International Journal of Renewable Energy Resources 3 (2013) 27-42

ENERGY AND EXERGY EFFICIENCIES IN INDUSTRIAL PUMPS

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ABSTRACT

In this paper, pumps of an industrial facility have been examined according to the energy and exergy efficiency. For this purpose; flow rate, pressure and temperature data have been measured for each pump under operating and maximum loading conditions. Additionally, applied electrical power on electric motors have been measured. The efficiencies of existing pumps and electric motors have been calculated by using measured data. As a result, maximum energy efficiency is estimated as 0.82 for number 5 tower pump system and maximum exergy efficiency is 0.23 for number 3 central pump system. Potential saving opportunities have been determined by taking into account the results of the calculations for each pump and electric motor. As a result, the required improvements, investment potential for these improvements and simple payback periods have been determined for each system. Determined main saving opportunities are: replacement of the existing low efficient pumps with more efficient new pumps, the maintenance of the pumps that their efficiencies started to decline at certain range, the replacements of the electric motors, had been chosen in higher capacity, with electric motors which has more suitable operating power for the system pumps, the usage of high efficient electric motors.

Keywords: Pump, exergy, electric motor, energy saving, payback period.

NOMENCLATURE

η: Efficiency
$\dot{E}_1$: Inlet exergy
$\dot{E}_2$: Outlet exergy
h_1: Enthalpy
Ψ_1: Inlet exergy of unit mass
Ψ_2: Outlet exergy of unit mass
$\dot{W}$: Power [kW]
A: Current supplied from network [A]
AUS: Annual usage [€/year]
DS: Monthly demand power saving for motors [kW/month]
h_e: Maximum head of suction line [m]
$I_{network}$: Network current [A]
$I_{nominal}$: Label current [A]
LC: Loading coefficient
MN: Motor number in the same power
N: Revolution [r/m]
η_m:Mechanical efficiency
OP: Operating period [month]
P_e: [Pa]
P_f: Power factor
P_{input}: Input pressure [Pa]
P_m: Medium pressure of the pump [Pa]
P_{mek}: Mechanical power [kW]
$P_{network}$: Network power [kW]
P_{sat}: Saturation pressure of water [Pa]
Q: Flow rate [m3/h]
S_1: Entrophy
T_0: Temperature [oC]
UF: Usage factor
US: Usage Saving [kWh/year]
V: Velocity [m/s]
$V_{network}$: Voltage supplied from network [V]
$V_{nominal}$: Voltage on label [V]
z_1: Distance between pump level and pool[m]
z_2: Distance between pump level and top of cooling tower [m]
Δy: Dynamic drop of pressure
ε: Exergetic efficiency

1. INTRODUCTION

In the studies that has been carried out for energy saving, it has been seen that one of the areas of high potential energy saving is pumping systems (Kaya et al., 2008; Kaya, 2002; Kaya et al., 2011; Kaya et al.; 2009). According to study of American Hydraulics Institute, 20 % of consumed energy has been consumed by pumps in developed countries (Ertoz, 1997). It has been explained that 30-50% of this energy can be saved with a good design of a system and choosing suitable pumps. This situation has caused to make new searches to find more efficient systems in production and operation by the producers and users of pumps (POMSAD, 1997; ISO 3555, 1998; ISO 2548, 1998; ISO 9905, 2000; ISO 9908, 2000). Furthermore, some legal regulations have been started to enact in this topic in some countries (Cuha, 2005). For example, it is obligatory that labeling of circulation pumps (P < 2.5 kW) has been at the last stage in EU. Placing the letter on the label to show energy efficiency is obligatory for circulation pumps that have been produced in Germany. Besides, it has been stated and published at the end of the studies that have been carried out, the flow rate, pump head and period number of the pump to know required efficiency, which have been showed on the diagrams to control the appropriation of the pump efficiency by clients when purchasing centrifugal pumps, in EU (POMSAD, 2001). Highly efficienct pumps are not only enough for a pump system to operate in maximum efficiency. Maximum efficiency is only obtained by completely optimized pump system while operating under optimum conditions. Otherwise, it is inevitable that even the most efficient pump in a system which has been wrong designed and wrong assembled is turned into inefficient (POMSAD, 2001; Kovats et al., 1968; Lakshminarayana, 1970; Lakshminarayana, 1986; Cherkassy, 1980; Kovats, 1964).

