameter pipe. Gigiri also supplies water to Serena (Kenyatta) station via a 1m diameter pipe and to karura station (1663m altitude) via a 0.8m diameter pipe. At Gigiri, there are four pumps which were found to be without name plates. The name plate data for two of the motors had the following specifications; 1488 RPM, 709 kW, 153 Amps, pf-0.904 and year of manufacture 1997; 1488 RPM, 850 kW, pf-0.904, year of manufacture – 1993; 1493 RPM, 850kW, pf-0.9 and the year of manufacturer-2004. These pumps work alternately for 12 hours. At the time of the visit, they were working for 18 hours due to breakdown of pump one.

Power consumption of the individual pumps could not be established as there were no metering instruments installed. The metering instruments that could be installed are portable and on-line energy meters, pressure gauges, hour meters to log operating hours of each pump and water meters. However, from the installations records, it was found out that pumps in this station were operating at 80% 0f the rated capacity. This was the closed operating point of the pumps to the rated load in the whole installation. As for the other pumping stations, Installation of the metering equipment at the time of the study could interfere with the operations of the installation and maintenance schedules were available. Throttling of the discharge lines was noted. This was to reduce variations in the level of the storage tanks whose storage capacity is 81,000 m^3. Variations in the level of the storage tanks existed due of poor system design that does not provide for balance between the distribution side and the supply side resulting in low levels of the reservoirs. Throttle valves needed to be removed and instead replaced with Variable Speed Drives or use multiple pump system (parallel pumps) for a balanced system between supply and the distribution networks to a void abnormal falls in the reservoir levels.

Pumps were coupled directly to the ordinary motors that were not energy efficient. The pumps were new compared to the other stations; however they were not using modern energy efficient technology. It was evident that the demand for the water had changed due to growth in population. As such it was likely that the system was being operated off the best efficiency point as a result of the additional connections hence change in the total head and therefore a shift in the system curve while maintaining the same pump curve.

4.1.4. Kabete Booster Station and Treatment Works

The station located at an altitude of 1818m above sea level receives raw water from Ruiru dam by gravity via three pipes of diameter 0.225m, 0.3m and 0.4m. It also receives water from Kikuyu springs which supply 4000 m^3 per day through pipes of diameter 0.175m and 0.225m and length 10,000m.

It is a booster station for water from Gigiri to Dagoret reservoir which has a storage capacity of 11000m^3 and at an altitude of 2340m. It also boosts water to hill tank through a 0.5m diameter pipe. Hill tank has a storage capacity of 18000 m^3 and at an altitude of 1749m. Water from Kabete was also supplied to Uthiru which has a storage capacity of 11000 m^3 and at an altitude of 1891m. Water flows to Uthiru through a 0.5m diameter pipe and length 4,384m. The storage capacity for Uthiru station is 59,000m^3.

The station had 9 centrifugal pumps with the following specifications of motors; Three motors coupled to pumps pumping water to Dagoretti; 1465RPM, 230kW. These three to Dagorretti operate two in parallel with one stand by. One motor out of the three motors coupled to the pumps pumping to Uthiru was with the following specification; 165kW, 1470 RPM and pf-0.91, while 185kW and 1480RPM for the motor of the other two pumps. These pumps operated two in parallel with one standby and at a pumping capacity of 69 % of the rated capacity. The pumps were not labeled.

The specifications for the two motors for the pumps to hill tank were as follows; 105kW, pf-0.91, 1470 RPM while the corresponding pumps had the following specifications- discharge – 0.098m^3/s, head-84.6m, 1470RPM. These operated in two parallel while the other pump was standby. The standby pump had a motor with the following specifications; 1160kW, 1470RPM and pf-0.91 and the corresponding pump specification of 84.6m head, 1470 RPM, and 0.98m^3/s discharge.

When the water level is low in the storage tanks, all the pumps to Dagorreti are switched off while pumping to Uthiru one pump can be operated when the level is low. There were eight other pumps in the treatment plant whose data could not be obtained. The station had small positive displacement pumps for injecting chemicals in the water.

Pumps were coupled directly to motors. The demand for water had changed due to growth in population. The pumps were operating at 70% of the rated capacity hence possibility that the system was being operated off the best efficiency point. Operation of the pumps away from the best efficiency point could also be due to the additional connections hence change in the total head and therefore a shift in the system curve while maintaining the same pump curve. There was need to review designs which were not optimized for energy consumption. Power consumption for each pump could not be established as there were no metering instruments installed; however, maintenance schedules were available as shown in Appendix 6.6. There was no evidence of compliance with the planned schedules.

4.1.5. Kenyatta Booster Station (Serena hotel)

This is a booster station that transfers water from Gigiri to a water reservoir known as hill tank. The reservoir is 8000m from Gigiri at an altitude of 1679m. The water is pumped from Gigiri via a 1m diameter pipe. It was found that the station had four pumps- without nameplates on both pumps and motors.

Again as in other reviewed stations, the pumps and motors were directly coupled and the flow control was by means of gate valves. The water demand was more than the station could supply and hence, the valves are likely to be fully open always. There was information about extra connections that were not in the original design. In this respect, the pumps were unlikely be operating at the maximum efficiency. There were no Power meters to determine the electric consumption of each or all pumps. This made it difficult to evaluate the pump or motor performances. This was one of the most recent stations constructed (1994). It was therefore expected that such a new station would use the latest energy efficient technology. However, lack of clear guidelines highlighting pump selection criteria and equipment purchased late in the design process to meet a system's dynamic needs, in other words, fitting the system to the pump, rather than the other way around contributed to the above problems. The detailed maintenance schedules for this station are shown in Appendix 6.6. It was not clear if the schedules were adhered to.

4.1.6. Loresho Booster Station

The station receives water from Sasumua and Ruiru dams through a 0.2m diameter pipe. It has two pumps whose motors have the following specifications; 2930 RPM, 30 kW. The pump specifications were not available. These pumps operate one at a time for 12 hours each. They pump to a tower distribution tank some 500 m away through a 0.25m diameter pipe at pressure head of 50.05m of water.

Pumps were coupled directly to motors that were not energy efficient and likely to have been rewound several times. It was evident that the water demand had changed due to growth in population. As such it was likely that the system was being operated off the best efficiency point as a result of the additional connections hence change in the total head and therefore a shift in the system curve while maintaining the same pump curve. Due to the above the system designs needed to be reviewed to take into consideration the changed water demand. Power consumption for each pump could not be established as there were no metering instruments installed; however, maintenance schedules were available as shown in Appendix 6.6.There was no evidence of compliance with the planned schedules.

4.1.7. Lower Kabete Pumping Station

These station pumps water to Kabete treatment works. It has one pump with the following specifications for the motor 1480RPM, 90kW. The pump specifications were; discharge-0.018m^3/ s, head-34.7m, 1460RPM, year of manufacture 1974.

The old pumps and motors were designed with little thought for energy efficiency; they were missing the name plates and having been overhauled several times specifically for the motor sets. This was evidenced by the fact that when a motor failed, it is rewound and not purchased. This has serious implications to EE as this equipment are overhauled not putting into consideration energy efficiency. At the same time, the workmanship and materials used may not be good to have the equipment work as the original that had not been overhauled. Similarly several motors overhauled in one place without proper identification and name plate details end up being coupled with the wrong machines resulting into poor matching hence loss of energy.

The pump was coupled directly to the motor. Power consumption for the pump could not be established as there were no metering instruments installed. Lack of these instruments to measure the current taken in by the respective pump motors makes it difficult to monitor the load current and the efficiency of the pump. Maintenance schedules were available as shown in Appendix 6.6 but there was no evidence of compliance with the maintenance schedules.

4.1.8. Gatina Booster Station

This booster station supplies water to Lavington and Langata. The water originates from Kabete treatment and pumping station. The Gatina station is at an altitude of 1782m above sea level and is approximately 1,672m from Kabete. The station has two pumps, one operating and the other on standby. Each pump operates continuously for twelve hours. The pumps were specified (name plate) as; discharge $0.04m^3/s$, year of manufacture 1987 and motors as; 2955 RPM, 44.8kW.

Concerning couplings, power meters and maintenance, the same as in the previous stations applies. This was found out by observing and also as given by the responses to the questionnaire.

Pump system summary for the whole installation is as shown in table 4. 1. The monthly reports in terms of the pumping hours, the discharge capacity, actual volume pumped, and electricity consumption are shown in tables 4.2 and 4.3. From table 4.2, it was found out those pumps at Gigiri/ Kabete operated at 83% of the discharge capacity of the pumps while for Kabete/Uthiru at 69% and 70% for Kabete/ Dagoreti. The pumping cost in Kenya shillings per unit volume (m^3) for the this stations was 7.4, 11.4 and 10.4 respectively.

A comparison of Gigiri/Kabete, Kabete/Uthiru, Kabete/Dagoret pump stations in Nairobi water and Sewerage Company in terms of cost of pumping per m3 of fluid showed huge variations as shown in table 4.2 and4.3. The cost in Gigiri/Kabete stations was about two thirds of that in Kabete/Uthiru. However a similar comparison of the same stations over different periods showed different results. This could be due to inconsistencies in the operating procedures, faulty equipment at some times indicating inconsistencies in the maintenance procedures.

Comparing the unit cost of pumping and the operating point of the pumps, it was found out that pumps operating close to the rated load are more energy efficient compared to those operating below. This information was for all the pumps and does not show the performance of individual pumps. Information on single pumps would have enabled the energy efficiency opportunities to be estimated more accurately. Similar information was obtained from table 4.3.

Table4.1: Summary of the pump system information at Nairobi water and Sewerage Company

NAIROBI CITY WATER & SEWERAGE COMPANY LIMITED								
PUMP DETAILS						MOTOR DETAILS		
NO.	PUMP DESCRIPTION	PUMP CAPACITY	RPM	PUMP HEAD	YEAR OF MAN.	MOTOR DESCRIPTION	RPM	MOTO RATIN
KAMITI PRISONS PUMPING STATION								
1	Discharging pump	-	-	-	-	Discharging pp motor 1	1445	3.7 kW
2	Discharging pp	-	-	-	-	Discharging pp motor 2	1445	3.7 kW
3	Discharging pp	-	-	-	-	Discharging pp motor 3	-	-
KENYATTA UNIVERSITY PUMPING STATION								
1	Feeding pp	-	-	-	-	Feeding pp motor 1	1440	14.9 kW
2	Feeding pp	-	-	-	-	Feeding pp motor 2	1440	14.9kW
3	Feeding pp	-	-	-	-	Feeding pp motor 3	1450	14.9 kW
4	Feeding pp	-	-	-	-	Feeding pp motor 4	1450	14.9kW
5	Feeding pp	-	-	-	-	Feeding pp motor 5	1450	14.9kW
GIGIRI PUMPING STATION								
	No details	-	-	-	-	Pumping motor 1	1488	709kW
	-	-	-	-	-	Pumping motor 2	1488	709kW
	-	-	-	-	-	Pumping motor 3	1488	850kW
	-	-	-	-	-	Pumping motor 4	1493	850kW
LERESHO PUMPING STATION								
	No details	-	-	-	-	Pumping motor 1	2930	30kW
	-	-	-	-	-	Pumping motor 2	2930	39kW
KABETE PUMPING STATION								
1	Feeding pump	-	-	-	-	Feeding pp motor 1	1465	230kW
2	-	-	-	-	-	Feeding pp motor 2	1465	230kW
3	-	-	-	-	-	Feeding pp motor 3	1465	230kW
4	-	-	-	-	-	Feeding pp motor 4	1470	165kW
5	-	-	-	-	-	Feeding pp motor 5	1480	185kW
6	-	-	-	-	-	Feeding pp motor 6	1480	185kW
7	-	-	-	-	-	Feeding pp motor 7	1480	185kW
8	-	-	-	-	-	Feeding pp motor 8	1480	185kW
9	Feeding pump	-	1470RPM,0.098m^3/s	8.4m	-	Feeding pp motor 9	1470	105kW
	Feeding pump	-	0.098m^3/s,1470RPM	84.6m	-	Feeding pp motor	1470	1160kW
LOWER KABETE PUMPING STATIONS								
1	Discharging pump	0.18m^3/s	1460RPM	34.7m	1974	Discharging pp motor	1480	90kW
GATINA PUMPING STATION								
1	Discharging pp	0.048m^3/s	-	-	1987	Discharging pp motor	2955	44.8KW
2	Discharging pp	0.048m^3/s	-	-	1987	Discharging pp motor	2955	44.8KW

Table 4.2**:** June 2009 Monthly Report of pumping costs (source - Company records)

Station	Actual pumping (hrs)	Pump discharge capacity per hrs pumped m^3	Actual volume pumped m^3	Electricity consumption (kshs)	Costs kshs/m3
Gigiri/Kabete	404	998,547	828,097	6,107,715	7.37
Kabete/Uthiru	121	116,953	80,121	913,746	11.4
Kabete/Dagoreti	88	91,646	63,750	664,543	10.4
Mean values	204	1207146	971968	7686004	9.7

Table 4.3: 4th Quarterly Report of pumping costs (April, May and June 2009)-source-company records

Station	Actual pumping (hrs)	Pump discharge capacity per hrs pumped m^3	Actual volume pumped m^3	Electricity consumption (kshs)	Costs kshs/m3
gigiri/kabete	1649	4,106,525	3,281,644	22,743,150	6.9
kabete/uthiru	461	445,581	321,844	2,865,878	8.9
kabete/dagoreti	549	571,745	455,032	3,308,624	7.2
Mean values	886	1707950	1352840	9639217	7.7

4.2. OPPORTUNITIES TO ENERGY EFFICIENCY, BARRIERS AND MEASURES TO MINIMIZE THE EFFECTS OF BARRIERS TO IMPLEMENTING EFFECTIVE ENERGY EFFICIENCY MEASURES AT NAIROBI WATER AND SEWERAGE COMPANY.

The opportunities for improving energy efficiency established during the study of all the stations by considering the design, operations and maintenance were as summarized below;

1. Each pump system in all the stations need to be installed with metering instruments to be able to monitor flow rates, power consumption and operating hours for each pump. This will provide mechanisms for monitoring of the power consumed to establish the system energy efficiency for appropriate energy efficiency measures to be undertaken. Similarly monitoring the operating hours will assist in planning for maintenance which is also important in improving the energy efficiency of the systems. Flow meter will assist in ascertaining the volume delivered and when compared with the customer billings, leakages can be established and corrected to reduce on water wastage and energy wasted on undelivered water. Energy savings as a result of this opportunity could not be quantified due to lack of specific energy meters and flow meters for every pump. Personal meters could not be installed to get the necessary information due facility regulations.
2. The installation had a great need of installing modern technology equipment that were more energy efficient i.e. variable speed drives, high energy efficient motors and system software to assist in monitoring the operating parameters and taking remedial action on energy inefficient activities at real time. It was established that all the installations had flow varying so much at peak and off peak times, they also practiced rationing and for that matter, multiple pumps alone could not meet these varied operating conditions, variable speed drives needed to be applied and this could provide savings in energy.
3. The stations were designed long time ago e.g lower Kabete in 1974. Since then, much has changed in terms of the pumping need hence the need to review the

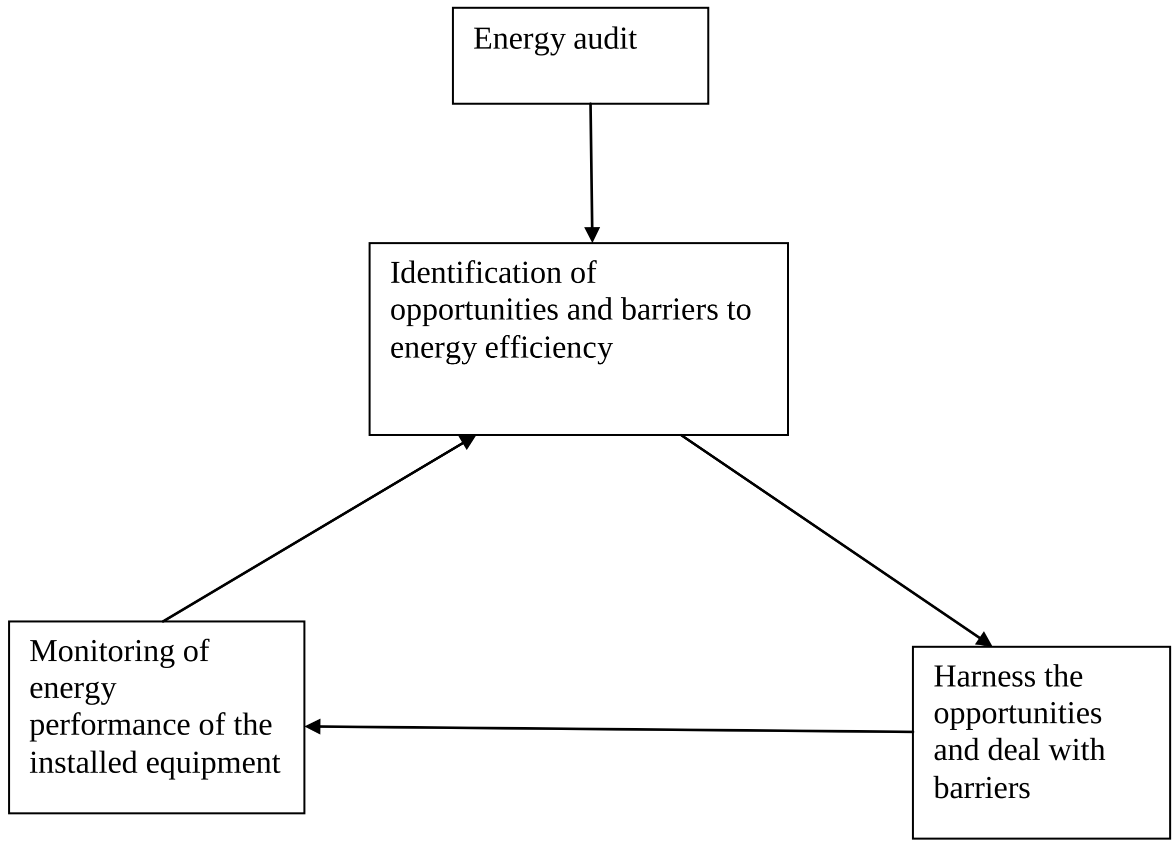
design probably by parallel line operation where an additional separate line is installed with an independent pump motor system. An extra pump could be installed for parallel pump operation. All this is with the view of optimizing the energy efficiency of the equipment. Current performance is off the B.E P as extra connections done to care for the increased customers has changed the system curve for the same pump curve hence a shift in the operating point to a less efficient one.

