International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

Considerations in Hydraulic Systems Design, A Pumping System Repowering

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Abstract **– This work deals with hydraulic machines engineering. It is an engineering study introduced to show some of the design considerations that must be perceived to avoid set of the common engineering mistakes. These mistakes are clarified practically depending on the case study adopted in fuel oil unloading system at one of the main power plants in country of Jordan. Fuel oil unloading system at Amman power station works with an overall efficiency of about 13.8%. This low efficiency comes from several design mistakes, which are mistakes in the pumps number selected and arrangement selection, pumps characteristics selection and pumps suction head selection. This work introduces two alternatives to solve these problems in shade of the design considerations deduced from the existing design mistakes and "Repowering" concept. The first alternative is to replace the pumps used in this system with screw type pumps; this solution increases the efficiency to about 75% and makes savings of about $11,283 annually for pay back period of 20 years. The second solution is to operate the existing pump in a different manner with making slight changes in the system; this solution increases the efficiency to about 37.96% and makes savings of about $11,174 annually with neglected capital cost. The economic- engineering optimization overbalances the first solution, as it is correlated with softer, safer and reliable performance in addition to the economic saving.**

Keywords **– Hydraulic Systems Design, Repowering, Centrifugal and Screw Pumps, Fuel Unloading System, Design Mistakes.**

I. Approach

1.1 The Case

Amman is the capital city of country of Jordan, which lies in the middle east. This developing country faces a strong challenge in the energy demand- production balance. So, the government started to contract with the foreign companies to solve this problem, especially in Amman city, which contains three private energy producers.

The unloading system in Amman power station consists mainly of six centrifugal pumps connected in parallel. Each pump capacity is 80 m^3/hr with 36.7 m total head and 15 kw motor drive power.

The general objective of this paper is to indicate some considerations in the hydraulic systems design, while the specific objective is to show that there is a deficiency problem in the fuel oil pumping system used to perform the unloading process in Amman power station, explain the problem symptoms, causes and products in addition to introduce a techno- economic solution for this problem.

The organization of this work is designed depending on this objective, so "The Problem Description" is introduced firstly, which divided into "The Deficiency Problem", which indicates the quantity of the deficiency and the design mistakes that causes it other problems can effect the performance and the safety. Then two engineering solutions is introduced in "The Solutions" to clarify how to cancel the energy loss or to reduce it in "The First Solution" and "The Second Solution" consequently. Finally; in "The Economic Statements" the economic feasibility of each solution or how each of these engineering changes is interpreted into a business expressions (money) will be discussed to identify the optimum solution.

1.2 What is "Repowering"?

"*Repowering*" is a term refers here to any set of the engineering processes that makes changes in the energy flow diagram and the relationships between the physical parameters, or in technical terms changes in the physical components[1], of an engineering system, since these changes introduce healthier, more integrated, and more feasible relationship between the system outputs, inputs and components considering the boundary conditions, customer demands inflation, the newer technology and the economics. Simpler and general speaking, Repowering is to reconsider the relationships between the input power and the output power. However, there are no independent publications talks about the Repowering, but this term is used usually in some industrial intermediates to refer to the reoperation of certain engineering device after recovery from maintenance processes.

Repowering can be apparently, i.e. technically, change some parts, install new parts, change inputs or outputs, alter some of system conditions and any other changes match the above definition and it can be operating the system in certain manner, but any how, all of these technical aspects can be briefed "actually", i.e. in engineering terms, in one aspect, that is to make changes in the relationships between the physical parameters . Making CHP (Combined Heat and Power) for an operating power plant, installing fogging system to change the inlet conditions of a gas turbine, redesign a hydraulic system and utilizing the modern control technologies and the automation in the airplanes are conventional examples on the Repowering.

[1]This is because there is a difference between the engineer and the technician when they are dealing with the technology; the technician sees and deals with a set of physical components that integrated to do certain objective, while the engineer sees and deals with a set of the physical principles, concepts and parameters correlated with each other to produce certain physical output. In other words, the difference between there point of views the thing called "Physics", which is the soul of the technology and which differentiates actually between who know how and who does not know how.

International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

Repowering, in general, provides with the following advantages:

- Efficiency improvement, so more incomes,
- System refreshment by replacing the old part,
- Open the door to utilize other forms of energy,
- going on with technology wheel,
- Increasing the size of the investment in case of demands inflation and
- To rethink in the environmental and safety issues and working under the implications of more strict and modern regulations.