In this study, pumps of an industrial facility have been examined according to the energy and exergy efficiency,so the required improvements, investment potential for these improvements and simple payback periods have been determined for each system.

2. EFFICIENCY AND THE FACTORS THAT INFLUENCE THE EFFECTIVENESS IN PUMPS

The effective usage of energy by a pump should be taken into account in the design and operating conditions. The device should be selected to meet the requirements of working under maximum capacity conditions, but in economic point of view it should also be known which capacity will be require for operating conditions. Then, the pipe system can be designed. If the maximum capacity required for short time period, it is not require a big diameter pipe. If the system works with a high capacity for a long time, this situation should be taken into consideration in the assignment of the pipe diameter (Kaya, 2002; Kaya, 2000).

While designing of a pipe system, the system curve must be precisely drawn. It is very important to choose a pump with maximum efficiency and the most convenient running clearance. The first purchasing costs are only between the ranges of 3-5% in the life cycle cost of the pump is brought the obligation to the administrators to make more careful selections.

It is very important the selection of an electric motor to work efficiently in suitable power. Generally, the motors are chosen in big capacities to meet the extra loading demands. This situation causes to work inefficiently and under low loading. Practically, motors are operated more efficiently is on 75% and above this values in rated load. The motors, are operated lower than 50% of rated load, have been chosen in big capacity, performing inefficiently and due to the reactive current increase, power factors are also decreasing. These type of motors don't efficiently consume the energy, because they have been chosen in big power, according to the needs. The consumed electricity in lower power level, converted to heat energy more than mechanical energy and this situation causes heating of the electric motors and decreasing the operating life of the motors. These motors should be replaced by new suitable capacity motors and when purchasing new motors it should be preferred energy saving motors. The energy consumption rate of that electric motors is about 65% of total energy consumption of facility. Purchase cost of a typical electric motor constitutes about 2% of the total cost. Energy cost is also constitutes 98% of the total cost as well. So, choosen of "high efficient" motors is very important in plants. Electric motors also can not completely transform the energy into mechanical energy. Motor efficiency is defined as the rate of mechanical power output of a motor and drawn electric power and according to its size it ranges between 70% and 96% (WAEO, 1993). Also, the motors, are operated in partial load, are in low efficiencies. The efficiency rate changes in a range by motors to motors. For example, when the efficiency of a motor is 90%, when it is full loaded, 87% when it is half loaded, 80% when it is 1/4 loaded; the efficiency of an another motor is 91%, when it is full loaded, 75% when it is 1/4 loaded.

Cost of high efficient motors that has been developed in the last years are more expensive than standard motors is about 15-25% , because of the low operating costs, this difference can be regained in short period of time (Cengel and Cerci, 2000, Kaya et al. 2000, Kaya and Gungor, 2002, Kaya and Kılıc, 2004). Different conditions to get a pump system with variable flow rates are: to operate the pump is require the operate under the partial load, to operate a pump continuously send back the some of the fluid to a reservoir (the by-pass system), by feeding a system from a tank to operate the pump under partial load condition with respect to the level of the tank, adjust the flow rate by regulating flow rate control valve at the outlet of the pump and system curve, to adjust pump rotational speed according to the needs of flow rate or pressure by putting hydraulic or electrical coupling between constant speed electric motor and the pump system, to set a parallel operating pump system, to change the belt and pulley system and pump rotational speed, to use a frequency converter. The most usable and widespread one of the mentined conditions is a system with frequency converters (Bejan et al. 1996).

2.1. The saving at the facility

The most important performance loss occurs at the stage operation of pumps at part-load condition. In the situation of pumps operated at nominal capacities, the highest efficiency can be achieved. Besides, on centrifugal pump if the flow rate value assumed as 100% that is the maximum efficiency is exist, if operated at flow rate value that approximately 40%, usually, vibration, increase of radial loads, excessive sound and decrease of the efficiency can be experienced. For this reason, it should be given more attention to operate the pumps close to their nominal capacities.

All the improvements are the elimination of clogging in valve, pipeline, pumps, and assurance the impermeability of the pipe circuit; maintenance of the belt, pulley, bearing, and filters, regularly; insulation of the heating circuit, the prevention of the vibration assure the energy saving and financial economy. In the design stage of the pumps examination of the economy of variable flow rate systems. The examinations should be made on the existing pumps. In the studies that have been made about the energy efficiency, it has been calculated that the frequency control application of the existing pumps will assure a very important rate of saving. Pumps are also like other mechanical devices wear out in time, the flow rate and pump head may decrease. The pump efficiency can be increased by polishing process for the pump surface coating and the elimination of the surface roughness. This is very effective especially in low powered pumps. If pumps are completed their economic period by their working conditions they will be taken in investment plan. Fig. 1 shows a pomp impeller, completed economic period.