4. Despite the availability of the maintenance schedules, an interview with the maintenance staff indicated poor compliance with the schedules. Strict compliance with the maintenance schedules will improve the energy efficiency of the pump systems. At the same time, it was found out that maintenance did not take into consideration the aspects of energy efficiency as energy performance of the equipment was not evaluated before and after maintenance.
5. There was no designated energy department in the whole installation. An energy department needed to set up to deal with energy related activities such as energy efficiency improvements. There is need to have a focused approach to energy efficiency by having organizational efforts in terms of budgetary allocation and training aimed specifically to energy efficiency. This will only happen if there is a department to spear head all these activities.
6. Nairobi water and Sewerage Company did not have an energy policy. Developing an energy policy could help put in place mechanisms and strategies for energy efficiency.

There were no performance goals and policies in terms of EE. Installation personnel in charge of the pumping were more concerned about delivery of water but little consideration was given to the efficiency of the service. Minimum attention was given to energy consumed and the efficiency due to lack of awareness. Technical staffs do not access electricity bills and therefore do not understand the energy implication of their actions.

Energy management practices of the installation were reviewed by conducting an interview with the operations manager. The interview focused on why the opportunities for energy efficiency were not implemented. From the interview, the following barriers were established and measures to minimize the effects of these barriers to realizing the expected energy efficiency recommended;

1. There was no energy department /manager at a level high enough in the organization to defend and promote energy efficiency awareness in the organization. The highest staffs relevant to energy were clerks that compile electricity bills for payment. These were in very low positions to promote energy efficiency. Because there was no energy department, there was lack of awareness of the benefits of energy efficiency and poor quantification of the cost of energy due to lack of installed energy metering instruments. An energy department could be set up with budgetary allocation to facilitate energy efficiency activities. Substantive qualified officers could also be posted to the department.
2. It was established that technical staff were not a ware of the existence of energy efficient technologies, and were not trained in the use of these technologies. Required skills include the ability to carry out energy audits, analyze performance data, from which opportunities to implement effective actions can be evaluated and properly justified in terms of the benefits achievable compared with the costs involved. Energy audits were found to be mostly subcontracted who do not sometimes provide sufficient information for energy efficiency improvements and in cases where the work is well done, the recommendations were not followed. Audits are a one-time activity using a seven step by step procedure as indicated in Appendix 6.4. Energy audit could be a one-time activity to act as starting point to energy efficiency measures. This could then be used to identify the opportunities for energy efficiency improvements. Thereafter, monitoring systems could be installed to provide real time information on the various pump system equipment. This could then lead to corrective action should the condition be different from that existing as a standard. This can be represented in the flow chart 4.2. The standard set should compare with that from the national energy policy or the installations' policies on energy management.



Flow chart 4.1: Energy Management Control Systems (EMCS)

3. Limited finance was also another factor hampering the implementation of specific energy efficiency measures. With the absence of an energy department, there was no budget for energy activities. This makes energy activities and hence energy efficiency to be handled on an ad hoc basis. This cannot be sustainable. An energy department could be set up with adequate funding.
4. Corporate priorities are another barrier. It came out clearly that energy efficiency was not a priority in the installation evidenced by lack of an energy department and quantified energy costs that are specific to the pump systems. Energy efficiency could also be given the same weight as water supply to the customers.

4.3. DESIGN, OPERATIONS AND ENERGY MANAGEMENT PRACTICES AT NZOIA SUGAR COMPANY LIMITED.

Nzoia Sugar Company Limited is located in Bungoma District, Western province and is within Kenya’s sugar belt. The company deals with milling raw sugarcane into sugar. Sugarcane from the cane fields i.e., out growers and nuclear estates is transported by trailers .It is then weighed on the cane weighbridge and offloaded either directly on feed tables or in the cane yard for later crushing for example at night. Sugar milling process is explained below and summarized in process flow diagram indicated in chart 4.2, while summary of pump and motor systems for the whole installation is as indicated in table 4.4.

The cane is feed on feed tables using Hilo cranes (side crane) or Gantry cranes (overhead crane).Feed tables are driven by motors and feed cane on to the cane carrier elevator. Cane on the cane carrier elevator passes first knife called chopper , second knife called level knives and fibrizer (with hammers that crush the cut cane).Cane fibre from fibrizer drops on rubber conveyor which passes through a magnet to remove metals from fibre. Fibre mills are driven by steam turbines.

From the rubber belt cane enters the first mill, then the inter carrier number one to the second mill, to the inter carrier number two, then to the third mill, then inter carrier three, then to the fourth mill, then inter-carrier number four and then to the fifth mill called fifth mill tendam.

From the first mill we get first express juice which is screened through a Cush Cush screen and then mixed with juice from other mills with has some imbition water added to wash sugar in the fibres. This imbition water can be hot or condensate. The mixed juice is pumped to a juice weighing scale by mixed juice pumps whose details are as shown in the table below. The pumps overcome a static head of approximately twelve meters, through a pipe of length 40m and diameter of eight inches. Two pumps are used. However only one pump works at a time, being changed over after one week.

From the weighing scale, the juice is mixed with lime and enters preliminary tank. The juice is then pumped by pre-limed pump number one to primary juice heaters. These pumps are two operating one at a time and changing over at the end of the week. The pumps operate a static head of 20meters, through a pipe length of 60 meters and diameter of ten inches. From the primary heaters the juice goes back to the limed tank. In the limed tank, lime is added then the juice pumped to clarifiers through secondary juice heaters using limed pump number three. The static head overcome by these pumps is 20 meters at pipe length of 70 meters and diameter of 0.25m. These pumps operate in parallel with one pump standby.

The juice decants in clarifiers and overflows with clear juice to clear juice tank. Clear juice is pumps from clear juice tank using 2 clear juice pumps to evaporator number one via pre heater. These pumps operate one at a time changing over after a week. These pump overcomes a static head of 12 meters, length of pipe 50 meters and diameter 0.2m. The evaporators evaporate water from the juice producing syrup.

The syrup is pumped directly either to pans hence brown sugar or through sulphitation station to make white sugar. This is done using 2 raw syrup pumps operating one at a time and changing over weekly. This raw syrup pumps operate at static head of 20 metres with a pipe length of 30metres and diameter of 15m. Other pumps dealing with the production of white sugar are the sulphited syrup transfer pumps and sulphited syrup recirculation pumps.

The next process is the pan boiling where crystallization of sugar is done in vacuum pans. The vacuum in the pans is created by high pressure water from the injection pumps which operate at a static head of 30 metres, length of pipe 60 metres and pipe diameter of 0.75m. There are three pumps operating here with two operating in parallel and one standby.

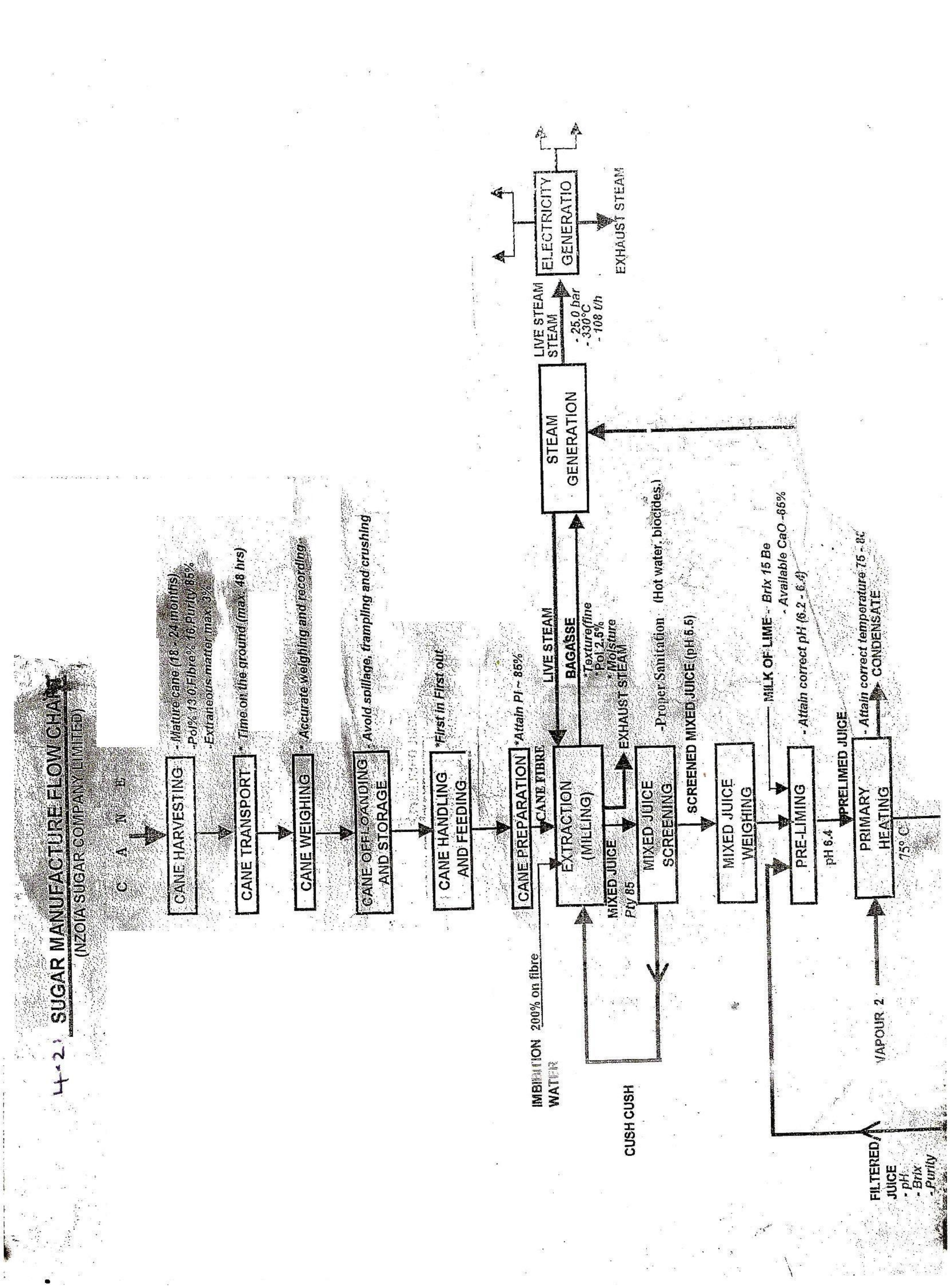
From the pans we get the A, B and C massecutes which are pumped to centrifugal machines by respective positive displacement pumps. From the massecutes we get the molasses.

Table4.4: Summary of the pump system information for Nzoia Sugar Company

NZOIA SUGAR COMPANY								
PUMP DETAILS						MOTOR DETAILS		
NO	Pump Description	Pump Capacity(Q)	RPM	Pump Head (H)	Year of manufacture	Motor Description	RPM	Motor Rating(KW)
1	Limed juice pump 1	$0.069m^3/s$	-	-	-	Limed juice pp motor 1	1470	746
2	Limed juice pump 2	$0.069m^3/s$	-	-	-	Limed juice pp motor 2	1475	55.9
3	Limed juice pump 3	$0.069m^3/s$	-	-	-	Limed juice motor 3	-	-
4	Clear juice pump 1	$0.069m^3/s$	1110	36m	-	Clear juice pp motor 1	-	-
5	Clear juice pump 2	$0.069m^3/s$	1110	36m	-	Clear juice pp motor 2	-	-
6	Clear juice pump 3	$0.04m^3/s$			-	Clear juice pp motor 3	-	-
7	Sulphite syrup pump 1	$0.037m^3/s$	-	-	-	Sulphite syrup pp motor 1	1500	22.4
8	Sulphite syrup pump 2	$0.037m^3/s$			-	Sulphite syrup pp motor 2	1775	29.8
9	Sulphite syrup pump 3	$0.037m^3/s$	-	-	-	Sulphite syrup pp motor 3	-	-
10	Milk of lime pump 1	-	-	-	-	Milk of lime pp motor 1	-	-
11	Milk of lime pump 2	-	-	-	-	Milk of lime pp motor 2	-	-
12	Separating pump	-	-	-	-	Separating pp motor	-	-
13	Liguidation pump 1	-	-	-	-	Liguidation pp motor 1	-	-
14	Liguidation pump 2	-	-	-	-	Liguidation pp motor 2	-	-
15	Hot water booster pump	-	-	-	-	Hot water booster pp motor	-	-
16	Filtrate pump 1	$0.014m^3/s$	-	-	-	Filtrate pp motor 1	1439	
17	Filtrate pump 2		-	-	-	Filtrate pump motor 2	1450	
18	Filtrate pump 3	$0.014m^3/s$	-	-	-	Filtrate pp motor 3	1730	3.7
23	Filtrate pump 4	$0.014m^3/s$	-	-	-	Filtrate pp motor 4	1435	4
20	Wash water pump	-	-	-	-	Wash water pump motor	-	-
21	Primary condensate pump 1	-	975	-	-	Primary condensate pp motor 1	1470	14.9
22	Primary condensate pump 2	-	975	-	-	Primary condensate pp motor 2	-	-
23	Secondary condensate pump 1	-	1460	-	-	Secondary condensate pp motor 1	-	-
24	Secondary condensate pump 2	-	-	-	-	Secondary condensate pp motor 2	-	-
25	Condensate test tank pump 1	-	975	-	-	Condensate test tank pp motor 1	975	18.6
26	Condensate test tank pump 2	-	975	-	-	Condensate test tank pp motor 2	975	18.6
27	Syrup extraction pump 1	-	-	-	-	Syrup extraction pp motor 1	1440	11.2
28	Syrup extraction	-	-	-	-	Syrup extraction pp	-	-

	pump 2					motor 2		
29	Syrup extraction pump 3	-	-	-	-	Syrup extraction pp motor 3	-	-
30	Syrup extraction pump 4	-	-	-	-	Syrup extraction pp motor 4	-	-
31	Sulphited pump 1	-	1500	-	-	Sulphited pp motor 1	-	-
32	Sulphited pump 3	-	1775	-	-	Sulphited pp motor 3	-	-
33	Sulphited pump 2	-	-	-	-	Sulphited pp motor 2	1775	29.8
Table 4.4 cont.								
34	Primary condensate pump 1	-	-	-	-	Pri. Condensate pp motor 1	975	14.9
35	Pri. Condensate pump	-	-	-	-	Pri. Condensate pp motor 2	975	26.1
36	Sec. condensate pump	-	-	-	-	Sec condensate pp motor	1460	15
37	Syrup pump emergency	-	1500	-	-	Syrup pp motor emergency	1500	29.8
38	Caustic soda pump	-	-	-	-	Caustic soda pp motor	1500	11.2
39	Sulphited syrup pump 1	-	1500	-	-	Sulphited syrup pp motor 1	1500	22.4
40	Sulphited syrup pump 2	-	1775	-	-	Sulphited syrup motor 2 emergency	1775	29.8
41	B Magma pump 1	-	1475	-	-	Magma pump motor 1	1475pm	18.6
42	B Magma pump 2	-	1455	-	-	Magma pump motor 2	1475	18.6
43	A molasses pump 1	-	1475	-	-	A molasses pp motor1	1475	18.6
44	A molasses pump 2	-	1460	-	-	A molasses pp motor2	1460	14.9
45	B molasses pump 1	-	1470	-	-	B molasses pp motor1	1470	29.8
46	B molasses pump 2	-	1460	-	-	B molasses pp motor2	1460	14.9
47	B molasses pump 3	-	1475	-	-	B molasses pp motor3	1475	14.9
48	B molasses pump 4	-	1430	-	-	B molasses pp motor4	1430	3.7
49	Clarifier pump1	$0.002m^3/s$	-	-	-	Clarifier pump motor	-	-
50	Clarifier pump1	$0.002m^3/s$	-	-	-	Clarifier pump motor	-	-
51	Clarifier pump1 liquification	$0.014m^3/s$	-	-	-	Clarifier liqufication pump motor	-	-
52	Clarifier pump2 liquification	$0.014m^3/s$	-	-	-	Clarifier liqufication pump motor	-	-
53	Clarifier pump2 liquification	$0.014m^3/s$	-	-	-	Clarifier liqufication pump motor	-	-
54	Injection pump 1	$0.047m^3/s$	960	27m	-	Injection pump 1 motor	1480	110
55	Injection pump 2	$0.047m^3/s$	960	27m	-	Injection pump 2 motor	986	111.9
56	Injection pump 3	$0.046m^3/s$	645	15m	-	Injection pump 3 motor	-	-
57	Injection pump 4	$0.046m^3/s$	645	15m	-	Injection pump 4 motor	990	149.2
58	Injection pump 5	$0.046m^3/s$	645	15m		Injection pump 5 motor	990	149.2
59	River water pump	$0.04m^3/s$	-	100m	-	Pump motor	2970	55.9
60	Raw water pump 1	$0.05m^3/s$	1500	-	-	Pump motor	-	-
61	Raw water pump 2	$0.05m^3/s$	1500	-	-	Pump motor	-	-
62	Decanter water pump 1	$0.05m^3/s$	1500	32	-	Decanter pump motor	40 hp	-
63	Decanter water pump 2	$0.05m^3/s$	1450	52.2				

From the table it can be seen that 80% of the pump systems did not have full name plate details for the motor and pump. There were also no records of the installed systems that could assist in the identification of the pump and motor systems installed.