Some of disadvantages can result from repowering process, as;

- Accommodation problems. The incompatibility between the new parts and the old ones, sometimes, can make difficulties in the commissioning process and normal operation.
- In certain cases, the installing of the new parts behind the old parts can decrease the effectiveness of the new parts and even the old parts sometimes.
- The system Repowering often is more complicated than the system design, because the engineer who make the repowering must understand a system he did not design further more understand his designing modifications and how to implement them in the optimal way. In other words, to deal with one design that you create is so easily than dealing with two designs one from you and the other from other one, because you must think as the first designer thought to understand the case then to start in the design, which is more difficult and take more time.
- Repowering sometimes is related with an investment risk.
- If the Repowering does not relate with an investment risk, it is also difficult sometimes to convince the owners to do the repowering, because the repowering represents a change in the investment matters, so a lot of the owners resist this change if they feel satisfying of there investment.

These disadvantages make some designers and owners prefer to leave the repowering choice. Anyhow, the experience of the designer plus the feasibility study of the repowering in addition to the management awareness reach always to the optimal decision.

This work, in fact, represents a living example shows a repowering for a hydraulic system in Amman power station.

II. The Problem Description

2.1 Introduction

The aim of the following section is to indicate that there is a design problem in the pumps used to perform the unloading process, explain the causes and results of this problem and how it reflects on the system efficiency.

In order to organize the explanation of the problem, the problem will be divided into: Deficiency Problem, and Other Problems. And because the output power (hydraulic power) is described using two parameters, the liquid pressure and flow rate, the Deficiency Problem also will be divided into "Working Flow Rate Problem", "Working Pressure Problem".

2.2 Deficiency Problem

2.2.1 Working Flow Rate Problem

The unloading pumps are six centrifugal pumps connected in parallel, these pumps are arranged in this way to obtain multiplicative flow rate according to the following relationship as known also [1];

$$Q = qn \qquad (1)$$

Where;

Q: Total delivered flow rate in case of parallel connected pumps (m^3/hr).

q: One pump delivered flow rate (m^3/hr).

n: Number of the pumps connected in parallel.

So knowing that we have 80 m^3/hr pumps, then we have to obtain (6×80 m^3/hr = 480 m^3/hr) theoretically, but we have not this flow rate but we have about 320 m^3/hr. This is the first problem, i.e. the flow rate decreasing problem. But what is the cause of this problem?

In fact; the configuration (six parallel centrifugal pumps, generally more than three pumps in parallel) is not preferable in the hydraulic system design…..why? Because of the following successive points:

Firstly: According to "Bernoulli Equation" in the fluids mechanics, which adopts the relationship between the static pressure and the velocity of a certain liquid at a given liquid elevation and friction loss, and according to the relationship between the liquid velocity and the liquid flow rate for a given cross section, the liquid flow rate proportions inversely [2] [9] with the pressure in a curvature manner as a function of second degree not in a linear relationship, so that in the pump performance curve the shut off pressure (the maximum static pressure) drops according to a parabolic curve with increasing in the flow rate as shown in Figure 1. So, because this curve is not linear or fit second degree curve, the flow rate will not equal an integer multiplicative of the single pump flow rate as illustrated in Figure 2.

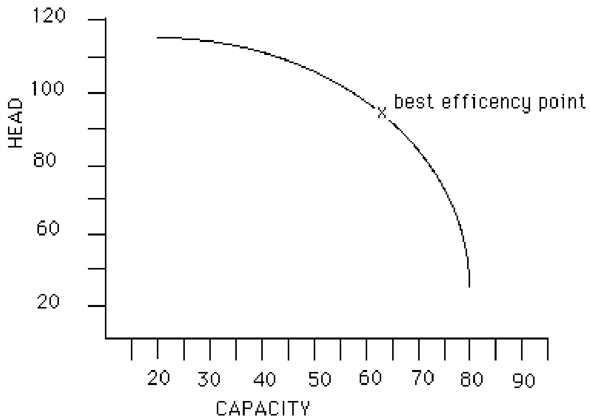

Fig.1. Pump Characteristic Curve; head (m) versus capacity (m^3/hr) [1]

The difference between being the relationship between the pressure and the flow rate represented by linear relationship (or integer multiplicative of the main

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Volume 3, Issue 3, ISSN: 2277 – 5668

parabolic function such as $2x^2$, $3x^2$,$4x^2$…etc for 2 pumps, 3 pumps, 4 pumps…etc connected in parallel) and the relationship between them as in the reality is shown in Figure 2, since the real curves is represented by the blue color and the linear curve is represented by the red color. It can be observed from this figure that the flow rate where there are two or three pumps in case of the real (parabolic) relationship equals or approaches from the flow rate as in case of the linear relationship, while the difference between the flow rate values on these curves expands as the number of the pumps increase, so the flow rate of four pumps get farther from the forth multiplication of the single pump flow rate, so practically; it is not preferable, but it is mistakable, to select 4 pumps or more in parallel.