Figure 1 An impeller completed economic period.

In the scope of energy efficiency study in the facility pumps, the measurements have been carried out in the factory within two different group; one is electrical and the other is mechanical. Electrical measurements are consists of the measurements that have been taken from electric motors that are used to drive pumps. Mechanical measurements are comprised of the values that have been measured flow rate, pressure and temperature of the pumps.

3. THE MEASUREMENT METHOD, DEVICES AND RESULTS

In the facility pumps in the scope of energy efficient study, the measurement that has been carried out in the factory comprises two different group; one is electrical and the other is mechanical. Electrical measurements are comprised of the measurements that have been taken from electric motors that are used to drive pumps. Mechanical measurements are comprised of the values that have been measured flow rate, pressure and temperature of the pumps.

3.1. Electrical Measurements

Applied electrical measurements in pump electric motors, motor feeding voltage, the current that drawn from the network, apparent power, active power, reactive power and motor power factor have been measured. By using the data of measurement electric motor loadings, operation efficiencies, and the power value that has been transmitted to the pump, have been calculated and then the results have been evaluated. Apparent power, active power, reactive power and motor power factor have been calculated by the Eq.(1), Eq.(2) and Eq.(3) below.

Apparent power: $(3^{1/2}VA)/1000$ (1)

Active power: $(3^{1/2}VAf)/1000$ (2)

Reactive power: $(AP^2-AC^2)^{1/2}$ (3)

During the measurements that have been carried out in all pumps the assumption that has been made that there is no big sudden change about the load variations that changes the behavior of system in wide range, and the measurements have been carried out on electric motors by getting the values for short terms. In measurements an electric energy analyzer device marked as UPM 6100 has been used, the measurements have been carried out in the form that “3-phases 1-lined”. In measurements 3 voltage props and a 200 ampere current prop have been used. The measurements have been made over current and voltage transformer exist in secondary part of feeding point in main panel of the motors that are fed from the medium voltage (3300 V) level. In measurement 3 voltage props of energy analyzer are connected to secondary part of voltage transformers and a 200-ampere current prop is connected to secondary part of current transformer. Measurement shape is given in Fig. 2.

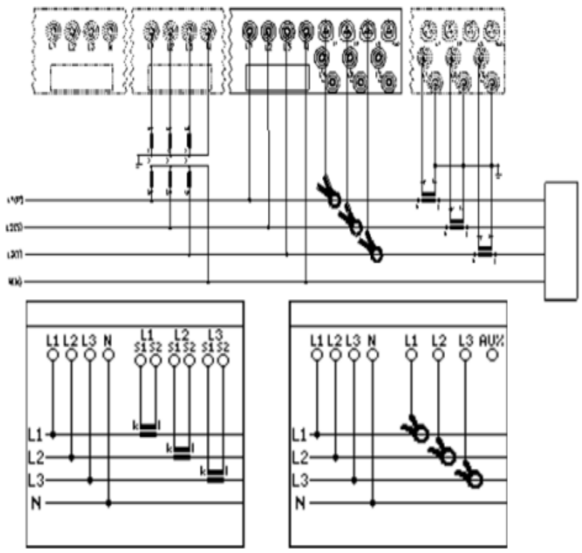

Figure 2 Schematical view of electrical measurements.

In the motors that are fed from the low voltage (400 V) level, the voltage has been measured by voltage props that is directly connected to feeding point in main panel of the motor, and motor current, has been measured over current transformer by using a 200 ampere prop. All measurements have been made in normally operating time of motors while driving the exist pump. In electrical power measurements that have been made by an energy analyzer, the values are drawn from network of the pump three-phase electric motor, apparent power, active power, reactive power, voltage, current and power factor have been measured. The measurements have been carried out on the pump motors that are driven by 16 electric motors in the facility. The name of the measurements points and nominal label values of the electric motors that measurements have been made on, are given in the Table1. Also, the results of electric motors of the pump in area of the measurements are given in the Table 2.

Table 1 The label values of electric motors.