4-2:
SUGAR MANUFACTURE FLOW CHART
(NZOIA SUGAR COMPANY LIMITED)
CANE
CANE HARVESTING
- Mature cane (18 - 24 months)
- Pol% 13.0 Fibre% 16 Purity 85%
- Extraneous matter max 3%
CANE TRANSPORT
- Time on the ground (max. 48 hrs)
CANE WEIGHING
- Accurate weighing and recording
CANE OFF-LOADING AND STORAGE
- Avoid spillage, trampling and crushing
CANE HANDLING AND FEEDING
*First in First out
CANE PREPARATION
*Attain PI ~ 85%
CANE FIBRE
IMBIBITION WATER
200% on fibre
EXTRACTION (MILLING)
LIVE STEAM
BAGASSE
- Texture fine
- Pol 2.5%
- Moisture
EXHAUST STEAM
MIXED JUICE
Pty 85
MIXED JUICE SCREENING
- Proper Sanitation (Hot water, biocides.)
CUSH CUSH
SCREENED MIXED JUICE (pH 5.5)
MIXED JUICE WEIGHING
MILK OF LIME
- Brix 15 Be
- Available CaO ~65%
PRE-LIMING
- Attain correct pH (6.2 - 6.4)
pH 6.4
PRELIMED JUICE
FILTERED JUICE
- pH
- Brix
- Purity
PRIMARY HEATING
75° C
VAPOUR 2
- Attain correct temperature 75 - 8
CONDENSATE
STEAM GENERATION
LIVE STEAM
STEAM
- 25.0 bar
- 330°C
- 108 t/h
ELECTRICITY GENERATIO
EXHAUST STEAM

4.4. OPPORTUNITIES TO ENERGY EFFICIENCY, BARRIERS AND MEASURES TO MINIMIZE BARRIERS TO EFFECTIVE ENERGY EFFICIENCY IMPLEMENTATION AT NZOIA SUGAR COMPANY

At this installation, 63 pump systems were studied. From the study, which involved the use of a questionnaire, interviews and observation, the following opportunities to energy efficiency were identified;

1. Pumps at the installation were not fitted with metering instruments to be able to monitor flow rates, power consumption and operating hours. Fitting metering instruments would assist in monitoring the power consumed to establish the system energy efficiency for appropriate energy efficiency measures to be undertaken. Similarly monitoring the operating hours will assist in planning for maintenance which is also important in improving the energy efficiency of the systems.
2. The installation did not have modern equipment that were energy efficient like motors and system software to assist in monitoring the operating parameters and taking remedial action on energy inefficient activities at real time. All the pump systems pumping sugar products like juice did not require to be fitted with variable speed drives as the flow was supposed to be constant. However it was necessary to fit variable speed drives to the pump systems pumping water, due to the variation in the quantities of water required for the various processes.
3. Despite the availability of the maintenance schedules, an interview with the maintenance staff indicated poor compliance with the schedules. There was little evidence showing how the schedules were being observed. Strict compliance with the maintenance schedules with documentation of the maintenance actions taken on equipment will improve the energy efficiency of the pump systems. At the same time, it came out clearly that maintenance did not take into consideration the aspects of energy efficiency as energy performance of the equipment was not evaluated before and after maintenance. Similarly it was also noticed that the installation had pump systems that were old, missing the name plates and having been overhauled several times specifically for the motor sets. Motors were not dedicated to the pump sets and were interchanged (mismatched) on failure after

maintenance (rewinding). Rewound motors lost efficiency by up to 3 % of the original due to poor workmanship and materials used during rewinding.

4. There was no designated energy department in the whole installation. For instance the head of the energy department was the factory manager with 500 employees. The factory managers' duties were diverse and energy was just part of them and hence no deliberate organizational goal, effort and resource allocation to EE An energy department needed to set up to deal with energy related issues such as energy efficiency improvement programe.
5. The installation had no energy efficiency policy despite generating its own energy. Setting up of an energy efficiency policy would help put in place mechanisms and strategies for energy efficiency.

In this installation just as in Nairobi water and Sewerage Company, there were no performance norms /goals and policies in terms of EE. Installation personnel in the factory dealing with sugar processing and maintenance were more concerned about delivery of sugar production goals but not about the energy efficiency of the service. They were not concerned about energy consumption and efficiency due to lack of awareness as the technical staff did not get in touch with the electricity bills and therefore did not understand the energy implication of their actions.

From the opportunities listed above the following barriers were established as the causes for not implementing these opportunities;

1. Lack of awareness of the benefits of energy efficiency. This could be due to lack of an energy department and poor quantification of the cost of energy due to lack of installed energy metering instruments and the fact the installation generates its own power for internal use. Lack of awareness of energy efficient technologies also contributed to non-implementation of energy efficiency strategies. Staff could be sensitized on energy efficiency and its benefits.
2. Poor technical capacity of the installation staff. It was established that despite the technical staff appreciating the existence of energy efficient technologies like high energy efficient motors, adjustable speed drives and system control software they

were not trained in the use of these technologies. Technical staff could be trained on modern energy efficient technologies.

3. Consideration of the installations' organizational structure showed that there was no energy department /manager at a level high enough in the organization to defend and promote energy efficiency awareness in the organization. The highest staffs relevant to energy were the electrical engineers and clerks that compile electricity bills for payment. These were in low positions to promote energy efficiency. Energy department could be put in place and senior officers posted to man the department.
4. Limited finance was also another factor hampering the implementation of energy efficiency strategies. This was similar to Nairobi water and Sewerage Company. With the absence of an energy department, there was no budget for energy activities. This makes energy activities and hence energy efficiency to be handled on an ad hoc basis. This cannot be sustainable. Energy department could be set up with sufficient budgetary allocation to fund energy efficiency activities.
5. Corporate priorities are another barrier. This was similar to Nairobi water and Sewerage Company. It came out clearly that energy efficiency was not a priority in the installation evidenced by lack of an energy department and quantified energy costs that are specific to the pump systems. Energy efficiency activities could be given equal priority with others such as sugar production.

4.5. OPPORTUNITIES TO ENERGY EFFICIENCY, BARRIERS AND MEASURES TO MINIMIZE THE BARRIERS TO EFFECTIVE ENERGY EFFICIENCY IMPLEMENTATION AT DAVIS & SHIRTLIFF COMPANY LIMITED.

Davis and Shirtliff was founded in 1946 by E.C. Davis and F.R. Shirtliff. Articles written a bout this company state that it grew from humble beginnings to become one of East Africa's leading specialists in the supply of water related equipment.

It has concentrated its activities in four principle product sectors: Water Pumps, Borehole Services, Water Treatment and Swimming Pools. Recently, the company ventured in to the solar sector with special emphasis on Solar Water Pumps.

Davis & Shirtliff boasts of a fully integrated computer system, world-class and well-equipped repair workshops, efficient mobile service teams, comprehensive spare parts stocks and training facilities that are used for internal and external training courses. The company has a factory where it produces fiberglass mostly for swimming pool filters and other accessories and, steel fabrication.

Distribution of water pumps is Davis & Shirtliff's main activity. The company has fully committed itself to provide an unparalleled pump service justifiably claiming that in its markets nobody knows more about pumps. Davis & Shirtliff offers a wide range of pump products sourced from Grundfos of Denmark, Davey and Ajax of Australia, Pedrollo/Linz of Italy, Flygt of Sweden and Koshin of Japan all who are global leading pump manufacturers.

The comprehensive range includes over 300 different models of water pumps. The models are available ex-stock in all sizes for boreholes, booster, irrigation, drainage, sewage, hot water, chemical dosage, domestic and hand powered applications. A wide variety of special duty pumps for industrial, agricultural and commercial uses are also available.

Davis & Shirtliff offers pump details reference literature in a comprehensive product manual, spare parts (also well documented in a spares manual), service facilities and unique expert advice from a team of highly trained sales engineers.

A wide range of accessories that includes electrical control panels, specialized fittings, control equipment, prime movers is available to ensure that all necessary hardware is available for a complete water installation.

On visiting the organization headquarters and conducting an interview with the human resource manager, marketing manager and technical manager the following issues were evident; that Davis and Shirtilliff offers sales and after sales services in pumping system equipment. They also conduct training in pump systems. However, various opportunities for improving energy efficiency to the pump systems sold and serviced by the organization were identified as follows;

1. There was no energy department; presence of energy department would direct the organizations' effort towards marketing of energy efficient equipment. Maintenance strategies could also be geared towards energy efficiency. Energy department could be set up to advocate for energy efficiency activities.
2. There were also no policies, norms and goals towards EE; leading to ad hoc management to energy related issues. Upper-level management focus on energy was minimum, energy efficiency activities were rarely done, after sales service was done with little consideration on EE.
3. The training programs needed to focus on energy efficiency and energy efficient technologies. As at the time of the survey, training programs focused on the products available in the company and there operation procedure. Training programs focused on energy efficiency will trickle down to the organizations customers. Given that this organization commands approximately 40% of the pump systems market share this will have a direct impact on the energy efficiency of pump systems.

There existed various barriers to implementing the above opportunities and these were;

1. The organization availed information on the costs and performance of specific energy-saving technologies like pump system control panels to pump system

consumers however it did not have the powers to enforce them on pump system consumers. Government could develop and enforce policy guidelines that enhance the use of energy efficient technologies.

2. Even though Davis and Shirtliff provides new technology equipment that is EE, poor enforcement of government regulations especially the energy act 2006 hampers pump system consumers moving in for EE equipment. Government could enforce the already existing energy policies.

4.6. FINDINGS AND DISCUSSION AT SPIN KNIT DAIRY

Spin knit dairy is a milk processing plant located in Nairobi on Nanyuki road industrial area. Due to access limitations only limited information could be obtained from the operations of this installation. The summary of the pump systems is as presented in the table 4.5. From the table, it can be seen that motors and pumps were low capacity with the biggest pump motor in the installation being 7.5 Kw and the smallest being 45W. The biggest pump was used to pump water with a flow rate of $45m^3/hr$ while the smallest pump was for chemical dosing at $0.108m^3/hr$. Pumps for chemical dosing, furnace oil transfer, boilers and chilled water had name plate details. Milk pumps, borehole pumps and cooling tower pumps did not have the name plate details.

Pumps and their motors were not fitted with any monitoring instruments like power meters, flow meters and control panels for monitoring the performance of the pump systems. The existing measurement of energy and other operational performance parameters were not for monitoring energy performance of the pumps. There was the need to install monitoring instrumentation like; on-line energy meters, pressure gauges, hour meters to log operating hours of each pump and water meters.

It was also noticed that 90 % of the pump systems were less than 10years old, hence relatively new but missing the name plates. Despite being relatively new compared to other installations, they were not energy efficient as seen from their construction (up to 60% more copper for the energy efficient motors).

There was no energy management department. This meant that there was little emphasis on energy efficiency measures in the installations’ activities.

Table4. 5: Summary of the pump system information for Spin Knit dairies.

Spin Knit dairies								
PUMP DETAILS						MOTOR DETAILS		
NO.	PUMP DESCRIPTION	PUMP CAPACITY (Q)	RPM	PUMP HEAD(H)	YEAR OF MAN.	MOTOR DESCRIPTION	RPM	MO RA (HP
1	Bore hole pump duty	-	-	-	-	Bore hole pump duty motor	-	-
2	Bore hole pump standby	-	-	-	-	Bore hole pump standby motor	-	-
3	NCC booster pump		-		-	NCC booster pp motor	2870	2..2
4	Factory booster pump 2	$16m^3$	-	34.4m	-	Factory booster pp 2 motor	2880	3kW
5	Factory booster pump 3	$16m^3$	-	34.4m	-	Factory booster pp3 motor	2880-2910	3kW
6	Factory booster pump 4	$16m^3$		34.4m	-	Factory booster pp 4 motor	2880-2910	3kW
7	Hydrant pump 5		-	-	-	Hydrant booster motor	2850	4kW
8	Chemical pump 6	-	-	-	-	Chemical pp motor 6	-	45w
9	Chemical pump 7	-	-	-	-	Chemical pp motor 7	-	45w
10	Pump 8	$0.00003m^3/s$	-	38-20m	-	Pump motor 8	2900	4kW
11	Pump9 back wash pump	-	1160	-	-	Back wash pp motor 9	1140	4.6k
12	Furnace oil transfer pump	-	-	-	-	Furnace oil transfer pp motor	960	4kW
13	Boiler no.1 feed pump	6m3	2900	101.5m	-	Boiler no 1 feed pp motor	2900	3kW
14	Boiler no.2 feed pump	5.7m3	2900	238m	-	Boiler no 2 feed pp motor	3480 3520	4kW
15	Chilled water pump no. 1	0.0125m3/s	2900	38.7m	-	Chilled water pp motor1	2890	7.5k
16	Chilled water pump no. 2	0.0125m3/s	2900	38.7m	-	Chilled water pp motor 2	2890	7.5k
17	Chilled water pump no.3	0.0125m3/s	2900	38.7m	-	Chilled water pp motor 3	2890	7.5k
18	Chilled water pump no.4	0.0125m3/s	2900	38.7m	-	Chilled water pp motor no.4	2890	7.5k
23	Condenser Recirculation pp no.1	-	-	-	-	Recirculation condenser pp motor no 1	2880	4.5k
20	Condenser Recirculation pp no.2	-	-	-	-	Recirculation condenser pp motor no. 2	2880	4.5k
21	Cooling tower duty pump	-	-	-	-	Cooling tower duty pp motor	2890-2910	5.5k
22	Cooling tower recirculation pump	-	-	-	-	Cooling tower recirculation pump motor	-	2.2k
23	Alcip 20 pressure pump	-	-	-	1996	Alcip 20 pressure pp motor	2850	-
24	Alcip 100 pressure pump	-	-	-	-	Alcip 100 pressure pp motor	2855	5.5k
25	Alcip 100 pressure pump(stand by)	-	-	-	-	Alcip 100 pressure pp motor(standby)	-	-
26	Alcip 20 metering pump for lye	$0.00006m^3/s$			2005	Alcip 20 metering pp for lye motor	-	-
27	Alcip 100 metering pump for lye	$0.0001m^3/s$			1999	Alcip 100 metering pump for lye motor	-	-
28	Milk reception pump tankers	-	-	-	1998	Milk reception pp tankers motor	2850	-
29	Milk reception pump farmers	-	-	-	1998	Milk reception pump-farmers motor	2850	-
30	Raw milk pump (lacta line 2-10kl/hr)	-	-	-	1997	Raw milk pp(lacta line1-7kl/hr) motor	2870	2.2k
31	Raw milk pump (lactaline2-10kl/hr)	-	-	-	1997	Raw milk pp motor(lacta line 2-10)	2870	2.2k
32	Pasteurized milk pump – flex1	-	-	-	1998	Pasteurized milk pp flex1 motor	2900	2.2k
33	Pasteurized milk pump – flex 2	-	-	-	2004	Pasteurized milk pump flex 2	2900	2.2k
34	Pasteurized milk pump – Nimco	-	-	-	-	Pasteurized milk pp motor – nimco	2900	3.0k
35	Pasteurized milk pump – TC	-	-	-	-	Pasteurized milk pp motor-TC	-	3.0k
36	Pasteurized milk pump-flex 1	-	-	-	1999	Pasteurized milk pp motor flex 1	2000	3.0k
37	CIP return pump-TC	-	-	-	1998	CIP return pp TC motor	2000	5.5k

Table4. 5 continued

38	CIP return pump- tank 10	-	-	-	1998	CIP return pp tank10 motor	1450	5.5k
39	Cream heater pump	-	-	-	2000	Cream heater pp motor	1400	2.0k
40	Rotary lobe pump mala/yoghurt cooling line	-	-	-	-	Rotary lobe pump mala/yoghurt cooling line motor	260	3.0k
41	Rotary lobe pump-cream line	-	-	-	-	Rotary lobe pump cream line motor	-	-
42	Pump no. 10	-	-	-	-		2870	5.5
43	Pump no. 11	-	-	-	-		2870	5.5

4.7. DESIGN, OPERATIONS, MAINTENANCE AT KENYA PIPELINE COMPANY LIMITED

The company was set up to provide the efficient, reliable, safe and least cost means of transporting petroleum products from Mombasa to the hinterland. From company information sources KPC has the mission of efficiently, economically and safely transporting, storing and delivering petroleum products to customers, with respect for the environment.