The scientific justification of this observation or phenomenon is the increasing of the total friction head whenever the number of the pumps installed in parallel increases. However; the points secondly, thirdly and fourthly below share in justifying this observation.

This represents one of the factors that make the flow rate 320 m^3/hr instead of 480 m^3/hr.

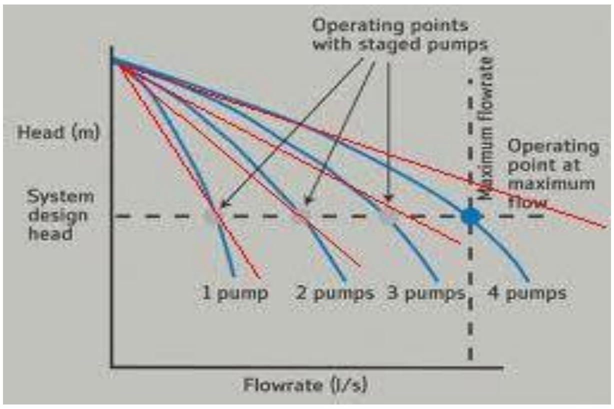

Fig.2. The difference between real head- flow rate characteristic curve of four pumps connected in parallel and four imaginary linear curves

Secondly: The pressure drop at the delivery header increases if the number of pumps increases, i.e. the pressure drop results from gathering six delivery lines in one header is higher than the pressure drop results from five or four lines as the turbulence increases so. So in the case; the pressure drop from the experience is quantified as more than 1 bar, and it is known that the pressure drop results from drop in the fluid kinetic energy, i.e. from velocity decreasing, that is: flow rate decreasing, so this is the second reason of flow rate drop and the fluid energy loss.

Thirdly: knowing that the flow velocity at the pump suction affects strongly the flow velocity at the pump delivery, so the pressure drop at the suction header which causes flow velocity decreasing affects the delivery flow rate negatively [3] [8].

Fourthly: the effect of the differentiation in the suction pipes friction, due to the difference in length, and being the suction pipes are not well sealed in addition to the low suction head plus the large clearances between the rotating parts result in flow pulsation, which introduces fluctuation in the performance tone, and this fluctuation in the performance can be normalized in one curve indicates lesser flow rate further more the bad performance due to the fluctuations and the vibration.

2.2.2 Working Pressure Problem

The working pressure problem represented in being the delivery pressure after the main header is about (1.4 bar) although the design pressure is about (3.5 bar). This problem is serous because it indicates that the current pumps efficiency is less than half the design efficiency.

The causes of this problem are adopted as followed:

Firstly; as mentioned above there is more than one bar pressure drop at the delivery secondary and main headers.

Secondly; the pumps installed with low suction head, so the air is sucked in considerable quantities due to being the suction pressure approaches to the atmospheric pressure value while the suction lines are not sealed perfectly. And because of the problem of air suction, the operators do not fully open the pump delivery pipes but they open it to about to 2/3 from the full opening in order to limit the air quantity passing through the delivery pipes. But such throttling represents sudden change in the cross section, so pressure drop, so energy loss…

2.2.3 The Resultant Deficiency

Then; taking the mentioned above two problems; the Working Flow Rate Problem and the Working Pressure Problem in consider, we can evaluate the pumps overall efficiency (and so the deficiency) using the following equation [2] [7];

$$\eta = \frac{HP}{EP} = \frac{P \times q}{EP} \qquad (2)$$

Where;

η: Pump Efficiency.

HP: Pump's Output Hydraulic Power (W).

EP: Pump's Electrical Input Power (W).

P: Pump's Delivered Pressure (Pa).

q: Pump's Delivered Flow Rate (m^3/s).

Knowing that we have 15 kw input power for each motor pump, average total flow rate of 320 m^3/hr and 1.4 bar delivery pressure, Then;

$$\eta = \frac{(320/3600\ 140\ \text{kPa})}{(15 \times 6)\text{kw}} \times 100\% = 13.82\%$$

So we have (0.138) efficiency and (1- 0.138), so, 0.862 deficiency!!!

This value is very low, it is mean that: when we add 10 kw of electrical Power we get 1.38 kw as useful hydraulic power and 8.62 is a waste…..

Considering the large total input power (90 kw), practically we are wasting 77.58 kw to produce 12.42 kw which we need at the current operation conditions.