Measured Electric Motors	Nominal Values					
	Power		Voltage	Current	Rotation	Power F.
	[HP]	[kW]*	[V]	[A]	[rpm]	[--]
Central pump 1	282	210	3300	48	725	0,85
Central pump 2	282	210	3300	48	725	0,85
Central pump 3	282	210	3300	48	725	0,85
Central pump 4	154	115	3300	27	970	0,86
Central pump 5	161	120	3300	28	730	0,84
Central pump 6	282	210	3300	48	730	0,85
Central pump 7	177	132	400	261	650	0,78
Tower pump 1	537	400	3300	89	-	0,84
Tower pump 2	537	400	3300	89	-	0,84
Tower pump 3	537	400	3300	89	-	0,84
Tower pump 4	537	400	3300	89	-	0,84
Tower pump 5	537	400	3300	89	-	0,84
Tower pump 6	537	400	3300	89	-	0,84
Tower pump 7	537	400	3300	89	-	0,84
Point pump 1	101	75	380	147	975	0,86
Point pump 2	101	75	380	147	975	0,86
Point pump 3	101	75	380	147	970	0,86

*1hp=0,745 kW

Table 2 The results of electric motors of the pumps.

Name	Voltage (V)	Current (A)	Apparent power (kW)	Active power (kW)	Reactive power (kW)	Power factor
Central pump Electric motor 1	3280	25,9	146,97	124,9	77,46	0,85
Central pump Electric motor 2	3280	28	158,88	135,1	83,61	0,85
Central pump Electric motor 3	3280	45	255,35	217,05	134,50	0,85
Central pump Electric motor 4	3368	27	157,32	135,29	80,28	0,86
Central pump Electric motor 5	3280	25,9	146,97	123,45	79,75	0,84
Central pump Electric motor 6	3280	26,4	149,80	127,3	78,96	0,85
Central pump Electric motor 7	389	250	169,59	132,28	106,12	0,78
Tower pumps Electric motor 1	3280	55	312,09	262,16	169,32	0,84
Tower pumps Electric motor 2	3280	58,6	332,52	279,32	180,41	0,84
Tower pumps Electric motor 3	3280	56,6	321,17	269,78	174,26	0,84
Tower pumps Electric motor 4	3280	56,8	322,31	270,34	175,55	0,84
Tower pumps Electric motor 5	3280	56,6	321,17	269,78	174,26	0,84
Tower pumps Electric motor 7	3280	55	312,09	262,16	169,32	0,84
Point-1 pumps Electric motor 1	397	130	89,29	76,79	45,56	0,86
Point-1 pumps Electric motor 2	397	134	92,03	79,15	46,95	0,86
Point-1 pumps Electric motor 3	397	112	76,92	66,15	39,25	0,86

3.2. Mechanical Measurements

In the scope of the mechanical measurement, pump fluid flow rate, inlet and outlet of the temperature and pressure values of the fluid have been measured. The flow rate that the pumps discharge has been measured by an ultrasonic flow meter that the brand is "GE-PANAMETRICS". Two transducers that belong to the flow meter are connected to the pipe from the outside, in the form of the parallel to the flow; the first transducer has been operated as a signal generator, and the second one as a signal receiver. The fluid velocity has been determined as the difference between the measured signal arrival time and the sound velocity. The device has also measured the diameter of the pipe the amount of the flow rate has been measured as online. The system of the measurement is given schematically in Fig. 3.

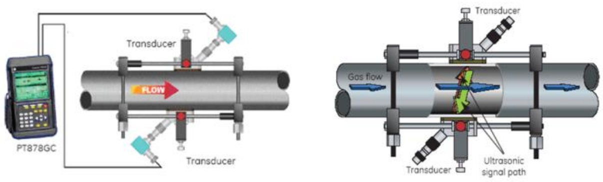

Figure 3 Schematic view of measurement system.

The measurement of the fluid inlet and outlet pressure values has been carried out by existing pressure gauges which are verified by an another calibrated gauge.

The fluid temperatures have been determined by existing pump inlet and outlet line temperatures which had been measured by a thermal camera and added about +2 ^{o}C as the surface temperature loss value. It has been seen that this measurement values are in harmony with the values that measured by the thermometers on the system. The result of the mechanical measurements is given in section 4.

4. THE CALCULATION OF THE EFFICIENCIES

4.1 The Calculation of Loading and Operating Efficiency of the Motors

The active power that has been drawn by the electric motor from the network is $P_{network}$ and the efficiency value is η_m the mechanical power value which is connected to the motor shaft transferred to the pump is P_{mec}, calculated in Eq.(4) as;

$$P_{mec}=P_{network}\,\eta_m \tag{4}$$

and it is showed schematically in Fig. 4.