The 0.36m (14”) diameter and 450,000m long pipeline from Mombasa to Nairobi (Line 1) was commissioned in 1978. However as part of the business development program of the organization, an extension of the pipeline to other parts of the country has been done creating a pipe network of 896,000m from Mombasa through Nairobi, Nakuru and Eldoret to Kisumu. The 446,000m pipeline extension was completed and commissioned in 1994. Pipeline network traversing the country is as shown in figure 4.5

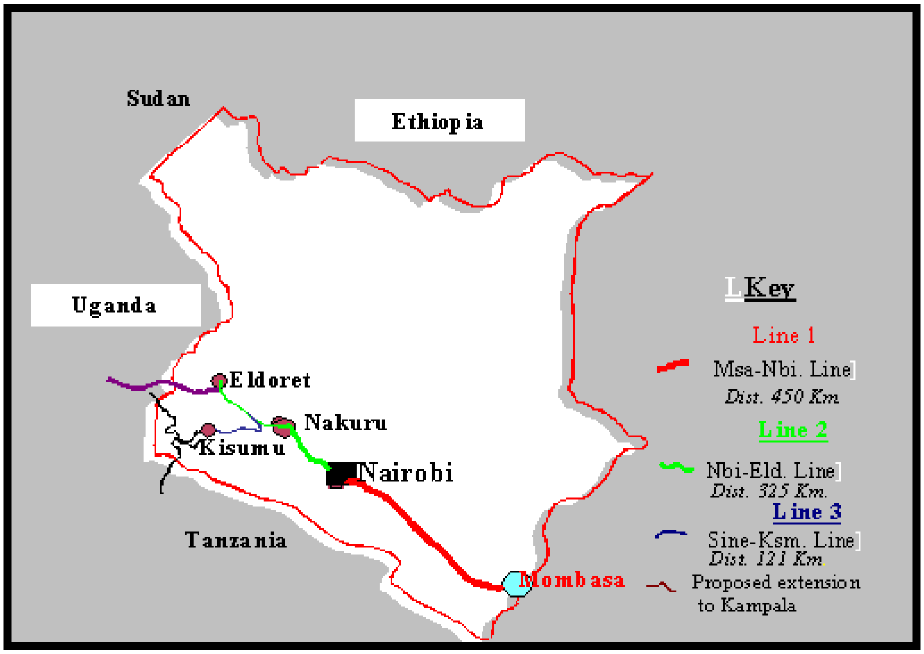


Figure 4.5: a line sketch of Kenya pipeline company network route from Mombasa (PS1) to Nairobi (PS10) and onwards to Eldoret and Kisumu.

The pipeline transports four different grades of refined petroleum products namely; Motor Spirit Premium (MSP), Motor Spirit Regular (MSR), Automobile Gas Oil (AGO), Jet A-1 and

Illuminating Kerosene (IK); all products are transported in a single multi-products line in batches. The responsibility of ensuring that there is no product contamination is assigned to the quality control section, which provides quality assurance of all products passing through the line on behalf of various oil companies at a fee. This fee was not established for confidential reasons.

4.7.1. Operations of the pipeline

The pipeline is centrally controlled and monitored 24 hours from Nairobi Terminal depot. The operation is mainly by remote control through a Supervisory Control and Data Acquisition System (SCADA). The SCADA system assists in monitoring the various operating parameters among them being the flow rates and pressure. Flow rates are important as they provide the volume of the product transferred either to the customers or the other stations for onward pumping. Flow pressures are important as the pipeline transports various products of different densities that have to be transported keeping a minimum length of the interfaces between the products. This is done by ensuring that the pressures do not fall. Other communication facilities used to enhance operations efficiency include: teleprinters, telephones, portable two-way radios, VHF radios, omnibuses, vehicles and helicopters.

A receiving tank at the Kenya Oil Storage Facility (KOSF), located in Kipevu area of the Port of Mombasa, is designated and initialized before receiving imported product. Imported product is then received into the KOSF through the Kipevu Jetty offloading facility. Product quality and quantity are determined after the receiving tank has settled. The product is then pumped from KOSF into the mainline to Nairobi via Pump Station 1 (PS1), located at Changamwe for onward transportation to Nairobi.

Locally produced refined products are received from the Kenya Petroleum Oil Refineries Limited (KPRL) directly into PS1 from where they are pumped via the same 0.36m diameter pipeline over a 450,000m distance to Nairobi in pre-determined batches. Jet A-1 product is transferred to PS12 from the Kenya Petroleum Refineries Limited (KPRL) via an off-take line from the dedicated Jet A-1 line from KPRL to PS1.

A batch number uniquely identifies each batch. The product is transported via the pipeline, which is maintained under pressure by means of booster pump stations, PS3, PS5 and PS9 located along the Mombasa-Nairobi Line 1. The average flow rate through Line 1 is 440 m3 per hour.

Products are received in designated storage tanks at pump station 10 (PS10) in Nairobi while some Jet A-1, for domestic usage within Kenya, is received and stored at Embakasi (PS 9). At Embakasi, Jet A-1 quality is controlled during receipt and distribution in accordance with the Joint International Group (JIG) standards.

The interface between two successive product batches is carefully monitored and controlled to avoid product contamination. Product interfaces are received in designated storage tanks from where the quality and quantity are determined before controlled blending with pure products in designated storage tanks.

Refined products for local use within Nairobi area are transferred to customer depots located within the vicinity of PS10 as required by the respective customers. Refined products for use in the Western Kenya towns of Nakuru, Eldoret and Kisumu, their environs and exports to the neighbouring countries are transported further from Nairobi to Nakuru via a 0.2m (8") diameter multi-product pipeline.

At Nakuru (PS 25), some products for domestic use are received into storage while the remaining products are pumped to Eldoret and Kisumu (Lines 2 and 3, respectively as shown in figure 4.5) via the branching point at Sinendet. These branch lines are 0.15m (6") diameter in size. At both Kisumu and Eldoret, the products and interfaces are received into designated storage facilities where they are left to settle before quantity and quality determination is done. Interfaces are blended with on-specification products in a controlled manner to maintain product quality. At Kisumu and Eldoret, products are loaded into customer trucks for further distribution into the hinterland. The pipe network, stations and respective location altitudes are as indicated in figure 4.6.

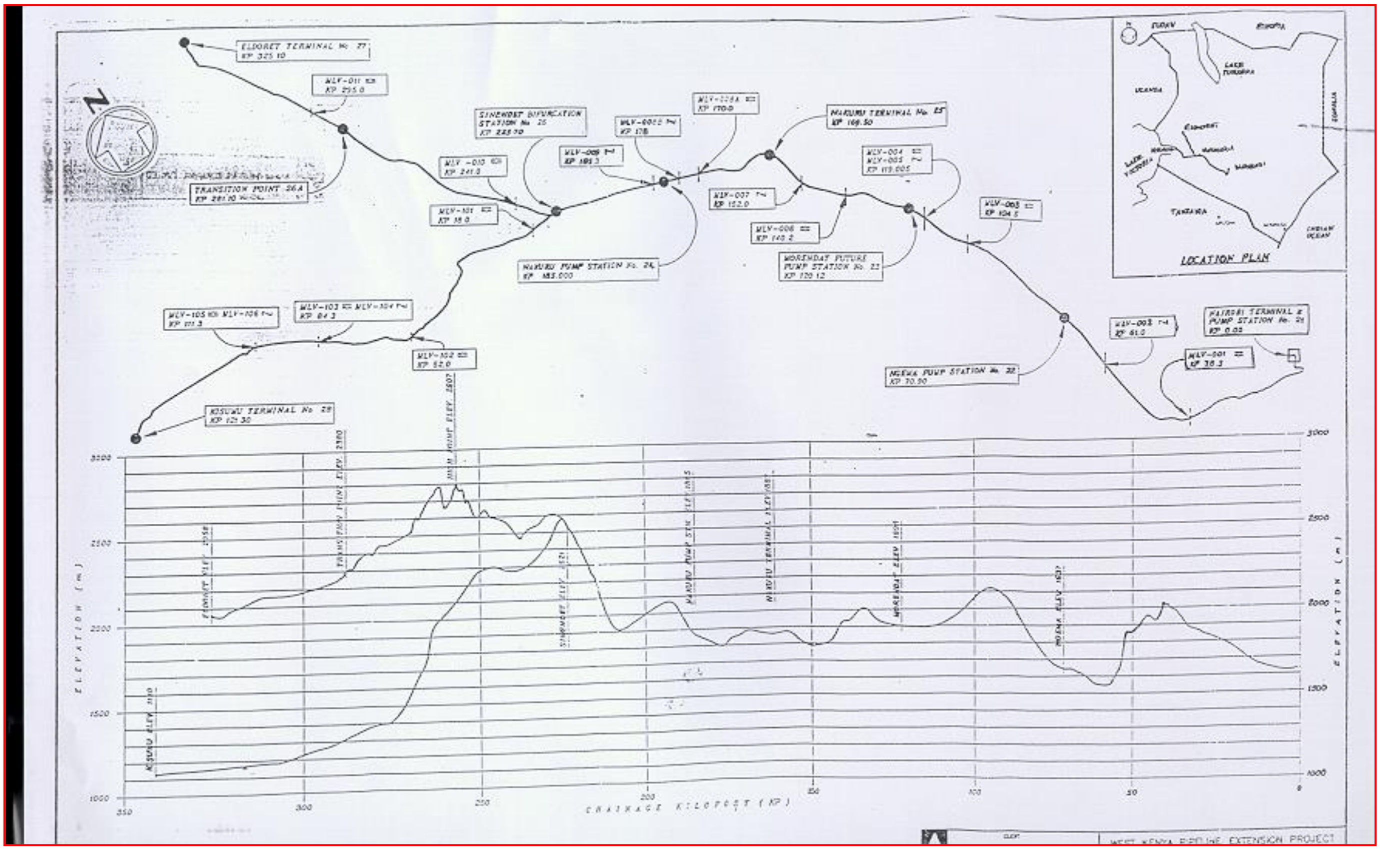


Figure 4.6: Kenya Pipeline Company pumping stations and respective location altitudes.

All the operations are controlled remotely from a central control room in Nairobi but local intervention is also possible at any point along the pipeline. All products are transported on behalf of customers who own the products and have entered in a formal Product Transport and Storage Agreement with the KPC. The customer's order and receive products at various points from the pipeline based on their product entitlement.

Customers place their orders either directly to the KPC depots or through their designated representatives. Customers in Nairobi are served by product dedicated transfer pumps at PS 11 while those of western Kenya by two main line pumps at PS 21.

4.7.2. Transfer pumps

These are pumps that transfer products for local use within Nairobi area. Customer depots namely shell, national oil corporation, caltex, kenol-kobil and total located 200m away were the destinations for these products. They in turn distribute as required by the respective customers. This takes place through product dedicated pumps and lines. Table 4.6 shows the transfer pump motor capacities. This is done on request by the various oil companies which liaise with the scheduling section to be given stock entitlement.

Table4.6: Transfer pump motor ratings at PS 10

Item	Transfer Motor	Number Installed	HP rating per motor	Product
1	11P411	2	10	IDF
	11P412			
2	11P111	3	25	MSR
	11P112			
	11P113			
3	11P211	2	50	MSP
	11P211			
4	11P311	3	50	AGO
	11P312			
	11P313			
5	11P511	2	20	KERO
	11P512			
6	11P711	2	25	JET- A1
	11P712			

All the motors are three phase induction motors running at 415V, 50 HZ AC supply

It was noticed that product transfers took longer time than necessary (sometimes 4hours) depending on the volume being transferred. This was due to the transfer pipe sizes being small i.e. 0.15m (6”) pipe for MSR, 0.25(10”) m pipe for MSP, 0.2m (8”) pipe for K, 0.3m (12”) pipe for AGO and 0.15m (6”) pipe for AV. At the same time, there was mismatch of motor-pump set-product line for instance a 0.15m (6”) product lines coupled with a 25hp motors while a 0.2m (8”) line coupled with a 20hp motor this could have been reversed. The pumps were designed to operate singly with one on standby.

4.7.3. Pumping Station no.21 (PS21)

The study of Kenya Pipeline Company Limited was conducted at PS 21. PS21 is the originating station for the oils being pumped to western Kenya and is located in Nairobi. This study covered the station together with the pipe network to the first booster station at Ngema located at a distance of 70,000 m.

In addition to the study of PS21, an assessment of the pumping systems that transfers oils to the marketing companies like Total and National was also studied i.e. PS11. Transfer to the marketing companies is a local transportation of oils to the companies located approximately 200m away from PS11.

Products had to be received at PS 10 and then stored in storage tanks at PS 11 before being transported to the Western region. The transfer to Western Kenya takes place through a 0.2m (8") Steel commercial pipe using two multi stage pumps. The original operating design for these mainline pumps was of single operation with one pump being on standby. However as at the time of study, the pumps were being run in parallel due to increased demand for the products. Towards the end of April and the beginning of May, a by-pass line to Western Kenya was under construction. Previously all fuel to western Kenya had to be received at PS 10 before transportation to Western Kenya.

From the companys' point of view, the SCADA system was found to be the one suitable for use to monitor the performance of the pipeline equipment and accessories of any deviations from the designed desired flow rates and pressures. This is because any deviations from the designed parameters could mean failure to achieve the pumping objective of that period in terms of volume targets and quality (I.e. low pressure will result into long interfaces between different products being pumped). This is undesirable as it causes more products sent to the slope tanks for further separation. This could also be costly to the company from the energy point of view given that optimal energy performance is at the design point of the equipment. However the SCADA system does not provide energy information as was with other flow parameters.

For the purposes of discussing Kenya Pipeline Company, the operations of the pipeline were viewed from the point of the control room and the scheduling sections of the organizations. The decisions made in these two sections were considered important to the energy performance of the pump systems in the organization as they interact directly with the pipeline and associated accessories which as pointed out earlier on are of importance to the energy performance of pump systems.

However, other sections in the organization like mechanical, electrical and instrumentation and control were also found to be important in optimizing the energy performance of the pump systems in the organization. These departments maintain the pumping system. Well-maintained machinery is more energy efficient and exhibits lower frictional losses, minimizes system vibration hence optimizing on the operating speeds and decreased operating temperatures.

Despite the existence of the above mentioned departments, management did not have energy efficiency consciousness. This can be seen from the fact that no attention was given to the power ammeters and voltmeters installed to record the power consumption of the various pump systems. Energy management practices needed to be developed to make use of the installed energy metering instruments. This could be achieved by; setting up an energy department to implement EE, enacting an energy policy and implementing it.

The fact that smaller capacity pumps exhibit lower efficiencies than higher capacity designs shows why the installation needed to give equal weight in maintaining small and large pumps and should not argue that small pumps consume little energy hence need not to be attended to as much as the large pumps . Smaller pumps were given less attention in terms of maintenance from the comprehensive maintenance details to the large pumps with less regard to the small pumps. This is illustrated by the sample maintenance chart for PS21-2004/2005 of Kenya pipeline in Appendix 6.6.1. There were generalized energy bills meaning that the energy behavior of individual pumps could not be established for corrective action.

Maintenance practices did not take into consideration the energy efficiency of the maintained pump set; only function ability was considered. There was no knowledge of the mode of operation of the parallel pumps at PS 21.This should take into consideration the fact that the pumps were to be started bearing in mind the strength of each pump. It should also be noted that, parallel pumping at PS 21 may not be the solution to meeting the demand of western Kenya as the original design did not take into consideration parallel pumping. Equal attention was not given to small pump sets as is given to big mainline pumps.

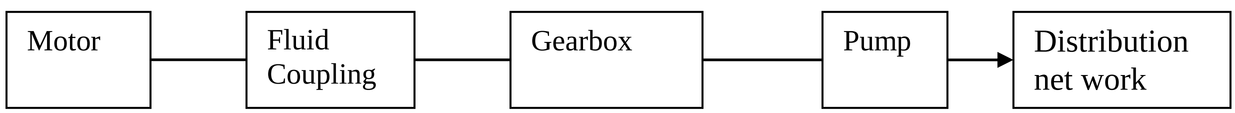
Discharge pipe 1 joint discharge pipe for two pumps Discharge pipe 2

Figure 4.7: discharge pipe layout for parallel pumping at PS 21 Nairobi.

The mainline pumps to western Kenya at the Nairobi terminal i. e. PS21 are as shown in figure 4.7.The pumps were found to be operating in parallel as at the time of the study. However, the original design was for single pump operation with one standby as seen from the discharge pipe configuration of both pumps, they pump into each other during parallel pumping hence choking their own developed pressure. They were not meant to be operated in parallel the installation had attempted to operate them in parallel at the time of the study. The results showed a change in flow from approximately a mean value of 223m^3/hr during single pump operation to a mean value of 229m^3/hr during parallel pump operation as shown in tables 4.8 and 4.9 respectively. This was too low as compared to the theoretical value of approximately 440m^3/hr when operating the two pumps in parallel. Despite minimum change in volume pumped, the energy consumption was nearly double as indicated in table 4.7 power demanded at the time of parallel pump operation rose to as high as 2310 KVA as compared to 1410 KVA during single pump operation.

Proper understanding of the strength of both pumps at PS 21 would be essential for proper parallel pump operation. Operation of the parallel pumps takes into consideration the fact that pumps are to be started bearing in mind the strength of each pump with the weak pump being started first.

The pumping system in the pump house was found to comprise of the motor, fluid coupling, gearbox and the pump coupled as shown by the line assembly diagram (flow chart 4.3) and photographs in figure 4.8.