At design conditions; we get about efficiency of 51.8% with 480 m^3/hr and about 3.5 bars. So we have an additional deficiency in these pumps can be quantified by the following equation;

$$\text{Additional Deficiency}\ \left(1 - \frac{0.138}{0.518} \times 100\%\right) = 73.35\%$$

Then about 73.35% are an additional deficiencies; i.e. the design efficiency is diminished three times.

International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

However; we are in front of "13.8%" Pumping System efficiency, which indicates an exaggerated energy waste.

2.3 Other Problems

Beside the above mentioned problems, there is other problems. These problems are a design mistake, flow discontinuity, safety problem.

The design mistake is a mistake in the pump characteristics selection, i.e. the pump selected and installed were not accommodated with the system total dynamic head, or at least system pressure drop, as will be discussed in "The Second Solution".

The flow discontinuity problem, which results from the insufficient suction head, makes the average produced flow rate of the pumps less than what mentioned above, less than 320 m^3/hr.

The safety problem is the possibility of the pipelines failure due to the highly pulsated flow rate and hammer.

III. The Solution

3.1 Introduction

In shade of the understanding of the problem, its resultants and the unloading system engineering requirements, in addition to being this study is built upon the briefing, then "the problem analysis" will not introduced in an independent section, but "the problem solution" is introduced directly and the expected content of the problem analysis will be introduced here as a justifications of the solution. So the reader will know "what the solution is" and "how this solution is made" instead of knowing "how the solutions can be made" then "what the solution is".

The solution here is expressed by two alternatives that will be introduced here beside there justifications, which can make the owner stands on the optimum solution briefly and directly. The justifications of each alternative are divided into engineering justifications and economic justification; the engineering justifications will be discussed in here and the economic justifications is discussed then in "The Economic Statement".

"The Engineering Justifications of The First Alternative" includes the screw pump characteristics that makes it an attractive choice in the fuel pumping system, and previewing a practical comparison between centrifugal pumps and screw pumps in the fuel pumping by introducing a case study related to the case. Then; "The Second Alternative" is introduced as a second exit from the problem and its justifications is introduced in "The Engineering Justifications of the Second Alternative" preparing to the Engineering and the economic optimization process between the two alternatives.

3.2 The First Alternative

In shade of the understanding of the problem, it is recommended to replace these six pumps with three screw pumps with 200 m^3/hr for each one, since; two in service and one as standby. This solution seems very feasible because the plant remaining age with the owner is about 20 years, so the cost of the bled energy in the current unloading system is definitively more than the capital cost of the screw pumps minus the salvage value of the centrifugal pumps.

The engineering justifications of the first alternative:

Firstly; screw pumps characteristics:

The screw pump is recommended here because it possess as a characteristic;

- Constant flow, even in the presence of varying system back pressures due to changes in viscosity, while the centrifugal pump efficiency is effected by the viscosity changes, which exists with fuel oil case, further more being the centrifugal pumps do not deliver constant flow.
- No need for flow pulsation dampeners, which eliminate stresses, imposed on the pipeline system reducing the risk of pipeline failures. And these dampeners are required in the centrifugal pumps case even it is not installed here.
- Low noise and vibration levels.
- The screw pump is more safe, as the risk of the pipelines failures and so the higher possibility of the explosions and the risk of the noise and the vibration on the human is lesser with the screw pump.
- Experimentally, lesser maintenance processes are needed for the screw pumps.
- Also, higher efficiencies, so lesser energy costs, besides, mostly, the lower capital costs.

Secondly; conducting case study***:***

To approach the difference between the screw and centrifugal pumps for the fuel oil transfer and to sense the difference; it is suitable to introduce a case study deals with a comparison between screw pumps and centrifugal pumps in pumping the liquid fuel (crude oil) in high flow rates, the study conditions and results were;

Study givens [4]: three screw pumps (one standby) transport 250,000 barrel of crude oil per day in a Canadian station compared with three centrifugal pumps (one standby) if it work instead of the screw pumps.

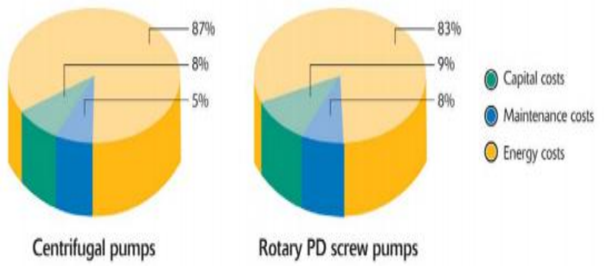

Fig.3. Capital, Maintenance and Energy Costs for Centrifugal and Rotary Positive Displacement Screw Pumps based on a 250,000 barrel per day crude oil pumping over Five years for a case study in Canada [4]

Study conclusion: Over a five-year period of using the positive displacement alternative, combined capital and maintenance costs account for less than 17 percent of the total cost of ownership, and efficiency is 27 percent higher than the centrifugal solution. Also, the positive displacement alternative reduced energy costs by 29 percent. Figure 3 shows these results in a chart while Table I shows the results of this comparison as cash values.