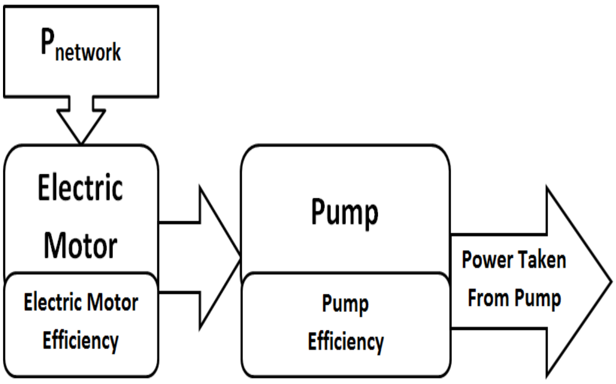

Figure 4 Schematic view of electrical motor and pump system.

P_e, power values of the electrical driven pump motors, which have been drawn from the network, have been measured in the factory. The efficiency values of these motors and efficiency loading curves that show the variation of motor efficiency as to loading, are not exist. Therefore, what would be the operation load and efficiency of the motors has been found by calculating. In these calculations, area measurements and motor nameplate values have been used.

The value of electric motors loading has been calculated according to current measurement technique. In the calculation of motor efficiency which has been operated in this loading value; the calculated loading value, the power of the motor that had been drawn from the network and the nominal (nameplate) power have been used.

Motor loading value has been calculated in Eq.(5) as (%) and it is showed below:

$$Loading(\%)=(I_{network}/I_{nominal})*(V_{network}/V_{nominal})*100 \quad (5)$$

Where; $I_{nominal}$ mominal current of the motor (A),$I_{network}$ the current that has been drawn by motor from the network (A), $V_{nominal}$ nominal voltage of the motor (V),$V_{network}$ the voltage that has been measured at the terminals of the motor (V).

Motor efficiency has been calculated in Eq.(6) with the ratio of useful exit power of motor to the power that has been drawn from network *($P_{network}$)*.

$$\eta_m(\%)=(Loading*P_{nominal}(kW))/P_{network}(kW) \quad (6)$$

Motors loading and operating efficiency values are given the Table 3. The mechanical power value that is connected to the motor shaft, transferred to the pump has been calculated with $P_{mec}=P_{network}*\eta_m$

Table 3 Electric motors loading and operating efficiencies.

Electric Motors	Network Power (P_n) [kW]	Loading (1) [%]	Efficiency (2) [%]	Mechanical Power (P_{mec}) [kW]
Central pump 1	124,92	53,63	90,16	112,63
Central pump 2	135,05	57,98	90,16	121,76
Central pump 3	217,05	93,18	90,16	195,68
Central pump 4	135,29	102,06	86,75	117,37
Central pump 5	123,45	91,94	89,37	110,33
Central pump 6	127,33	54,67	90,16	114,80
Central pump 7	132,28	93,90	93,70	123,94
Tower pump 1	262,16	61,42	93,72	245,69
Tower pump 2	279,32	65,44	93,72	261,77
Tower pump 3	269,78	63,21	93,72	252,84
Tower pump 4	270,74	63,43	93,72	253,73
Tower pump 5	268,78	63,21	93,72	252,84
Tower pump 7	262,16	61,42	93,72	245,69
Point pump 1	76,79	92,39	90,24	69,29
Point pump 2	79,15	95,23	90,24	71,43
Point pump 3	66,15	79,60	90,24	59,70

(1). Current measurement is taken into account in the electrik motor loading calculations.
(2). Loading is taken into account in the efficiency calculations.

As can be seen in Table 3 central pumps number 1,2,6. engine's loading values are less than 60% of their commemoration load in our calculations. Central pumps on the electric motors of number 3,4,5,7 and Point 1 pumps number 1,2 loading values are higher than 90% of nominal value. The efficiency values of electric motors are in a suitable range between 86%-93%.