Flow chart 4.3: Equipment layout at ps21

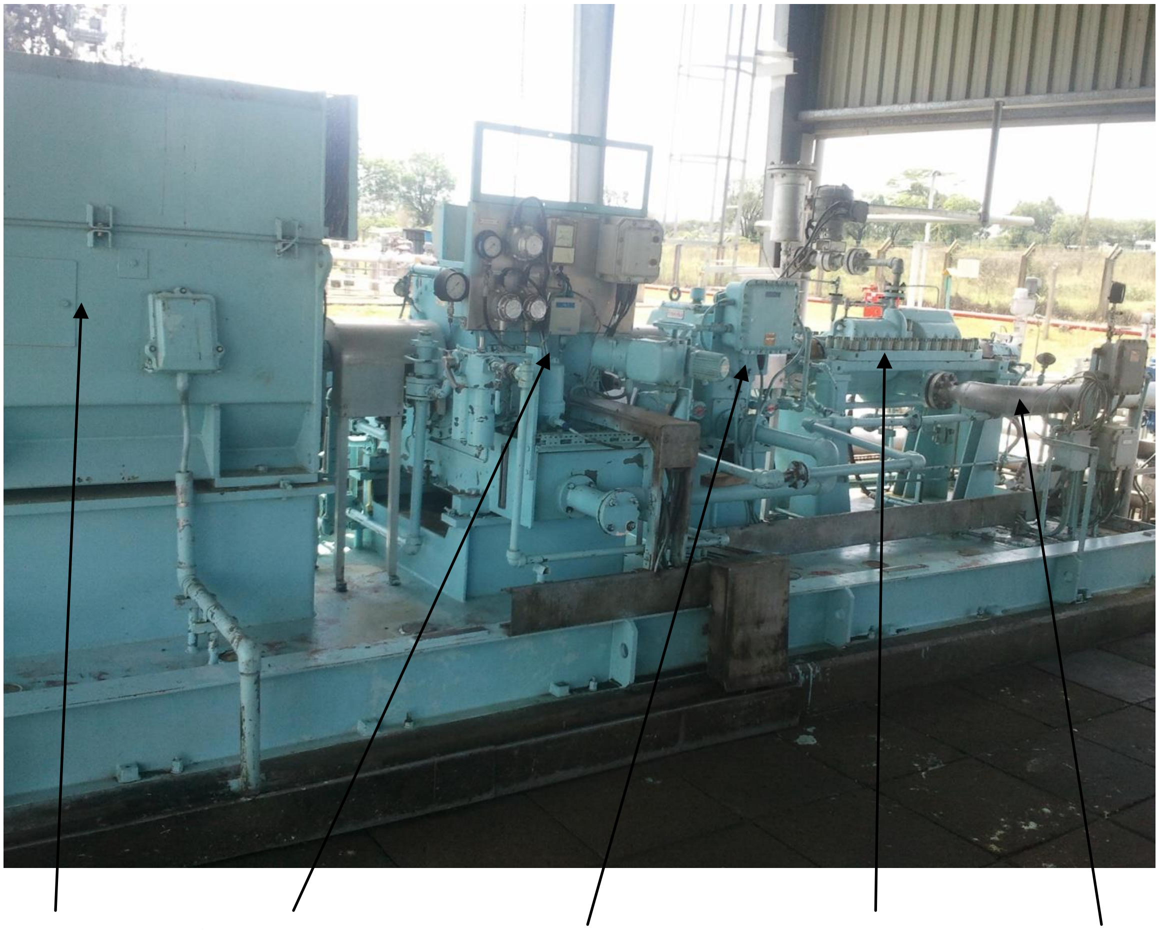


Figure 4.8: Motor, fluid coupling, gearbox and pump assembly at pumping station 21 at Nairobi.

The pumping system was found to be having inherent energy wastages such as pressure control valves, the long coupling of the motor, fluid coupling, gearbox and pump, strainers and the design of the delivery sides of the two mainline pumps.

There was a separate room- called the switch room set side to house the controls to the pumping system. A current of 4mA to 20mA was found to be used to transmit a signal of the condition in the pumping system to the switch room which will then be picked up at the control room. The whole system was monitored from a central room called the control room by a team of operators working on a 3 shift system. This team of operators worked by liaising with the scheduling section. The scheduling section gives the stock entitlement to be pumped for that particular period.

During the data collection exercise at PS21 data in tables 4.8 and 4.9 was gathered from which table 4.10 was developed. From these data, the pumps of PS 21 were found to be operating at a mean speed of 4617 RPM at a flow of $222m^3/hr$ for single pump operation and 4160 RPM at a flow of $229m^3/hr$ for parallel pump operation. However, the manufacturer's optimal operating speed was 4990 rpm. The optimal speed for the mainline pumps at PS 21could not be achieved because the operating pumps vibration at the time of the study 1.1microns would go beyond that set by the control system i.e. first alarm at 1.5 microns and the second alarm comes on at 3.0 microns.

The vibration problem is combinations of various factors among them are the design problem and maintenance problem. In fact maintenance problem is a consequence of the design problem. The long chain of the motor, fluid coupling, gearbox and the pump could have been eliminated by a simple easy to maintain design of only the motor fitted directly to a variable speed drive and pump. Long chains of equipment assembled together are difficult to maintain in terms of balancing as illustrated in section 2.2.2 of literature review and the maintenance sample report attached in Appendix 6.6.5. Lack of balance is what brings about the high vibration problem.

Equally, the optimal discharge could not be realized i.e. $280m^3$ for single pump operation and approximately 560 m^3 for parallel pump operation because of loses in the pipes due to friction and failure to operate the pump at the manufacturers recommended speed. The desired flow rate to western Kenya- $280m^3/hr$ could be achieved by operating at the manufactures best efficiency point i.e. at 4990 rpm of pump. This could be possible only if other limitations like vibration levels and the temperature at the various points could be handled by the maintenance department. These could be achieved without further capital investments but with the perfecting on the maintenance practice. High vibrations could be attributed to poor maintenance due to fact that if the manufacturers optimal speed was 4990 RPM at a flow of $280m^3/hr$, then it was expected that minimum vibrations should exist at the B.E.P and higher as you move off to the left and off to the right of the B.E.P.

However this was not true for the pumps and the only explanation that could be given is poor maintenance.

Pump curves are generated by tests performed by the pump manufactures based on a specific gravity of 1.0; hence, the variation between the design flow and the actual flow could also be because of the different operating specific gravity of approximately 0.735.

The long term solution to the vibration and temperature problem could be obtained by the elimination of the long coupling comprising of the drive motor coupled to the fluid coupling then the gearbox and finally to the pump by replacing it with a drive motor fitted with a variable frequency drive direct coupled to the pump.

The temperature at various points of the pump bearings was not a limitation. Oil temperature entering the plain/thrust end bearings should be maintained at arrange between 15.6^{o}C and 71^{o}C. The alarm temperature was 76.7^{o}C while the mean operating temperature was found to be 33.38^{o}C way below the alarm temperature.

Capacity enhancement can be achieved by the use of a 10 inches pipe for a flow of up to 340m^3/hr with a saving of energy. A 12 inches pipe could also used to provide more energy savings depending on the strategic plan of the company regarding the potential for business growth. If the company plans to serve even bigger geographical area then the twelve inches pipe and above would be ideal.

Graphs showing the performance of the pumps were also sketched as shown in graph6.2.1, 6.2.2 and 6.2.3 in Appendix 6.2. The measured mean power input at the motor for driving the pump to transport the fuel along the 8 inch line between PS21 and PS22 was also determined as 1066.5 kW from table 4.7 and sample calculations in Appendix 6.3. This value differs from that measured at the time of parallel pumping of 1538 kW because the former is an average of single pump operation round the year. This is an indicator of the fact that the system was not designed for parallel pump operation as the discharge did not change to justify the huge power difference. The calculated water horse power was determined to be 933kW (see sample calculations in Appendix 6.3) .For parallel pump operation; the loss is 605 kW as compared to single pump operation where the loss is 134 kW.

Table4.7: Energy consumption data for PS21 for the year 2006 (Kenya pipe line)-source company records

PS 21	**ACC. NO. 0531725**	**2006**	
MONTH	**AMOUNT PAID KSH.**	**kWh TOTAL**	**MAXIMUM DEMAND KVA**
JANUARY	6,931,511.60	893200	1750
FEBRUARY	6,309,982.00	809800	1720
MARCH	5,585,421.10	637800	1700
APRIL	6,043,638.00	828200	1790
MAY	5,735,284.00	721400	1570
JUNE	5,726,778.30	767000	1390
JULY	5,620,538.40	718800	1400
AUGUST	6,757,112.50	790400	1460
SEPTEMBER	6,426,485.20	777100	1740
OCTOBER	7,543,514.90	812900	2310
NOVEMBER	6,723,766.60	753500	1450
DECEMBER	5,366,923.50	704600	1410
TOTAL	**74,766,956.10**	**9214700**	

For the 0.2m diameter pipe the operating velocity at the time of the study was 1.92m/s between PS21 and PS22 which was below the recommended value of 2.1- 4.6 m/s for oil as indicated in table 6.1.5 of Appendix 6.1.

The Reynolds number as 5.13×10^5. The friction factor was 0.0152 while the pressure head was 994.08 m and the surface roughness as 0.06. The calculated power consumed to move one cubic meter of fluids for a distance of one meter along this line was found to be 4.8 kW/m^3 (see sample calculations Appendix 6.3).

Table 4.8: Pumping data for pump 02

P1	P2	P3	Q	T1	T2	N
5.83	87.12	15.37	224.66	34.31	34.9	4695
5.57	83.46	16.79	234.35	34.38	35.05	4695
5.74	83.35	14.25	230.04	34.33	35	4654
5.96	85.07	8.39	224.35	34.05	34.78	4655
5.99	86.39	9.77	222.23	34.11	34.68	4655
5.91	84.23	10.36	224.7	34.11	34.8	4635
5.89	84.38	11.5	224.35	33.98	34.79	4636
6.22	86.57	11.73	211.39	34.09	34.51	4595
6.38	102.47	24.87	209.02	30.65	32.45	4616
6.37	101.77	17.3	218.18	32.25	31.37	4655
5.98	93.05	20.64	225.15	29.17	32.34	4695
5.52	81.41	15.31	236.51	34.3	35.06	4675
5.77	83.75	17.52	231.47	34.4	35.01	4675
5.74	83.46	18.16	228.94	34.35	35.01	4655
5.89	83.68	14.93	221.39	34.25	34.89	4615
5.42	73.06	11.63	248.23	32.52	33.92	4616
5.83	93.49	23.85	212.59	32.74	33.97	4523
6	91.59	23.97	202.78	32.91	33.97	4440
5.89	93.53	14.66	214.95	33.75	35.17	4518
5.52	79.36	14.66	206.83	32.9	35.17	4459

From table 4.8, P1= pump inlet suction pressure (bars), P2=pump outlet discharge pressure (bars), P3= pipeline end discharge pressure at 70km, Q =flow rate, T1 and T2= bearing temperatures, N = pump speed (RPM).

Table 4.9: Pumping data for parallel pump operation

P1	P2	P3	T1	T2	Q (m3/Hr)	N1	N2
5.8	99.35	11.54	35.49	35.99	222.8	4093	4241
5.54	100.2	10.72	35.07	35.06	225.01	4152	4161
5.2	88.99	16.23	34.13	34.34	268.55	4330	4340
5.44	104.15	10.59	34.05	34.56	233.23	4290	4281
5.81	108.58	22	34.3	33.74	223.44	4349	4340
6.56	98.29	17.52	31.07	33.12	209.01	4211	4182
5.28	89.65	23.32	34.22	34.4	267.45	4349	4340
5.9	103.71	14.66	34.59	35.17	223.37	4230	4222
5.86	99.98	12.57	35.47	36.08	222.77	4093	4261
6.29	77.78	33.54	34.59	36.17	203.93	3740	3789
5.26	72.69	17.49	33.91	34.78	233.35	3916	3828
6.36	92.54	10.21	35.13	35.13	223.5	4053	3966
MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN
5.78	94.66	16.36	34.34	34.88	229.37	4150.5	4162.58

Table 4.10: Values for determining the value of a in the equation; $H = h + aQ^2$ for PS 21 Parallel pumping

Q actual	T1	T2	N	Q^2	H	A	H	Q
224.66	34.31	34.9	4695	0.003894	995.0973	250894.6	18	0
234.35	34.38	35.05	4695	0.004238	924.643	213949.6	25.96302	20
230.04	34.33	35	4654	0.004083	958.3446	230295.4	49.85207	40
224.35	34.05	34.78	4655	0.003884	1063.471	269233.7	89.66717	60
222.23	34.11	34.68	4655	0.003809	1062.639	274234.6	145.4083	80
224.7	34.11	34.8	4635	0.003896	1024.5	258352.4	217.0755	100
224.35	33.98	34.79	4636	0.003884	1010.769	255623.7	304.6687	120
211.39	34.09	34.51	4595	0.003448	1037.952	295812.2	408.1879	140
209.02	30.65	32.45	4616	0.003371	1076.231	313913.3	527.6332	160
218.18	32.25	31.37	4655	0.003673	1171.51	314048.4	663.0045	180
225.15	29.17	32.34	4695	0.003911	1004.251	252143.9	814.3023	200
236.51	34.3	35.06	4675	0.004316	916.7377	208227.9	981.5252	220
231.47	34.4	35.01	4675	0.004134	918.5407	217830.6	1164.675	240
228.94	34.35	35.01	4655	0.004044	905.6426	223482.4	1363.75	260
221.39	34.25	34.89	4615	0.003782	953.4905	247359.4	1578.752	280
248.23	32.52	33.92	4616	0.004754	851.9697	175406.9	1809.679	300
212.59	32.74	33.97	4523	0.003487	1021.31	287709.6	2056.533	320
202.78	32.91	33.97	4440	0.003173	993.2944	307390.5	2323.312	340
214.95	33.75	35.17	4518	0.003565	1093.844	301772.4	2598.018	360
206.83	32.9	35.17	4459	0.003301	897.3212	266394.6	2892.65	380
222.6035	33.3775	34.342	4617.9	0.003832	994.078	258001.8	3203.207	400
							3529.691	420

Maintenance was organized on annual basis with different equipment receiving different attention over the whole maintenance period. The maintenance schedules are as indicated in Appendix 6.6. The mainline pumps at PS21 were given special maintenance attention as evidenced by comprehensive maintenance data like alignment readings recorded during maintenance.

4.7.4: Energy saving opportunities at Kenya pipeline

The study of Kenya pipeline established that cost-efficient energy conservation measures had not been implemented. There existed a number of opportunities for energy savings i.e.

1. The organization did not have an energy department to deal with energy related issues. This was an opportunity for further energy savings if the department was formed to deal with energy related matters of which among them would be energy efficiency.
2. There was mismatch of equipment for example pumps were poorly matched with motors.
3. There were no energy conservation guidelines in the institution (energy policy). This could also be an opportunity for saving energy as it will lead to addressing of potential energy wasting activities.
4. Poor monitoring and evaluation of energy consumption by the pump systems. Despite their existing comprehensive sub-metering for the various pump systems, there was no monitoring and evaluation of the energy consumed by the various systems. This is an opportunity as it will lead to identification of energy wasting equipment.
5. Lack of information concerning modern equipment and technologies. The organization did not have sufficient information regarding modern equipment and technologies. This is due to the fact that despite implementing new projects as late as the year 2012, the organization did not use the recent technologies but used the old ones that were used in 1994 i.e. the use of motor, gearbox, fluid coupling and pump.

4.7.5: Barriers to energy efficiency and measures to minimize the effects of the barriers to effective implementation of energy efficiency at Kenya pipeline company limited.

1. Lack of awareness of the benefits of energy efficiency. This could be due to lack of an energy department and lack of quantification of the cost of energy due to lack monitoring and evaluation of the installed metering instruments. Installed metering instruments could be monitored for any deviations in the desired values and appropriate corrective action taken.
2. Inadequate technical capacity of the installation staff. It was established that the technical staff had little appreciation of existence of energy efficient technologies and competency levels in the use of these technologies were low. Required skills include the ability to carry out energy audits, analyze performance data, from which opportunities to implement effective actions can be evaluated and properly justified in terms of the benefits achievable compared with the costs involved. Technical staff could be trained in modern energy efficient technologies. Energy audits are sub contracted and clear information on energy saving opportunities is not established. Energy audits could be a onetime activity serving as the starting point to real time energy efficiency monitoring for the various pump system equipment.
3. The installations' organizational structure showed that there was no energy department /manager at a level high enough in the organization to defend and promote energy efficiency awareness in the organization. The highest level of staff relevant to energy efficiency activities was clerks that compile electricity bills for payment. These were in very low positions to promote energy efficiency. Energy department could be developed with personnel in charge being high enough in the organizational structure to promote and defend energy efficiency measures
4. As in Nairobi water and Sewerage Company, limited finance was also another factor hampering the implementation of energy efficiency strategies. With the absence of an energy department, there was no budget for energy activities. This

made energy activities and hence energy efficiency to be handled on an ad hoc basis. Setting up of an energy department could create a basis of allocation of funds for energy efficiency measures.

5. Corporate priorities are another barrier. It came out clearly that energy efficiency was not a priority in the installation evidenced by lack of an energy department and quantified energy costs that are specific to the pump systems. Energy efficiency could be given equal priority as pumping of oil products to the customers.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.2. CONCLUSIONS

This study was aimed at assessing energy efficiency opportunities in selected five pumping installations and to identify barriers to implementing these opportunities. Measures to minimize the effects of the identified barriers were also recommended. The study involved the identification of industrial installations in the country (Kenya) whose operations were mainly pumping. The selected firms were; Nairobi Water and Sewerage Company, Nzoia Sugar Company, Spknit Diary Company, Davis and Shirtlif and Kenya Pipeline Company. Information concerning design, operations maintenance procedures and energy management practices from the firms was obtained through interviews of the personnel and plant observations. The following were the energy saving opportunities and the respective barriers as identified;

5.2.1. Lack of metering instruments in four out of the five installations studied namely; Nairobi water and Sewerage Company, Nzoia Sugar Company and spknit diary. This provided an opportunity to improve energy efficiency as the absence of this instruments makes it difficult for the operators to monitor and evaluate the energy performance of the system with the view of improving its performance. Metering instruments could not be installed in the above installations due lack of awareness of the importance of these instruments in improving energy efficiency. Further, finances could also have been a barrier to acquiring this metering equipment. As a solution, adequate funding towards purchase of metering instruments could assist in evaluating and monitoring of the energy performance of the pumps. Further training of staff could be done to create awareness of the importance of instrumentation in enhancing energy efficiency.

5.2.2. It was found out that all the installations did not have distinct Energy Department. Management was focused on departments such as accounts, production and maintenance which had direct impact on production. This led to non-implementation of energy related projects and policies. Setting up of the energy department could re-direct the installations' focus and priorities to energy efficiency with great savings in energy.

5.2.3. Nairobi water and Sewerage Company and Nzoia Sugar Company are equipped with some old pumps and motors (30 years or more) that were installed when energy efficiency was not a factor in energy utilization. Upgrade of the pumping system equipment with modern energy efficient ones can provide huge energy savings.