Study Projection: this study can be utilized in here to make a conception about the difference between the two pumps in liquid fuel transfer in general. Even the crude oil is more viscous and the pumps used in this comparison works at higher flow rates, this understanding of this comparison conclusion is useful in our case, as this comparison indicates being the screw pumps better than the centrifugal pumps at more difficult conditions.

Table I: Capital, Maintenance and Energy Costs for Centrifugal and Rotary Positive Displacement Screw Pumps based on a 250,000 barrel per day crude oil pumping over Five years for a case study in Canada [4]

	Centrifugal Pumps	Screw Pumps
Capital cost	$2,263,313	$1,917,764
Maintenance cost	$1,439,200	$1,738,745
Energy cost	$24,854,086	$17,585,577
Total cost of owning and operating	$28,566,599	21,242,086

3.3 The Second Alternative

The Second Solution is introduced here as an alternative track rather than the pumps replacing with screw type pumps, i.e. to avoid paying the high capital cost of the screw pumps.

Here; it is recommended to operate three pumps at the same row[2] and make the other three as standby pumps.

Depending on this recommendation, it is expected to obtain saving of three pumps input energy cost, so 27.6% efficiency with appropriate outputs. It is important here to know that this solution is related with longer operation time, because the number of the needed pipes venting processes will be more, as the air quantity passed through the pumps, which decreases the flow rate sharply, will be more**.**

This solution provides with doubled efficiency, but "with more engineering, more improvements can be accomplished", so by making another engineering modification about tripled efficiency can be achieved. Another once, with more engineering, the higher operational costs related with this solution can be canceled, even it can be converted into incomes. Thirdly, with more engineering, the problem of the flow pulsation can be so reduced. But fourthly and the most wonderfully, the engineering can make the above three improvements by one engineering change, this change is to install flow pulsation dampener after the delivery header of the pumps.

Because the above introduce is an engineering introduce and because the engineering is a practical knowledge rather than theoretical, the results of testing the above mentioned mode of operation without the dampener provides with the expected results, which are 410 m^3/hr and 1.5 bars after the delivery header. Then the efficiency of the system now can be calculated;

$$\eta = \frac{(150 \text{ kPa} \times 410/3600)}{(15 \times 3)\text{kw}} \times 100\% = 37.96\%$$

The engineering justifications of these practical and wonderful results are introduced as followed;

The engineering justifications of the Second Alternative:

A questioner can ask: how can a flow rate of three pumps equal to about 410 m^3/hr even each pump flow rate is 80 m^3/hr?

Yes; if we acknowledge that each pump produces 80 m^3/hr, then four pumps at fully opened discharge valve will produce 80 × 3 = 240 m^3/hr at the perfect cases, but in fact each pump do not produce 80 m^3/hr but it produces more than 140 m^3/hr…. but how?

Although the labeled flow rate at the name plate at each pump is 80 m^3/hr, each pump gives more than 140 m^3/hr because the pumps was selected mistakably, the designer did not select pumps accommodated with the total dynamic head[3] (TDH) of the system[4].

However; as a result of this false design, the pumps optimum performance point (operation point) is transferred from point A(80 m^3/hr flow rate with 36.7 head) to point B (about 140 m^3/hr with 20 head) as shown in Figure 4.

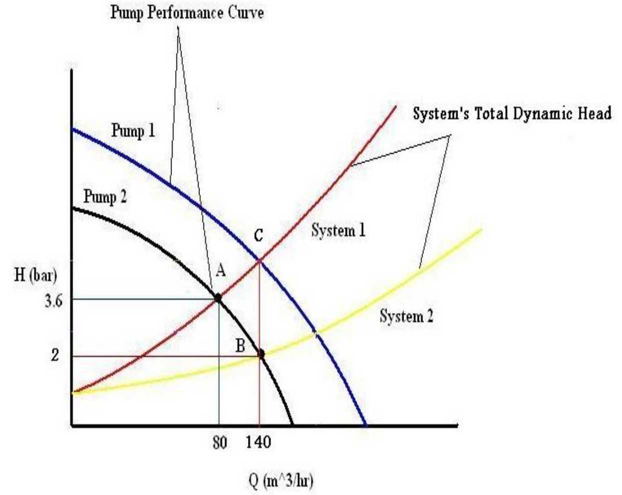

Fig.4. A sketches of four curves; two for systems Total Dynamic Head (red and yellow) versus the Flow Rate and two curves for The Operating Head of two different pumps versus the Flow Rate (blue and black).