In our investigations central pumps 1,2,3 are working under low loading ranges. Loading values are 53%, 57% and 54% and transmitted powers are 112 kW, 121 kW, 114 kW respectively. These values are lower according to label values of the motors. In case of the pump efficiency is low, they will be recommended to renew. Number 3,4,5,7 pums electric motors of the pums in central pump loadin values are 93%,102%,91% and 93%. Number 1,2 pumps electric motors loadings are %92 and %95 in Point 1. Loading values on the tower pumps between (60-65)%. Mechanical powers transferres to fluid are between 240-265 kW. These values are low according to label values of the electric motors (400 kW), in case of the efficiency of pumps which drown by these engines are low, they will be recommended to change with the suitable ones.

The pump efficiency for normal operation conditions in each pump station has been calculated by using the pump flow rate, inlet and outlet pressure, and electrical power that has been transferred to the pump. Calculation results of 1-7th pumps in the central pumps are given in the Table 4, Tower pumps 1-7th pumps are given in Table 5, Point 1-3rd pumps are given in Table 6. Elecrtrical measurements in central pumps 1,2 couldn't be performed because of the insuitable material of the pipes for measurement. Measurement 6th pump in the tower pumps also couldn't be performed because of the engine fault.

Table 4 Efficiency calculations of central pumps.

Pump	1	2	3	4	5	6	7
Flow rate (Q, ton/h)	-	-	2285	1805	2011	2280	2265
Input pressure (P_1, bar)	-	-	-0,5	-0,35	-0,5	-0,5	-0,5
Output pressure (P_2, bar)	-	-	0,8	0,9	0,8	0,8	1
Pressure Difference (P_2-P_1, bar)	-	-	1,3	1,25	1,3	1,3	1,5
Power transmitted to fluid. (P_a=Q*(P_2-P_1)/36, kW)	-	-	82,51	62,67	72,62	82,33	94,38
Power transmitted to pump (P_{mec}, Electrical power, kW)	112,63	121,76	195,68	117,37	110,33	114,80	123,94
General Efficiency (P_a/ P_{mec} or P_a/P_t, %)	-	-	42,17	53,40	65,82	71,72	76,14

Table 5 Efficiency calculations of tower pumps.

Pump	1	2	3	4	5	6	7
Flow rate (Q, ton/h)	4025	3147	3240	3607	3416	-	3148
Input pressure (P_1, bar)	-0,5	-0,5	-0,5	-0,5	-0,5	-	-0,5
Output pressure (P_2, bar)	1,4	1,4	1	1,25	1,7	-	1,5
Pressure Difference (P_2-P_1, bar)	1,9	1,9	1,5	1,75	2,2	-	2
Power transmitted to fluid. (P_a=Q*(P_2-P_1)/36, kW)	212,43	166,09	135	175,34	208,76	-	174,89
Power transmitted to pump (P_{mec}, Electrical power, kW)	245,69	261,77	252,84	253,73	252,84	-	245,69
General Efficiency (P_a/ P_{mec} or P_a/P_t, %)	86,46	63,45	53,39	69,10	82,56	-	71,18

Table 6 Efficiency calculations of point-1-3rd pumps.

Pump	1	2	3
Flow rate (Q, ton/h)	1055	1145	890
Input pressure (P_1, bar)	-0,5	-0,5	-0,5
Output pressure (P_2, bar)	1,15	1,15	0,65
Pressure Difference (P_2-P_1, bar)	1,65	1,65	1,15
Power transmitted to fluid.(P_a=Q*(P_2-P_1)/36, kW)	48,35	52,48	28,43
Power transmitted to pump (P_{mec}, Electrical power, kW)	69,29	71,43	59,70
General Efficiency (P_a/ P_{mec} or P_a/P_t, %)	69,78	73,47	47,62

5. POTENTIAL SAVING OPTIONS AND RECOMMENDATIONS

In the studies that have been carried out in the facility pump systems the potential saving options have been determined as follows: the replacements of the existing low efficient pumps, the maintenance of the pumps that their efficiencies started to decline at certain range, the replacements of the electric motors that had been chosen in high power with electric motors that have suitable power, the usage of high efficient electric motors, elimination of cavitations problems.

5.1. The replacements of the existing low efficient pumps

5.1.1. Central pumps

It has been determined by the measurements that the pump efficiencies are below 60% for Number 3 and 4 Pumps and for Number 5 Pump is approximately 65% under the operation conditions. The new pump offers have been taken from the manufacturer company for these mentioned pumps that have the same pressure and capacities. To assure flow rate and pressure values at measurements conditions, electric motor power and pump efficiency value have been determined by using of the offered pump efficiency, power, pressure and flow rate diagrams.Calculations of the existing and the offered pumps are given in Table 7.