5.2.4. Due to many retrofits over time and system degradation, the design limitations of the systems are likely to have been distorted. For example for Nairobi water and sewerage Company, the population increase and distribution networks are likely to be very different from the initial design such that a new fresh design may be necessary. The new design could now incorporate energy efficient measures.

5.2.5. Maintenance and operations procedures in some installations (such as nzoia sugar company) were found to not to have been well executed according to the best industry practices. Training in modern energy efficiency technologies could enhance the knowledge and skills of the technical personnel in all of the firms.

5.2.6. Information from management staff interviews indicated that there was limited finance to fund energy efficiency measures. This was the reason given for non-implementation of capacity enhancement.

5.2.7. It is common for the existing energy efficiency opportunities to be identified through system wide energy audits. However, audits are usually one time activities and do not involve emerging opportunities or barriers. Hence continuous monitoring in necessary. This requires installations of the monitoring instruments. These were found to be largely absent from all the installations except Kenya Pipeline Company

5.3. RECOMMENDATIONS

The following recommendations are suggested for further work

5.3.1. From the study, it was established that energy efficiency measures have not been embarrassed in pumping installations across the country. It is therefore recommended that another study can be conducted to focus on water services boards since they are similar in operations. This will facilitate the establishment of best practices in the water supply industry.

5.3.2. Quantification of energy savings potential was not possible in four out of the five pumping installations studied because of lack of installed metering equipment. More energy efficiency information can be obtained if portable metering equipment can be used in collecting data.

5.3.3. One out of the five installations studied could not provide full access to the installation for confidentiality reasons. Sufficient information can be obtained if more access to the premises is availed.

CHAPTER 6

APPENDICES

Appendix 6.1: Tables

Table 6.1.1: Pipe material roughness coefficients

	Nature of interior surface	Index roughness ε
1	Copper, lead, brass, stainless	0,001 to 0,002
2	PVC pipe	0,0015
3	Stainless steel	0,015
4	Steel commercial pipe	0,045 0,09
5	Stretched steel	0,015
6	Weld steel	0,045
7	Galvanized steel	0,15
8	Rusted steel	0,1 to 1
9	New cast iron	0,25 to 0,8
10	Worn cast iron	0,8 to 1,5
11	Rusty cast iron	1,5 to 2,5
12	Sheet or asphalted cast iron	0,01 to 0,015
13	Smoothed cement	0,3
14	Ordinary concrete	1
15	Coarse concrete	5
16	Well planed wood	5
17	Ordinary wood	1

Table 6.1.2: Values for Typical Overall Pumping Plant Efficiency Classifications

motor horse power	Low	fair	good	excellent
3-7.5	<44.0	44-49.9	50-54.9	>54.9
10	<46.0	46-52.9	53-57.9	>57.9
15	<47.1	48-53.9	54-59.9	>59.9
20-25	52<48.0	50-56.9	57-60.9	>60.9
30-50	<52.1	.1-58.9	59-61.9	>61.9
60-75	<56.0	56-60.9	61-65.9	>65.9
100	<57.3	57.3-62.9	63-66.9	>66.9
150	<58.1	58.1-63.4	63.5-68.9	>68.9
200	<59.1	59.1-63.8	63.9-69.4	>69.4
250	<59.1	59.1-63.8	63.9-69.4	>69.4
300	<60.0	60-64.0	64.1-69.9	>69.9

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Table 6.1.3: friction loss in valves and fittings

Fitting	Equivalent length in feet per inc diameter
Angle valve (fully open)	12.0
Butterfly valve	3.3
Gate valve (fully open)	1.1
Globe valve (fully open)	28.0
Foot valve with strainer	6.3
Swing check valve	11.0
Water check valve	12.5
90^o elbow	2.5

Table 6.1.4: Efficiencies for motors at various speeds

Average Efficiencies for Standard Efficiency Motors at Various Load Points

Efficiencies for 900 rpm, Standard Efficiency Motors								
Motor Size	Load Level In Percent							
	ODP				TEFC			
	100%	75%	50%	25%	100%	75%	50%	25%
10	87.2	87.6	86.3	78.3	86.8	87.6	86.8	77.3
15	87.8	88.8	88.2	79.6	87.5	88.7	88.1	79.1
20	88.2	89.2	88.0	81.8	89.2	89.9	89.2	82.6
25	88.6	89.2	88.0	83.0	89.7	90.3	89.1	78.6
30	89.9	90.7	90.2	84.5	89.6	90.5	86.5	84.1
40	91.0	91.8	91.7	86.2	90.5	91.4	85.5	85.0
50	90.8	91.9	91.1	87.1	90.2	91.0	90.2	84.9
75	91.7	92.4	92.1	86.5	91.6	91.8	91.0	87.0
100	92.2	92.2	91.8	85.8	92.4	92.5	92.0	83.6
125	92.9	92.3	91.7	86.9	93.0	93.1	92.1	87.9
150	93.3	93.1	92.6	89.5	93.0	93.4	92.5	NA
200	92.8	93.5	93.1	NA	93.7	94.1	93.4	NA
250	93.1	93.5	93.0	NA	91.7	94.8	94.5	NA
300	93.1	93.7	92.9	92.7	94.4	94.2	93.7	NA

Table 6.1.4 cont.

Efficiencies for 1200 rpm, Standard Efficiency Motors								
Motor Size	Load Level In Percent							
	ODP				TEFC			
	100%	75%	50%	25%	100%	75%	50%	25%
10	87.3	86.9	85.7	78.5	87.1	87.7	86.4	80.3
15	87.4	87.5	86.8	80.8	88.2	88.1	87.3	80.7
20	88.5	89.2	88.8	84.1	89.1	89.7	89.4	82.8
25	89.4	89.7	89.3	85.0	89.8	90.5	89.8	83.5
30	89.2	90.1	89.8	87.6	90.1	91.3	90.7	84.6
40	90.1	90.4	90.0	85.8	90.3	90.1	89.3	85.3
50	90.7	91.2	90.9	86.9	91.6	92.0	91.5	86.7
75	92.0	92.5	92.3	88.6	91.9	91.6	91.0	87.2
100	92.3	92.7	92.2	87.4	92.8	92.7	91.9	86.5
125	92.6	92.9	92.8	87.9	93.0	93.0	92.6	88.7
150	93.1	93.3	92.9	89.7	93.3	93.8	93.4	91.1
200	94.1	94.6	93.5	91.5	94.0	94.3	93.6	NA
250	93.5	94.4	94.0	91.9	94.6	94.5	94.0	NA
300	93.8	94.4	94.3	92.9	94.7	94.8	94.0	NA

Efficiencies for 1800 rpm, Standard Efficiency Motors								
Motor Size	Load Level In Percent							
	ODP				TEFC			
	100%	75%	50%	25%	100%	75%	50%	25%
10	86.3	86.8	85.9	80.0	87.0	88.4	87.7	80.0
15	88.0	89.0	88.5	82.6	88.2	89.3	88.4	80.7
20	88.6	89.2	88.9	83.3	89.6	90.8	90.0	83.4
25	89.5	90.6	90.0	86.6	90.0	90.9	90.3	83.4
30	89.7	91.0	90.9	87.3	90.6	91.6	91.0	85.6
40	90.1	90.0	89.0	86.3	90.7	90.5	89.2	84.2
50	90.4	90.8	90.3	88.1	91.6	91.8	91.1	86.3
75	91.7	92.4	92.0	87.7	92.2	92.5	91.3	87.1
100	92.2	92.8	92.3	89.2	92.3	92.1	91.4	85.5
125	92.8	93.2	92.7	90.7	92.6	92.3	91.3	84.0
150	93.3	93.3	93.0	89.2	93.3	93.1	92.2	86.7
200	93.4	93.8	93.3	90.7	94.2	94.0	93.1	87.8
250	93.9	94.4	94.0	92.6	93.8	94.2	93.5	89.4
300	94.0	94.5	94.2	93.4	94.5	94.4	93.3	89.9

Table 6.1.4 cont**.**

Efficiencies for 3600 rpm, Standard Efficiency Motors								
Motor Size	Load Level In Percent							
	ODP				TEFC			
	100%	75%	50%	25%	100%	75%	50%	25%
10	86.3	87.7	86.4	79.2	86.1	87.2	85.7	77.8
15	87.9	88.0	87.3	82.8	86.8	87.8	85.9	79.5
20	89.1	89.5	88.7	85.2	87.8	89.6	88.3	79.7
25	89.0	89.9	89.1	84.4	88.6	89.6	87.9	79.3
30	89.2	89.3	88.3	84.8	89.2	90.0	88.7	81.0
40	90.0	90.4	89.9	86.9	89.0	88.4	86.8	79.7
50	90.1	90.3	88.7	85.8	89.3	89.2	87.3	82.0
75	90.7	91.0	90.1	85.7	91.2	90.5	88.7	82.5
100	91.9	92.1	91.5	89.0	91.2	90.4	89.3	83.8
125	91.6	91.8	91.1	88.8	91.7	90.8	89.2	82.6
150	92.0	92.3	92.0	89.2	92.3	91.7	90.1	85.6
200	93.0	93.0	92.1	87.9	92.8	92.2	90.5	84.9
250	92.7	93.1	92.4	87.1	92.7	92.5	91.2	90.3
300	93.9	94.3	93.8	90.4	93.2	92.8	91.1	89.9

Table6.1.5: Reasonable Velocities of fluid in Pipes

Medium	Pressure (bar)	Service	Velocity (m/s)	Notes
Steam (sat)	0 - 1.7	Heating	20 to 30	+ 100mm dia
Steam (sat)	over 1.7	Process	30 to 50	+150mm dia
Steam (sup)	over 14	Process	30 to 100	+150mm dia
Air		Forced Air Flow	5 to 8	e.g. AC Reheat
Water	-	General	1 to 3	
Water		Concrete Pipe	4.7	
Water		Pump Suction	1.2	
Water		Horizontal Sewer	0.75	Minimum
Water		Pump discharge	1.2 to 2.5	Minimum
Oil		Hydraulic Systems	2.1 to 4.6	Minimum
Ammonia		Compressor Suction	25	Max. Permissable
Ammonia		Compressor Discharge	30	Max. Permissible

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Table 6.1.6: Conversions

To Convert	Into	Multiply By
Bar	PSI	14.5
cc	Cu. In.	0.06102
°C	°F	(°C x 1.8) + 32
Kg	lbs.	2.205
kW	HP	1.341
Liters	Gallons	0.2642
mm	Inches	0.03937
Nm	lb.-ft	0.7375
Cu. In.	cc	16.39
°F	°C	(°F - 32) / 1.8
Gallons	Liters	3.785
HP	kW	0.7457
Inch	mm	25.4
lbs.	Kg	0.4535
lb.-ft.	Nm	1.356
PSI	Bar	0.06896
In. of HG	PSI	0.4912
In. of H20	PSI	0.03613

Table 6.1.7: Table of values showing the current consumed during single pump operation at ps21

Time	Current in amps			Discharge	Speed of pump
9.00	154	154	154	228.3	4685
9.20	150	150	150	226.8	4655
9.30	150	150	145	223.6	4642
9.50	145	145	141	225.0	4632
10.00	145	145	141	222.2	4657
10.20	150	145	145	227.9	4676
10.30	150	150	145	229.6	4670
10.50	151	150	145	224.6	4680
11.00	150	150	145	226.4	4730
11.20	154	150	150	228.6	4710
11.30	154	145	143	225.8	4601
11.50	145	150	141	223.9	4605
12.00	150	150	150	226.5	4672
12.20	154	150	145	231.1	4653
12.30	150	150	145	229.3	4675
12.50	137	137	133	238.6	4454
1.00	141	141	141	207.9	4500
1.10	158	158	154	235.1	4663
1.20	158	158	158	236.2	4661
1.30	141	141	137	233.7	4496
1.40	145	145	141	239.4	4507
1.50	150	150	145	243.7	4562
2.00	150	150	145	220	4586
2.10	158	158	158	236.2	4661
SUM	**149.58**	**148.83**	**145.71**	**227.1**	**4626.38**

MEAN CURRENT=148.04 AMPS, MEAN DISCHARGE =227.1 M^3/HR AND MEAN SPEED=4626.4 RPM

Appendix 6.2: Graphs

Figure 6.2.1: System curves for the pipe sizes 8 and 10 inches for ps21

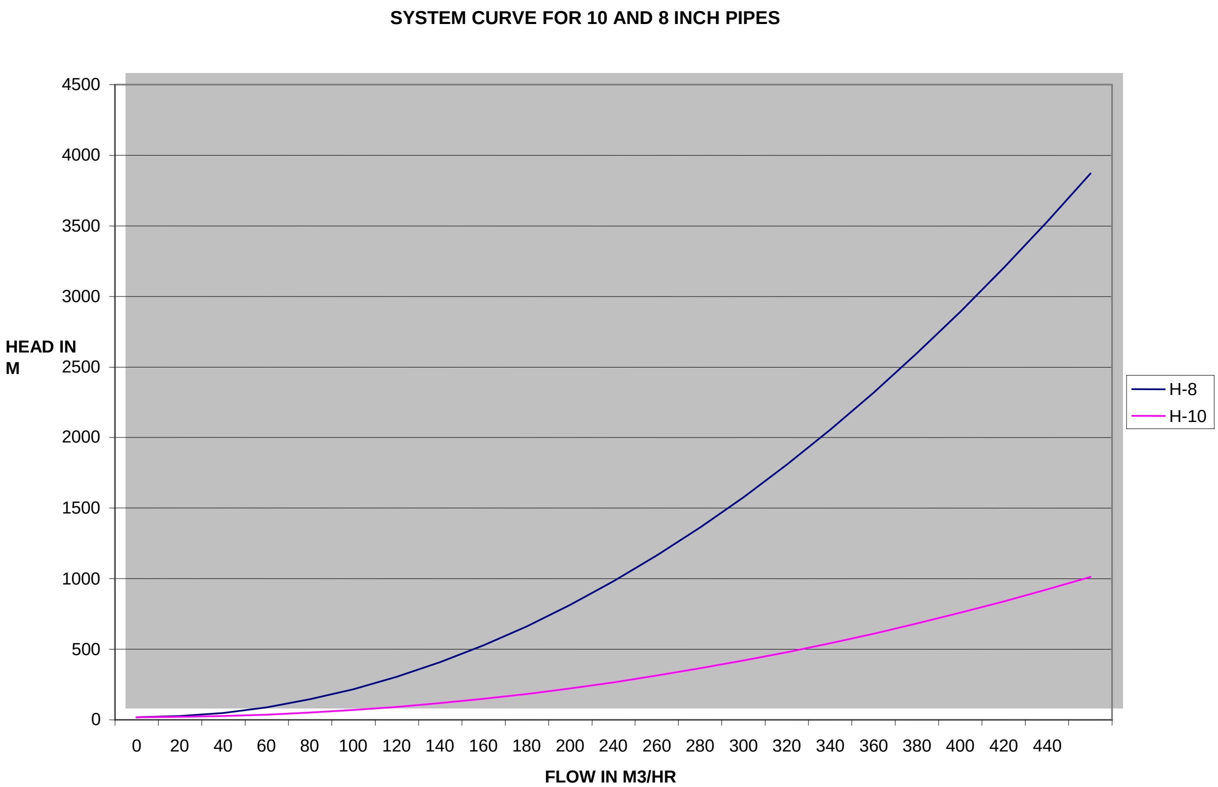


Figure 6.2.2: Operating points for parallel and single pump operation at 4990 and 4617 rpm for PS21.