[2] Operating three pumps at the same raw, not from different rows, decreases the pressure drop at the discharge header because of the lesser turbulence that may result from the discrepancy of the flow direction at the pumps delivery header.

[3] The TDH is given by the following equation [6];

$$H_t = H_s + H_d + H_p + H_l + H_v \qquad \text{(I)}$$

Where;
H_t: Total Dynamic Head
H_s: Static Head (Static Lift + Static Discharge)
H_d: Drawdown
H_p: Operating Head
H_l: Friction loss Head
H_v: Velocity Head

[4]The designer as can be noticed is not a designer, is not mechanical engineer, this is what can be observed from his huge mistakes that shown consequently. So, this can make sense about the difference between the engineering work and the non engineering work. Yes, if a trained mechanical engineer had designed this system, the efficiency of the system would not dropped down 65%, so five times the current efficiency.

The black curve in Figure 4 represents each unloading pump curve, the point A represents the operational point of the pump which selected depending upon existing a system its total dynamic head is represented by the red curve, but our system in fact does not have TDH (or specifically a pressure drop) as in the red curve but as in the yellow curve (less TDH), so the operation point becomes point B instead of point A. However; the operation at point B is positive thing because it provides with more flow rate without excessive mechanical stresses as if the pump works at any point on its curve then this mean that it works within its design boundaries.

3.4 Engineering Optimization

Depending on the engineering justifications of each alternative, The first solution is optimal from the engineering point of view, because it possesses the higher efficiency, the softer performance, the lesser maintenance, the safer case and the faster process.

IV. The Economic Statements

4.1 Introduction

The economic statements are important as the engineering statements are important, because the engineering designs and productions are considered in a lot of cases as a way to establish and develop the business. Here, then, it is important to translate the engineering statements into an equivalent economic statements to be absorbable by the business owners.

4.2 The Economic Statement of the First Alternative

If three screw pumps, two in work and one standby, with 75% efficiency and 200 m^3/hr for each one, so 400 m^3/hr is the total flow rate, then the following economic advantages will be gained;

- (0.75/0.138) or (5.43) Saving ratio will be gained, that is: diminish the unloading pumps input energy cost to more than five times at the same output.
- Lower maintenance costs.
- The higher flow rate will make save in the operational costs of the labors and the operation engineers when they come in specifically to cover the unloading area operation.

From the other hand, the following economic disadvantages would be introduced;

- The capital cost of the two screw pumps will be paid.
- The current value of the used centrifugal unloading pumps will be loosed or still as stand by.

Then, depending on the above advantages and disadvantages, the economic statement of this alternative is established;

Knowing that;

- The working time of the fuel oil unloading system is about 9 months per year and for a twelve hours a day.
- The three screw pumps that substitute the existing ones has an efficiency of about 75% each, total flow rate of 200 m3/hr and 1.7 total head each, two in work and one as standby and total capital cost (3 pieces) of $22,000. Then the total input power save is about 60 kW, and the annual equivalence of the capital cost along the project remaining life (20 years) is $22,000/20 that is $1100 annually.
- Each GJ is sold to NEPCO by $6.8;.
- The average of the save in daily paid- labors expenditures each day is about 20 JOD due to the lesser working hours as the flow rate is more here.

Then, the annual saving in the input energy costs as a result of this redesign can be calculated as follows,

$$60\ \frac{kJ}{s} \times \frac{3600\ s \times 12\ hr \times 270\ day}{1\ year} \times \frac{\$6.8}{1\ GJ}$$
$$= \$4778/year$$

And as a saving in the operational costs is;

$$(20)\frac{JOD}{day} \times 270\frac{day}{year} = 5400\ JOD/year$$

And by USD's;

$$3600\frac{JOD}{year} \times \frac{\$1}{0.71\ JOD} = \$7605/year$$

The annual maintenance costs of the screw pumps experimentally is less than the maintenance costs of the centrifugal pumps for oil transmission [4]. However, In the past five years, the maintenance costs of the centrifugal pumps is neglected number . So the difference in the maintenance cost will be neglected.

$$\mathrm{TAS} = \mathrm{AIECS} - \mathrm{AOCS} - \mathrm{AMCS} - \mathrm{AECCS} \qquad (4)$$

Where,

TAS: Total Annual Saving [$].