Table 7 Comparison of new and existing pumps.

PUMP		Power Transmitted to Pump	Power Transmitted to Fluid	Pump Efficiency
		[kW]	[kW]	[%]
Number 3	Existing Pump	195,68	82,51	42,17
	Offered Pump	99	84,6	85,5
Number 4	Existing Pump	117,37	62,67	53,40
	Offered Pump	99	84,6	85,5
Number 5	Existing Pump	110,33	72,62	65,82
	Offered Pump	99	84,6	85,5

As given above when existing pumps replaced with the new ones, there is a improvement about 20-43% at the efficiency of the pumps. In case of the existing pumps and electric motors are replaced with new ones together, annual money savings, investment costs and payback periods are given in Table 8. From 8 pumps, 3 pumps in the central pump are operated alternately. By considering efficiency and energy consumption, calculations of replecement of number 3,4,5 pumps and electric motors and in the condition of operating continuously, other ones are spare, are given Table 9. For the offer above, calculation are given in Table 10. if only inefficient pumps are replaced. As it can be seen in Table 10, when we replaced pump number 3,4,5 and run them continuusly, without changing pump number 6,7 payback period of the investment is between 7-60 months. This result indicates that replecament of inefficient pumps operating continuously is more suitable. When comparing Table 9 and 10 we can see replaceing only pump in number 3 pump and electric motor and replacing pump and electric motor together in number 4 and 5 pump and electiric motor is more suitable. In the tables above, only own payback periods of the pumps and electiric motors are given. But after the total investment and chnages in the operating conditions, when central pump is taken into account as a complete system, we can see that the payback period is lower. Payback period of the Central Pump is given in Table 11. When total investment and total cost is taken into account, Central Pump will redeem in 16 months and after this time it will save money annual 85.045 € in the operating costs of the company.

Table 8 Annual saving, investment costs and payback periods of new and existing pumps.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving [€]	Investment Cost(Pump + Motor) [€]	Payback Period [Month]
Number 3	217,05	104,5	112,55	4128	32.522,45 €	47.195,00 €	17,4
Number 4	135,29	104,5	30,79	5664	12.207,62 €	47.195,00 €	46,4
Number 5	123,45	104,5	18,95	3264	4.329,70 €	47.195,00 €	130,8

Table 9 Replacement of number 3,4,5 pumps and electric motors and in the condition of operating continuously.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment Cost(Pump + Motor) [€]	Payback Period [Month]
Number 3	217,05	104,5	112,55	8760	69.015,66 €	47.195,00 €	8,2
Number 4	135,29	104,5	30,79	8760	18.880,43 €	47.195,00 €	30,0
Number 5	123,45	104,5	18,95	8760	11.620,14 €	47.195,00 €	48,7

*1 kw/h electricity taken 7 EURO.

Table 10 Condition of only inefficient pumps are replaced.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment Cost(Pump + Motor) [€]	Payback Period [Month]
Number 3	217,05	110	107,05	8760	65.643,06 €	38.163,00 €	7,0
Number 4	135,29	114,35	20,94	8760	12.840,41 €	38.163,00 €	35,7
Number 5	123,45	111	12,45	8760	7.634,34 €	38.163,00 €	60,0

*1 kw/h electricity taken 7 cent EURO.

Table 11 Payback period of central pump.

Pumps	Total energy consumption before investment [kWh]	Total energy consumption after investment [kWh]	Annual energy consumption [kWh]	Annual saving* [€]	Total investment cost [€]	Payback period [month]
Central Pump	4.009.381	2.794.440	1.214.941	85.045,92 €	114.489,00 €	16,15

*1 kw/h electricity is taken 7 cent EURO.

5.1.2. Tower pumps

At operating conditions, as a result of efficiency measurements,in the tower pumps room, number 3 pump efficiency is calculated as 53,39% and number 2,4,7 pumps efficiencies are calculated as between 63-72%. Electric motors efficiencies are 93% and no need to replecememnt. The new pump offers have been taken from the manufacturer company for these mentioned pumps that have the same pressure and capacities. To assure flow rate and pressure values at measurements conditions, electric motor power and pump efficiency value have been determined by using of the offered pump efficiency, power, pressure and flow rate diagrams. The calculations of existing and offered pums are given in Table 12.