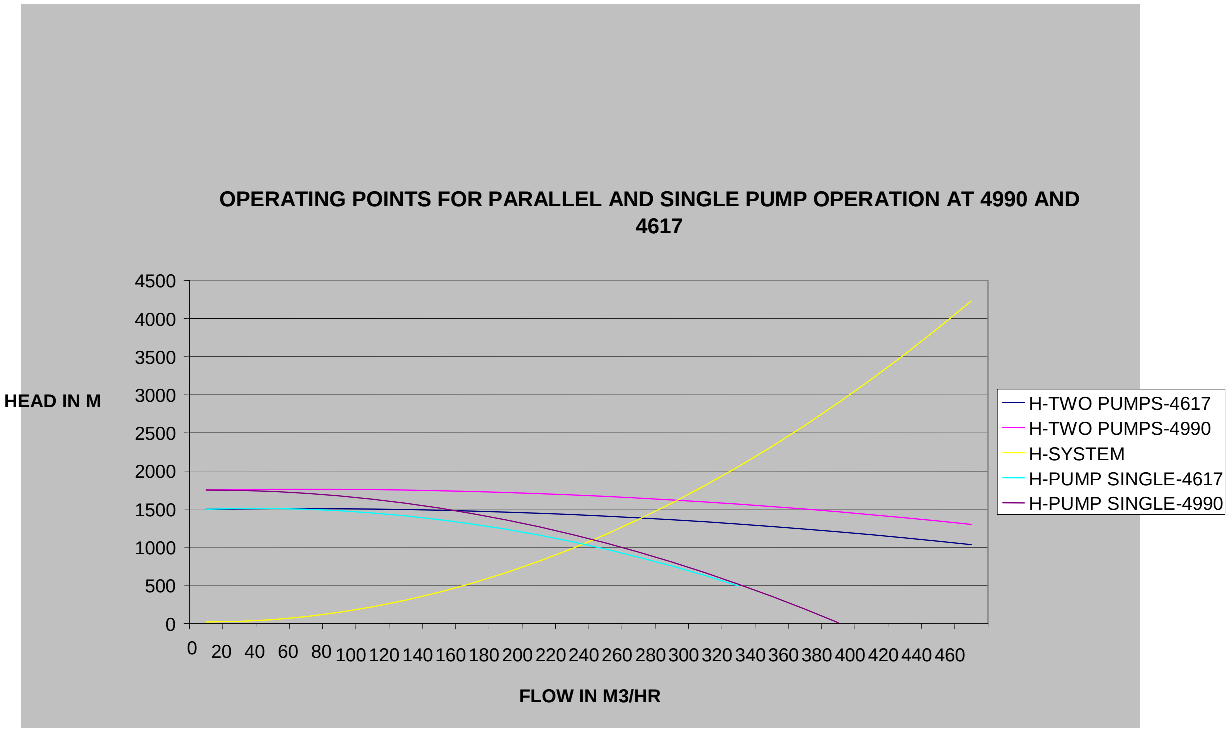
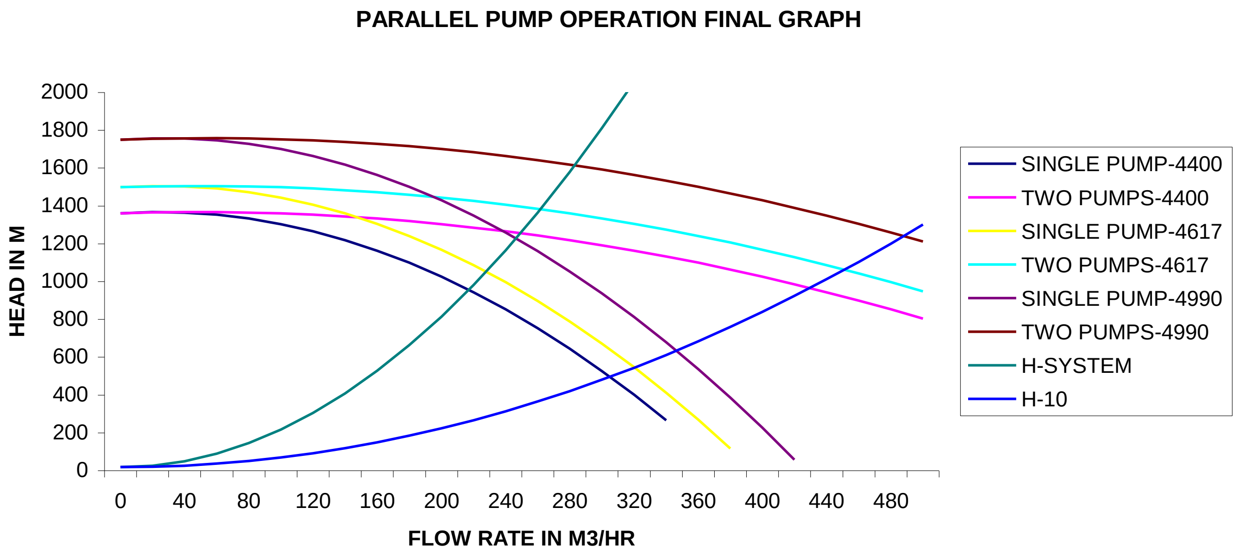


Figure 6.2.3: Parallel pump operation curves for pipe sizes 8 and 10 inches for the various operating speeds for ps21



Current system of 8 inches pipe diameter

For single pump at 4400rpm………………230m^3/hr -(operating point 4400rpm, 230m^3/hr)

For single pump at B.E.P i.e. 4900rpm……250m^3/hr

Manufactures results at factory test (4900rpm, 280m^3/hr) for single pump operation.

There was no manufactures data for parallel pump operation.

For parallel pump at 4400rpm……………260m^3/hr

For parallel pump at B.E.P. i.e4900rpm…290m^3/hr

For system with 10 inches pipe diameter

For single pump at 4400rpm………………310m^3/hr – (supposed operating point 4400rpm, 310m^3/hr)

For single pump at B.E.P i.e. 4900rpm……355m^3/hr

For parallel pump at 4400rpm……………335m^3/hr

For parallel pump at B.E.P. i.e4900rpm…435m^3/hr

Appendix 6.3: Sample calculations

6.3.1. Developing a pump performance curve sample calculations

6.3.1.1. Determining pressure drop in terms of Head (m)

How pressure changes with elevation can be expressed as:

$dp = - \gamma \, dz$ -------------------------(1)

Where;

dp = change in pressure

dz = change in height

γ = specific weight

The pressure gradient in vertical direction is negative - the pressure decrease upwards.

However, Specific Weight can be expressed as:

$\gamma = \rho \, g$------------------------------------ (2)

Where

γ = specific weight

g = acceleration of gravity

In general the specific weight - γ - is constant for fluids. For gases the specific weight - γ - varies with the elevation.

6.3.1.2. Static Pressure in a Fluid

For an incompressible fluid as a liquid, the pressure difference between two elevations can be expressed as:

$$P2 - P3 = \gamma\left(Z2 - Z3\right)$$

Where

P2 = pressure at level 2

P3 = pressure at level 3

Z2= level 2

Z3= level 3

The above equation can be transformed to:

$$P2 - P3 = \gamma H$$

Where

H= Z3-Z2 difference in elevation - the depth down from location *z2*.

Or

$$P3 = P2 - \gamma H$$

The Pressure Head

Making H the subject in the above equation, we have:

$$H = \frac{\left(P2 - P3\right)}{\gamma}$$

H expresses the pressure head, the height of a column of fluid of specific weight γ required to give a pressure difference of (*p2 – p3)*. For our case applying the average operating values of discharge pressure at PS 21 as p2 and suction pressure at PS22 as p3 we have p2-p3= 78.3 bars (from data of parallel pumping table 4.9). Converting into Newton per meter squared we have 78.3×10^5 N/M^2.

From the above equation and taking the value of ρ as 735 kg/m^3 we H as 1085.9m.

Hence using the equation for pressure drop above we have

$$\Delta H_p(q) = \Delta H_F(q) + \Delta H_{EQ}(q) + \Delta H_{TS}(q)$$

$$\Delta H_F(q) = \frac{4fL}{D}\frac{V^2}{2g}$$

$$\Delta H_{EQ}(q) = K_{EQ}\frac{V^2}{2g}$$

$\Delta H_{TS} = Z_{NGEMA} - Z_{NAIROBI}$ =1648m -1630m = 18m

Hence

$$994.08 = \frac{4fL}{D}\frac{V^2}{2g} + K_{EQ}\frac{V^2}{2g} + 18$$

From Appendix 6.1, table 6.1.3 and the hydraulic Institute pipe manual 3rd edition, the values of k for the various pipes fitting along the line can be determined as shown in the table 6.3.1.

Pipe fitting Description	No. of fittings	Value of K	Total K
Non- Return valve (Fully open)	3	2.5	7.5
Ball valve (fully open)	8	4.5	36.0
Gate valve (fully open)	1	0.2	0.2
Tee (flow thro' run)	1	0.6	0.6
Bends (90^0)	8	0.9	7.2

Table 6.3.1: table to determine the total value of k foe fittings along the pipeline- ps21-22

From the table, the total value for k is 51.5, which is then applied in the equation below.

$$994.08 = \left(\frac{4fl}{D} + k\right)\frac{V^2}{2g} + 18$$

All the values on the right side of the above equation are known apart from the value of v and f.

6.3.1.3. To determine the value of v for the 8 inch pipe

From the equation

$$V = \frac{4Q}{\pi D^2}$$

For a an average flow rate (Q) of 222.6 m^3/hr meaning 0.06 m^3/hr we have

$$V = \frac{4x0.06m^3s^{-1}}{0.041\pi}$$

For a pipe size of 8 inches to Ngema the above equation gives as the value of v as 1.92m/s

6.3.1.4. Determining the value of f

Determine the Reynolds number to ascertain the nature of flow regime

$$\mathrm{Re} = \frac{\rho VD}{\mu}$$

The above equation transforms into $\mathrm{Re} = \frac{VD}{\eta}$ using ρ = 735 kg/m3 and η = 0.76 cst. (kinematic viscosity) and for an 8 inches pipe diameter the value of Re was found to be 1.6x 10^5

The flow is in the turbulent regime, we therefore apply the equations of this regime to determine the friction factor f.

Using the more general Darcy-Weisbach equation we have

$$994.08 = \left(\frac{4fl}{D} + k\right)\frac{V^2}{2g} + 18$$

From this equation the approximate value for f is 0.0041 (fanning's friction factor)

The friction factor can also be determined from the equation

$$H = h + aQ^2$$

Where

H = Total head (m)

h = static head (m)

a = a constant which is a function of the flow

Q = Flow rate

From table 4.10 the average value of a is $258001.8 s^2/m^5$.

But we also know that $h_f = \dfrac{4fLV^2}{D.2g}$, therefore we substitute for the value of v to get

$h_f = \dfrac{32fLQ^2}{D^5\pi^2 g}$ Hence $aQ^2 = \dfrac{32fLQ^2}{D^5\pi^2 g}$ giving us the following relationship

$a = \dfrac{32fL}{D^5\pi^2 g}$. Making f the subject in this equation and substituting for the value of a, we have

$f = \dfrac{aD^5\pi^2 g}{32L}$. This equation gives the value of f as 0.0038

Using this value of f from the Darcy-Weisbach equation in the Colebrook-White equation below, we can approximate the value of the current surface roughness for the pipe.

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log_{10}\left(\frac{\varepsilon}{D} + \frac{21.25}{R^{0.9}}\right)$$

Making ε the subject in the above equation gives

$$\varepsilon = D.anti\log_{10}\left(0.57 - \frac{1}{2\sqrt{f}}\right) - \frac{21.25D}{\mathrm{Re}^{0.9}}$$

Solving for ε gives 0.001mm

Using the relationships for determining the friction factor for smooth pipes we have, from an explicit equivalent of the Colebrook equation as

$\frac{1}{\sqrt{f}} = 1.8\log_{10} R - 1.5186$ f is determined to be 0.013.

From the above calculations, we can make a simple comparison of the friction factor values for the various states of the pipe as indicated in table 6.3.2.

Table 6.3.2: Comparison of the friction factor values for the various states of the pipe

Description of the pipe	Value of the friction factor at the Re=$1.6x10^5$	Value of the surface roughness.
8 inch, new commercial steel pipe	0.0143	0.045
8 inch commercial steel pipe currently in use	0.0152	0.06
8 inch, smooth pipe	0.013	0

The value of the surface roughness does not vary very much from that provided in hand book- Steel/Wrought Iron 0.051

6.3.2. CALCULATIONS FOR A 10 INCH PIPE

6.3.2.1. Determination of the velocity of flow

$$V = \frac{4Q}{\pi D^2}$$

For a an average flow rate (Q) of 222.6 m^3/hr meaning 0.06 m^3/s we have

$$V = \frac{4x0.06m^3s^{-1}}{0.0645\pi}$$

For a pipe size of 10 inches to Ngema the above equation gives as the value of v as 1.18m/s

6.3.2.2. Determining the value of friction factor

Determine the Reynolds number to ascertain the nature of flow regime

$$\mathrm{Re} = \frac{\rho V D}{\mu}$$

The above equation transforms into $\mathrm{Re} = \frac{VD}{\eta}$ using ρ = 735 kg/m3 and η = 0.76 cst. (kinematic viscosity) and for an 10 inches pipe diameter the value of Re was found to be 3.96x 10^5

The flow is in the turbulent regime, we therefore apply the equations of this regime to determine the friction factor f.

Using the more general Darcy-Weisbach equation we have

$$994.08 = \left(\frac{4fl}{D} + k\right)\frac{V^2}{2g} + 18$$

From this equation, the approximate value for f is 0.012

The friction factor can also be determined from the equation

$$H = h + aQ^2$$

Where

H = Total head (m)

h = static head (m)

a = a constant which is a function of the flow

Q = Flow rate

From table 4.10 the average value of a is 258001.8s^2/m^5.

But we also know that $h_f = \frac{4fLV^2}{D.2g}$, therefore we substitute for the value of v to get

$h_f = \frac{32fLQ^2}{D^5\pi^2 g}$ Hence $aQ^2 = \frac{32fLQ^2}{D^5\pi^2 g}$ giving us the following relationship

$a = \frac{32fL}{D^5\pi^2 g}$. Making f the subject in this equation and substituting for the value of a, we have

$f = \frac{aD^5\pi^2 g}{32L}$.This equation gives the value of f as 0.012

Using this value of from the Darcy-Weisbach equation in the Colebrook-White equation below and having known the surface roughness of the pipe of such an age from the calculations of the 8-inch pipe we can approximate the value of the friction for the pipe as.

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log_{10}\left(\frac{\varepsilon}{D} + \frac{21.25}{R^{0.9}}\right) = 0.0148$$

For a new pipe ε is found to be 0.045mm and applying this value in the Colebrook equation given below

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log_{10}\left(\frac{\varepsilon}{D} + \frac{21.25}{R^{0.9}}\right)$$

The friction factor for a new pipe is obtained as 0.0141

Using the relationships for determining the friction factor for smooth pipes we have, from an explicit equivalent of the Colebrook equation as

$\frac{1}{\sqrt{f}} = 1.8\log_{10} R - 1.5186$ f is determined to be 0.013.

From the above, we can make a simple comparison of the friction factor values for the various states of the pipe based on calculations.

To plot the pump characteristics curve, we apply the equation

$H = AN^2 + BNQ + CQ^2$

From the pump characteristics curve given by the manufacturer, we use the points; (0,1750), (180,1500), (240,1250) to determine the values of A, B, and C at 4990 RPM the values of A, B and C obtained at this speed can be used in the above equation to obtain the pump curve at the mean operating speed 4617 RPM.

These values are determine as A= $7.03X10^{-5}$, B= 0.430, C= -142826. Substituting these values in our equation above gives

$H = 7.03X10^{-5} N^2 + 0.43NQ - 142826Q^2$. This equation is used to obtain values of H for assumed values of Q from 0 to 340 at intervals of 20, which are then used to plot the characteristic curve at 4617 RPM.

Given that for parallel pump operation, the common operating speed in the organization is approximately 4400 RPM, we will plot this curve also.

Tables 4.2, 4.3 and 5.1.1 facilitated the development of the pump characteristic curve at the stated speeds.

6.3.2.3. Determination of power delivered to the motor

Mean power per month is found from table 4.7 i.e.

9214700÷12=767891kWh

To determine the value for one hour

767891÷ (30×24) =1066.5 kW

6.4. Sample questionnaires for data collection.

6.4.1. Sample questionnaire on opportunities

a) Record of the nameplate information from the pumps, and other mechanical equipment was taken.

b) Type and amount of fluid pumped was determined.

c) The way the pumps operate was determined i.e. (continuously or intermittently, series or parallel?) If intermittent, the controls of the pumping cycle were determined and the length of operation of each pump was also determined.

d) A sketch of the process flow diagram (PFD), including valves, pumps, process equipment, tanks, and instrumentation was obtained.

e) Determination of the operating conditions of all valves was made i.e. are they operable or leaking?

f) The pumps were determined whether they were of appropriate type for the system and fluid i.e. if they were of fixed or variable speeds?

g) Length of operation of the pumps was determined i.e. whether the pumps operate continuously or intermittently? And if intermittent, what controls the pumping cycle and how long are the pumps on and then off?

h) Flow rates and discharge heads were determined to establish if they are as currently required for effective remediation and if they are the same as those in the design specifications?

i) The fluid velocities in each pipe were calculated to determine whether they are within the normal design range?

j) Verification that all ancillary equipment is maintained per manufacturers' recommendations was done.

k) Determination whether the piping is clearly labeled and whether all valves are tagged was done?

l) Verification whether the piping is adequately supported? And whether the hangers and supports were in good condition was done?

m) A determination of the appropriateness of the piping alignment, location and spacing was done.

n) A check was done of whether valves, valve operators, drivers, and controllers were inspected and maintained as recommended in the operation and maintenance manual.

o) Determination of the condition of sample ports, valves, and drains was done.

p) Metering systems were inspected to determine if they are maintained as recommended in the operation and maintenance manual?

q) Pumps were inspected of any physical signs of pump leakage at shaft seals or packing.

r) Pumps were inspected for any signs of excessive vibration and whether all pump anchor bolts were in good condition.

s) Pumps were inspected for any throttle down to nearly shut-off to achieve the required flow rate.

t) An inquiry on the practice of a preventative maintenance program for pumps and whether the pump maintenance records complete and up to date was made.

u) Verification of whether controls and alarms were working and whether there are telemetric provisions to notify an operator of a problem when the unit is not being attended was done.

v) Determination of the presence of change in flow rate, temperature, or pressure over time was done.

w) Determination of whether the constituent concentrations were high enough to be of concern in selecting pipe or valve materials was done.

x) Length of the pumping cycle duration was determined to see if it is excessively short or approaching the ½-on-½-off sequence.

y) For submerged pump installations, determination of the availability of sufficient submergence of the pump.

z) Inquiry of any pumps reported to have excessive bearing wear and replacement frequency was done. (Excessive bearing wear may indicate misalignment or eccentric flow entering the pump inlet.)

6.4.2. Sample questionnaire on barriers

Survey question

The survey question is *"We would like to understand what makes it difficult or easy for your company to become more energy efficient/implement energy efficiency measures.*

a) Do you have an energy department in your organization..NO.:......................

b) What priority is placed on the energy department by the management of you organization

- number of employees under the department---0
- are the officers trained in energy related issues---N/A----
- the title/level of the person in charge of the department------N/A-----------
----
- how does the number of employees in this department compare with other departments------N/A--

c) Does the organization have energy consumption bills---YES-------------------?

-Are these bills specific on equipment or general for the whole organization--------BILLS ARE SPECIFIC TO STATIONS (I.E. PUMPING STATIONS & DEPOTS)-----------------?

-In the case of specific equipment fitted with energy meters, how are they monitored for energy efficiency---NOT MONITORED.-----------------------------?

d) How do find the cost of energy--FROM THE BILLS (UTILITY)

e) What is the approximate budget for implementing energy efficiency in the organization--0-----------------------?