AIECS: Annual Input Energy Costs Saving [$].

AOCS Annual Operational Costs Saving [$].

AMCS: Annual Maintenance Costs Saving [$].

AECC: The Annual Equivalence of the Capital Cost [$].

Then the total annual saving for,

$$TAS(Alt. 1) = \$4778 + \$7605 - \$1100 - \$0 = \$11283$$

4.3 The Economic Statement of the Second Alternative

The second solution, which is to keep using the existing centrifugal pumps but in a different operation manner with adding flow pulsation dampeners, is in fact a easy way to make input energy saves. In the inverse of the first solution; the second solution is correlated with the following advantages:

- Relatively, no capital costs will be paid. Without installing pulsation dampener; this solution needs to no capital costs to implement it., and with Without installing pulsation dampener the capital cost may reaches to about $2000, and if this capital cost converted to uniform annual payments along to the remaining age of the plant, 20 years, it will be about $100, which is so silly and can be neglected.
- The current value of the used centrifugal unloading pumps will not be loosed.
- The input energy costs will be diminished to the half. So, the input power will be 45 kw instead of 90 kw.
- The output energy of the system will be more, so 410 m3/hr liquid flow rate with 1.5 bars working pressure will be gained comparing with 320 m3/hr and 1.4 bars in the existing case.

- The operational costs will be diminished to about 20 JOD/unloading day.
- From the other hand; this solution accompanies the following disadvantages:
- The efficiency of 37.96% which gained by this solution is also so low. Even it is considered a wonderful improvement relative to the current efficiency 13.8%, but it is considered a very low efficiency relative to the common used similar pumping systems which have an efficiency of up to 65%to 75%. This means that this solution reserves and extends the unreasonable energy bleeding of a large portion of the input energy of this system.
- It is expected to increase the maintenance costs as a result of applying this solution, as the operating pumps will suffer from more flow interruptions or separations due to the larger sucking and passing air quantities. This increasing in the maintenance costs, in fact, is not significant, because the pumps works under appropriate conditions usually, but more difficult some times, at the latest interval of each unloading process due to the drop in the suction head that cause sucking more air.

In shade of the above advantages and disadvantages, the economic statement of this alternative is established on the annul basis;

The save in the input energy costs can be calculated as follows;

$$45\,\frac{kJ}{s}\times\frac{3600\;s}{1\;hr}\times\frac{12\;hr}{1\;day}\times\frac{270\;day}{1\;year}\times\frac{\$6.8}{1\;GJ}$$
$$=\ \$3569/year$$

The save in the operational costs related with this alternative is;

$$(20)\,\frac{JOD}{day}\times 270\,\frac{day}{year}\times\frac{\$1}{0.71\;JOD}=\$7605/year$$

The save in the capital and maintenance costs is zero, then the total annual save results from this solution is expressed, according to equation (4), by the following economic statement;

$$TAS(\;Alt.2)=\$3569+7605-\$0-\$0=\$11174$$

Then; the total annual save related with this solution is $11174.

4.4 The Economic Optimization

Table II**:** Capital, Operation and Energy Savings for Centrifugal and Screw Pumps over twenty years for the fuel oil pumping system in Amman East Power Plant

	Alternative 1	Alternative 2
Capital Costs' Saving $	-1100	0
Input Energy Costs' Saving $	+4778	+3569
Operational Costs' Saving $	+7605	+7605
Maintenance Costs Saving $	0	0
Annual Saving in bay back period of 20 years $	11,283	11,174
Annual Saving in bay back period of 10 years $	10,183	11,000

The economic optimization can be done depending on the results shown in Table II. Clearly, it is difficult economically to determine the optimum solution, because the alternatives give appropriate savings. However, it can be said, economically, in the long term the first alternative is the optimum, while in the short term the second alternative is the optimum. So, the owner can decide which alternative is suitable, because he know more his economic givens!

V. The Decision Making

Depending on the results of the engineering optimization and the economic optimization, the resultant optimization can be coined. The final decision is made according with the resultant optimization. According to the author insight, the first alternative seems to be the optimum solution.

VI. Conclusion

- Generally, engineering speaking, to use more than three centrifugal pumps in parallel to transfer a liquid is not a healthy design act, because the pumps practical performance curves show that the total efficiency of such hydraulic system will be less and less as the number of the pumps increases due to the excessive energy loss, pressure drop, at the suction header and the delivery header. The pump characteristics selection is an engineering process that must be adopted proficiently and strictly according to the true and scientific criteria and in shade of the given engineering conditions. The selection of the suitable suction head is an important issue in the design of the pumping systems, so a lot of the performance problems and energy wasting can be avoided. Particularly, The Fuel Oil Unloading System at Amman power station suffers from design mistakes in the above mentioned points, which makes its efficiency reaches to about 13.8%.
- The design mistakes cost a lot, as it is correlated with permanent, or uniform, costs that should be paid, i.e. higher input energy costs, maintenance costs and operational costs. The business men do not recognize this point, because they do not have a background in the engineering. Now, the recommendation here for any investor needs to make the highest incomes avoiding such design mistakes is to not account on a technician, even who have a long experience, in the system construction, commissioning and even the operation, but to account on an engineer, who have bachelor degree with good experience, because the engineer knows "how" and the technician does not have the needed knowledge, i.e. the

physics, which is the soul of the engineering systems. So, in the design and commissioning, the knowledge owned by the person doing these works must be given higher attention.

Here, in the case study of Amman power station, a fuel unloading pumping system with $11,000 annul loss is introduced because the designer of this system was not an "Engineer", as can be observed from his huge design mistakes. This is a small case study, sub- system, with small system overall cost, so it can be imagined here that such mistakes are introduced in a bigger engineering system resulting in such low efficiencies and dramatically in mush more money loss. And here, it must be known that the owner of the plant equalizes between the engineers and the technicians who have good experience even they are not equal in front of the eyes of the fact.

This scientific paper; its givens, analysis and results certifies that certifies that there is a real difference between who know and who does not know. Oh who invest in the engineering and power production sectors! You must know that your investment are built on the knowledge, so you must respect each difference in this knowledge, because this knowledge had let you invest and make money… and if you choose to renounce the allegiance to the knowledge, then the power of the knowledge will draw the carpet beneath your feet, making you loss the money while you do not know that you losing the money, so you do not know that you do not know, because you did not respect the knowledge, since the knowledge is belonging to the other knowledge. Think!

- The engineering corrective decision that must be followed in order to solve the problem at Amman power station fuel oil unloading system is one of two; the first one is to replace the existing centrifugal pumps with three screw type pumps, two in service and one in standby, with capacity of 200 m3/hr for each one, which will increase the efficiency to about 75%. This solution will make savings of about $11,283 annually for pay back period of 20 years. The second one is to operate 3 centrifugal pumps from the existing ones at the same side, fully opened discharge and with flow pulsation dampeners equipped at the delivery and suction sides. This solution will make savings of about $11,174 annually for pay back period of 20 years. Now, the optimization between these two alternatives is difficult economically, but the engineering optimization, i.e. the more stable performance, safer and reliable system, overbalances the first alternative.

Acknowledgment

Thanks for Allah who supported me to do this work. Peace be upon prophet Mohammad. This work is presented to my mother and my family; brothers and sisters. I present this work to my father, oh Allah bless him and give him the heavens. This work is dedicated to my friend Ahmad Ktefan- shift charge engineer at IPP1. Oh Ahmad: I am very thankful for your support, honesty and fairness.

References

[1] S.C. SHARMA and T.R. BANGA, Hydraulic Machines with fluid power engineering", Khanna publishers, sixth edition.
[2] Crane Valve Group, Flow of Fluids through Valves, Fittings and Pipe, Crane Technical Paper TP-410M metric edition, available from www.tb410.com.
[3] H. Vogelesang, 'An introduction to energy saving in pumps, World Pump No 496, 2008.
[4] Mike Moore, Colfax Care, "Why Rotary Positive Displacement Screw Pumps are an Efficient pumping Solution over Time", http://www.colfaxcorp.com/admin/modules/article_manager/uploads/PumpSystems.pdf
[5] M.T. Schobeiri, Fluid Mechanics for Engineers, Springer Berlin Heidelberg 2010.
[6] Dorota Z. Haman, Fedro S. Zazueta, Forrest T. Lzuno, Selection Of Centrifugal Pumping Equipment, University of Florida- Florida Cooperative Extension Service, 1048, November 1994.
[7] Anthony Esposito, Fluid Power with applications, Pearson Education, seventh edition.
[8] Karassik, I. J., Krutzch, W. C., Fraser, W. H. and Messina, J. P."Pump Handbook." McGraw-Hill, Inc., 1976.
[9] Stepanoff, A. J., "Centrifugal and Axial Flow Pumps." John Wiley & Sons, Inc., 1948, 1957.
[10] API Std 610 8th Edition—Centrifugal Pumps for General Refinery Service.
[11] Hydraulic Institute Standards, Fourteenth Edition, Hydraulic Institute, 1983.

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