-Do you feel you are well supported comparing with other departments--N/A------?

f) Do you have policies, procedures and systems within your company on energy issues-------NO--?

g) Do you believe that further improvements can be made in improving energy efficiency in you organization---YES----------------------------?

- if yes, what do you think should be done--IMPLEMENT SMART METERING OF EQUIPMENT (I.E. MAINLINE PUMPS), INCORPORATE ENERGY MANAGEMENT SYSTEMS THAT INTEGRATE WITH SCADA & PUMPING OPERATIONS.

h) how does the energy department work with other departments in ensuring energy efficiency-----N/A---

i) How do you get new technologies on energy efficiency--A NEED IS DETERMINED FOLLOWED BY JUSTIFICATION, IF APPROVED, PROCUREMENT FOLLOWS.

j) can you quantify the benefits of energy efficiency in your organization --OUR PRIMARY CONCERN WOULD BE A REDUCTION IN ENERGY COSTS INCURRED.

8/7/2012

For and on behalf of:—
KENYA PIPELINE COMPANY LIMITED

6.5. STEPS FOR CONDUCTING ENERGY EFFICIENCY ASSESSMENT TO IDENTIFY ENERGY EFFICIENCY OPPORTUNITIES.

6.5.1. Identify the problem or objective

It is important that at the start of the project, consultations with the people who operate the system should be done in order to gain their support. Tasks to be conducted include a review of system and definition of objectives; i.e., energy savings. Identify whether problems experienced are sporadic or continuous, when they started to appear, and changes to production or system operation, etc.

6.5.2. Gather information

Produce a line diagram that identifies all components and other associated pipeline accessories that place energy demands on the system. Prepare a detailed description of the system documenting the type of motor-pump system, operational requirements, system controls and nameplate information. A site inspection will determine whether components are functioning and being operated correctly.

6.5.3. Measure system operation

Prepare a measurement plan that defines what is to be measured and under what conditions. Assess operational needs versus preferences. Compare measured data with design information.

6.5.4. Develop technical options

Develop alternative solutions, calculate savings and estimate cost to implement and determine financial and operational feasibility. Identify technical options to increase system efficiency and meet production needs.

6.5.5. Evaluate proposals

Evaluate the options, including system benefits, opportunities for improvement and recommendations.

6.5.6. Implement the project

Make the necessary changes and install the equipment. Once the project is installed, verify the savings with measurements and compare actual savings with calculated savings.

6.5.7. Communicate

Communicate progress to management and plant personnel. This will build support for further initiatives.

6.6. Sample Maintenance Schedules

6.6.1. Sample maintenance chart for Kenya Pipeline PS21- 2004/2005

6.6.1: T/I MAINTENANCE CHART FOR PS 21 - 2004/2005

DATE	July					August				September				October					November				December				January					February				March				April					May				June			
FINANCIAL YEAR WEEK NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
CALENDAR YEAR WEEK NO.	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
MAINLINE INSTRUMENTS																																																				
PRESSURE IND./TRANSMITTERS											3M													A													3M													6M		
TEMPERATURE TRANSMITTERS											3M													A													3M													6M		
HIGH PRESSURE SWITCH											3M													A													3M													6M		
DISCHARGE PRESSURE SWITCH											3M													A													3M													6M		
CONTROL VALVES											3M													A													3M													6M		
LOCAL PANEL INSTRUMENTS																																																				
VIBRATION MONITOR SYSTEM				4M																	4M																		4M													
SPEED INDICATING CONTROLLERS				4M																	4M																		4M													
FISCHER PORTE CONTROLLERS				4M																	4M																		4M													
METERING (DANIEL) COMPUTERS				4M																	4M																		4M													
PRINTER FOR PROVER COMPUTER				4M																	4M																		4M													
ANN / MIMIC/ COSs				4M																	4M																		4M													
MAINLINE PUMPSETS INSTRUMENTS		P101								P201				P101									P201				P101									P201						P101								P201		
PRESSURE INDICATORS/SWITCHES		3M								3M				6M									6M				3M									3M						A								A		
THERMOMETERS		3M								3M				6M									6M				3M									3M						A								A		
LEVEL SWITCHES		3M								3M				6M									6M				3M									3M						A								A		
PROXIMITOR PROBE		3M								3M				6M									6M				3M									3M						A								A		
TEMPERATURE SWITCHES		3M								3M				6M									6M				3M									3M						A								A		
ACCELEROMETER PROBE		3M								3M				6M									6M				3M									3M						A								A		
OUTPUT SPEED IND./TRANSDUCER		3M								3M				6M									6M				3M									3M						A								A		
PRESSURE TRANSMITTER		3M								3M				6M									6M				3M									3M						A								A		
BOOSTER PUMPS INSTRUMENTS																																																				
PRESSURE GAUGES												6M																										6M														
LEVEL SWITCHES												6M																										6M														
FIELD INSTRUMENTS																																																				
DIFF. PRESSURE GAUGE/SWITCH											3M													A													3M													6M		
TURBINE METER											3M													A													3M													6M		
TEMP. INDICATORS/TRANSDUCERS											3M													A													3M													6M		
PRESSURE TRANSDUCERS/SWITCHES											3M													A													3M													6M		
PROVER SWITCHES											3M													A													3M													6M		
LEVEL SWITCHES											3M													A													3M													6M		
OTHERS																																																				
TANK LEAK SWITCHES			M				M				M				M				M				M				M				M				M				M				M				M				M	
JUNCTION BOXES														A																																						
PLCs				6M																												6M																				
TBs																								A																												
MODEMS/BLACK BOXES				4M																	4M																	4M														
ENRAF LEVEL GAUGES/COUNTERS										6M																										6M																
MANIFOLD LEAK DETECTORS			M				M				M				M				M				M				M				M				M				M				M				M				M	

6.6.2. Sample annual preventive maintenance for Nairobi water and Sewerage Company for the pumpsets

6.6.2:

NCWSC/TEC/O&M/EM/001 -Doc 5

Annual Preventive Maintenace for Pumpsets

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Sun						1						
Mon						2			1			1
Tue	1			1		3	1		2			2
Wed	2			2		4	2		3	1		3
Thur	3			3	1	5	3		4	2		4
Fri	4	1		4 Em ps	2	6	4 Em ps	1	5	3		5
Sat	5 Em-ps	2	1	5	3	7 Se	5	2	6	4 Em Ps	1	6
Sun	6	3	2	6	4	8	6	3	7	5	2	7
Mon	7	4	3	7	5	9Ga-ps	7	4	8	6	3	8
Tue	8	5	4	8	6	10	8	5	9	7	4	9
Wed	9	6	5	9	7	11	9	6	10	8Se Ps	5	10
Thur	10	7	6	10 Kw	8	12	10	7	11	9	6	11
Fri	11Kw ps	8 Se	7	11	9	13 BII	11Kw	8	12	10	7	12
Sat	12	9	8	12	10	14	12	9	13 BII ps	11	8	13 BII
Sun	13	10	9	13	11	15	13	10	14	12	9	14
Mon	14 Gi	11	10	14 Gi Ps	12	16	14 Gi	11	15	13Kw	10	15
Tue	15	12	11	15	13	17	15	12	16	14	11	16
Wed	16	13	12 BII ps	16	14	18	16	13	17	15 Gi	12	17
Thur	17	14	13	17	15	19	17	14	18	16	13	18
Fri	18	15 Sa	14	18	16 sa	20	18	15 Sa	19	17	14 Sa	19
Sat	19	16	15	19	17	21	19	16	20	18	15	20
Sun	20	17	16	20	18	22	20	17	21	19	16	21
Mon	21	18	17	21	19	23	21	18	22	20	17	22
Tue	22	19	18	22	20	24	22	19	23	21	18	23
Wed	23	20	19	23	21	25	23	20	24	22	19	24
Thur	24	21	20	24	22	26	24	21	25	23	20	25
Fri	25 Ga ps	22 Ku ps	21	25 Ga	23Ku ps	27	25 Ga ps	22Ku ps	26	24 Ga	21Ku ps	26
Sat	26	23	22	26	24	28	26	23	27	25	22	27
Sun	27	24	23	27	25	29	27	24	28	26	23	28
Mon	28	25	24	28	26	30	28	25	29	27	24	29
Tue	29	26	25	29	27		29	26	30	28	25	30
Wed	30	27	26	30 BI	28		30	27		29	26	31
Thur	31 BI	28	27		29		31 BI	28		30	27	
Fri			28		30			29		31 BI	28	
Sat			29		31			30			29	
Sun			30					31			30	
Mon			31									

Key

PS: Pumpsets

Em- Embakasi
Sa-Sasumua
Se-Serena
Gi-Gigiri
Ga-Gatina
Kw- kabete W W
BI-Booster I
BII-Booster II
Lo-Loresho
Ku-Kenyatta university

Pumpset Maintenance Activities

1 Check mechanical coupling
2 Check vibration levels
3 Check all motor contacts for wear
4 Inspect and test the control panel
5 Check stator windings
6 Grease
7 Check gland packing leaks
8 Check end bearing temp.
9 Check scroll casing temp.

6.6.3. Sample annual preventive maintenance for Nairobi water and Sewerage Company for the gensets

NCWSC/TEC/O&M/EM/001 -Doc 5

6.6.3. **Annual Preventive Maintenace for Gensets**

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Sun						1						
Mon						2			1			1
Tue	1			1		3	1		2			2
Wed	2			2		4	2		3	1		3
Thur	3			3	1	5	3		4	2		4
Fri	4	1		4	2	6	4	1	5	3		5
Sat	5	2	1	5	3	7	5	2	6	4	1	6
Sun	6	3	2	6	4	8 Sr	6	3	7	5	2	7
Mon	7	4	3	7	5	9	7	4	8	6	3	8
Tue	8	5	4	8	6	10	8	5	9	7	4	9
Wed	9	6	5	9	7	11	9	6	10	8 Sr	5	10
Thur	10	7	6	10	8	12 Ga	10	7	11 Cr	9	6	11
Fri	11Cr	8 Sr	7	11	9	13	11	8	12	10	7	12
Sat	12	9	8	12	10	14	12 BII	9	13	11	8	13
Sun	13	10	9	13	11	15	13	10	14	12 Ga	9	14 Ws
Mon	14	11	10	14 Ws	12 Cr	16	14	11	15	13	10	15
Tue	15	12 Ga	11	15	13	17	15	12	16	14	11	16
Wed	16	13	12 BII	16	14	18 Ru	16	13	17	15	12 BII	17
Thur	17 P	14	13	17	15	19	17 C	14 Ws	18	16	13	18
Fri	18	15 Sa	14	18	16 sa	20	18	15 Sa	19 P	17	14 Sa	19
Sat	19	16	15	19	17	21	19	16	20	18 Ru	15	20
Sun	20	17	16	20	18	22	20	17	21	19	16	21
Mon	21	18 Ru	17 C	21	19 P	23 Ka	21	18	22 Mw	20	17 C	22
Tue	22 Mw	19	18	22	20	24	22	19	23	21	18	23
Wed	23	20	19	23	21	25	23	20	24	22 Ka	19	24
Thur	24	21	20	24	22 Mw	26	24	21	25	23	20	25
Fri	25	22 Ka	21	25	23	27	25	22	26 K	24	21	26
Sat	26 K	23	22	26	24	28	26	23	27	25	22	27
Sun	27	24	23	27	25	29	27	24	28	26	23	28 BI
Mon	28	25	24	28	26 K	30	28	25	29	27	24	29
Tue	29	26	25	29	27		29 Kw	26	30	28	25	30
Wed	30	27	26	30	28		30	27 BI		29	26	31
Thur	31	28	27		29		31	28		30	27	
Fri			28Kw		30			29		31	28 Kw	
Sat			29		31			30			29	
Sun			30					31			30	
Mon			31									

Key

PS: Genset
Sa-Sasumua
Ru-Ruai
Ka-Kampala HQ
Cr- Central Region
Sr- Southern Region
Gi-Gigiri
Ws-western Region
Ga-Gatina
Kw- kabete W W
Bl-Booster I
P-Pangani/Northern
Lower kabete-Booster II(BII)
C-Comcraft
Mw-Mobile workshop
K-Kariobangi

Genset Maintenance Activities

1 Check Oil Level
2 Check the coolant level
3 Check the coolant level leaks
4 clean the cooling system radiator/ cooling pins
5 Check the tention of the belts & their condition

6.6.4. Sample preventive maintenance card for Nairobi water and Sewerage Company

NCWSC/TEC/O&M/EM/001- Form 5a

6.6.4 : **Preventive Maintenance Card**

Equipment Name : Generator

Location :

Date			Date			Date			Date		
Hrs			Hrs			Hrs			Hrs		
	Checked	Changed		Checked	Changed		Checked	Changed		Checked	Changed
Air filter			Air filter			Air filter			Air filter		
Oil filter			Oil filter			Oil filter			Oil filter		
Fuel filter			Fuel filter			Fuel filter			Fuel filter		
Engine oil			Engine oil			Engine oil			Engine oil		
Belt tension			Belt tension			Belt tension			Belt		
Battery			Battery			Battery			Battery		
Greasing			Greasing			Greasing			Greasing		
Coolant			Coolant			Coolant			Coolant		
Next service			Next service			Next service			Next service		
Date			Date			Date			Date		
Hrs			Hrs			Hrs			Hrs		
	Checked	Changed		Checked	Changed		Checked	Changed		Checked	Changed
Air filter			Air filter			Air filter			Air filter		
Oil filter			Oil filter			Oil filter			Oil filter		
Fuel filter			Fuel filter			Fuel filter			Fuel filter		
Engine oil			Engine oil			Engine oil			Engine oil		
Belt tension			Belt tension			Belt tension			Belt		
Battery			Battery			Battery			Battery		
Greasing			Greasing			Greasing			Greasing		
Coolant			Coolant			Coolant			Coolant		
Next service			Next service			Next service			Next service		

Maintenance Supervisor: .... Sign: ....

Electro-Mechanical Eng: .... Sign: ....

O&M Manager: .... Sign: ....

6.6.5. Sample comprehensive maintenance report for the main line pump of Kenya pipeline.

PS 21 MECHANICAL MAINTENANCE CHART FOR 2004/2005

DATE	July				August				September				October				November					December				January				February					March				April				May					June				
CALENDAR YEAR WEEK NO.	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	[illegible]	[illegible]	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
FINANCIAL YEAR WEEK NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	[illegible]	[illegible]	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
MAINLINE PUMP 21-P-01	33,000(9,000Hrs)																																																			
MAINLINE PUMP 21-P-02																														45,000(9,000hrs)																						
BOOSTER PUMP 21-P-04			M				M				M				A				M				M				M				M				M				6M				M				M				M	
BOOSTER PUMP 21-P-05				M				6M				M				M				M				M				M				M				A				M				M				M				M
BOOSTER PUMP 21-P-06	M				M				M				6M				M				M				M				M				M				M				A				M				M			
DUMP TANK LIFT PUMP 21-P-07		M				A				M				M				M				M				M				6M				M				M				M				M				M		
INHIBITOR PUMP 21-P-08A			M				M				M				M				M				A				M				M				M				M				M				6M				M	
INHIBITOR PUMP 21-P-08B				M				A				M				M				M				M				M				6M				M				M				M				M				M
METER STRAINERS 21-X-03A/B	M				M				M				6M				M				M				M				M				M				M				A				M				M			
TURBINE METERS 21-X-03C/D																										6M																										6M
METER PROVER 21-X-04			M				M				M				M				6M				M				M				M				M				M				M				A				M	
INHIBITOR PACKAGE 21-PK-01				6M				M				M				M				M				M				M				A				M				M				M				M				M
PRODUCT TANK 11-TK-504	A				M				M				M				M				M				6M				M				M				M				M				M				M			
PRODUCT TANK 11-TK-303		A				M				M				M				M				M				6M				M				M				M				M				M				M		
DUMP TANK LIFT 21-TK-1902			M				M				M				M				M				6M				M				M				M				M				M				M				A	
INHIBITOR TANK 21-TK-1901				M				M				M				M				A				M				M				M				M				M				6M				M				M
ESDV 8" #600 21-EDS-957	6M				M				M				M				M				M				M				A				M				M				M				M				M			
ALL ELECT. OPR. #900 BALL VALVES		M				M				M				A				M				M				M				M				M				6M				M				M				M		
ALL ELECT. OPR. #600 BALL VALVES			M				M				M				M				A				M				M				M				M				M				6M				M				M	
ALL ELECT. OPR. #150 BALL VALVES				M				M				A				M				M				M				M				M				6M				M				M				M				M
ALL ELECT. OPR. #150 TRU SEAL V.	M				M				M				A				M				M				M				M				M				6M				M				M				M			
ALL ELECT. OPR. #150 WG VALVES		M				M				M				M				M				A				M				M				M				M				M				6M				M		
ALL MANUAL #900 BALL VALVES			M				M				A				M				M				M				M				M				6M				M				M				M				M	
ALL MANUAL #150 BALL VALVES				M				M				6M				M				M				M				M				M				M				A				M				M				M
ALL MANUAL # 150 TRU. SEAL V.	M				M				M				M				6M				M				M				M				M				M				M				A				M			
ALL MANUAL #150 SSWG. VALVES		6M				M				M				M				M				M				M				A				M				M				M				M				M		
HATCH END CLOSURES							3M													3M													3M													3M						
ALL PRES. & TR VALVES			M				M				M				M				6M				M				M				M				M				M				M				A				M	
MLV AT KP 38 & 61				M				M				M				M				6M				M				M				M				M				M				M				A				M
SWING CHECK VALVES # 150	M				M				A				M				M				M				M				M				6M				M				M				M				M			
SWING CHECK VALVES # 900			M				M				A				M				M				M				M				M				6M				M				M				M				M	

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