Table 12 Existing and offered pump pressure, flow, efficiency and electric motor power values

Pump		Power transmitted to pump	Power transmitted to fluid	Pump efficiency
		[kW]	[kW]	[%]
Number 1	Existing Pump	245,69	212,43	86,46
	Offered Pump	231,6	191,3	82,6
Number 2	Existing Pump	261,77	166,09	63,45
	Offered Pump	231,6	191,3	82,6
Number 3	Existing Pump	252,84	135	53,39
	Offered Pump	231,6	191,3	82,6
Number 4	Existing Pump	253,73	175,34	69,10
	Offered Pump	231,6	191,3	82,6
Number 5	Existing Pump	252,84	208,76	82,56
	Offered Pump	231,6	191,3	82,6
Number 7	Existing Pump	245,69	174,89	71,18
	Offered Pump	231,6	191,3	82,6

As shown at above when number 2,3,4 are replaced with the new ones, there will be 20-30 improvement at the efficiency. In the state of the pumps and the electrik motors replaced with new ones, annual money savings, investment cost and payback periods are given in Table 13. As seen at above in the Tower pumps, with the money saving by the replecament of pumps and electric motors all together is became 5-7 years. In the tower pumps 6 pumps are running cantinuously and 1 pump is spare. When efficiency and energy consumption considered, number 2,3,4 pumps and electric motors are replaced, payback periods are given in Table 14. The situationwithout replacing electiric motors, repaying periods are given in Table 15. As seen in the Table 15, in the result of replacement and running number 2,3,4 pumps continuously is and decreasing operating time of the other pumps, payback periods are changing 36 months and 51,5 months. This result shows that, replacement of low efficient pumps and running continuously is more suitable. Electrik motors of mentioned pumps efficiencies are about 93% and difference between the offered electric motors are 1%. So it's not economical the replace the electric motors. In the tables above, only own payback periods of the pumps

Table 13 Annual saving, investment costs and payback periods of new and existing pumps.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time[h]	Annual Saving* [€]	Investment cost (Pump+Electric Motor) [€]	Payback Period [Month]
Number 2	279,32	242,7	36,62	4632	11.873,67 €	81.000,00 €	81,9
Number 3	269,78	242,7	27,08	8136	15.422,60 €	81.000,00 €	63,0
Number 4	270,74	242,7	28,04	6120	12.012,34 €	81.000,00 €	80,9

*1 kw/h electricity taken 7 cent EURO.

Table 14 Annual saving, investment costs and payback period in the state of replacement and operating continuously 3 pumps and electric motors which have lowest efficiency.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment cost (Pump+Electric Motor) [€]	Payback Period [Month]
Number 2	279,32	242,7	36,62	8760	22.455,38 €	81.000,00 €	43,3
Number 3	269,78	242,7	27,08	8760	16.605,46 €	81.000,00 €	58,5
Number 4	270,74	242,7	28,04	8760	17.194,13 €	81.000,00 €	56,5

*1 kw/h electric is taken 7 cent EURO.

Table 15 Payback periods in the situation without replacing electric motors, repaying periods.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment cost (Pump + Electric Motor) [€]	Payback Period [Month]
Number 2	279,32	247,1	32,22	8760	19.757,30 €	59.720,00 €	36,3
Number 3	269,78	247,1	22,68	8760	13.907,38 €	59.720,00 €	51,5
Number 4	270,74	247,1	23,64	8760	14.496,05 €	59.720,00 €	49,4

*1 kw/h electric is taken 7 cent EURO.

Table 16 Payback period for the lowest cost.

Pumps	Total energy consumption before investment [kWh]	Total energy consumption after investment [kWh]	Annual energy consumption* [kWh]	Annual saving* [€]	Total investment cost [€]	Payback period [Month]
Tower Pumps	10.698.852,00	10.091.289,60	607.562,40	42.529,37 €	179.160,00 €	50,55

*1 kw/h electric is taken 7 cent EURO.

and electiric motors are given. But after the total investment and changes in the operating conditions, when central pump is taken into account as a complete system, we can see that the payback period is lower. Payback period of the Tower Pump is given in Table 16. When total investment and total cost is taken into account, Central Pump will redeem in 50 months and after this time it will save money annual 42.529 € in the operating costs of the company.

5.1.3. Point-1 pumps

It has been determined that the number 3 pump efficiency is below 50% and number 1 is almost equal to 70%, at the measurements that have been carried out at operation conditions.The new pump offers have been taken from the pump suppliers for these mentioned pumps that have the same pressure and capacities. To assure flow rate and pressure values at measurements conditions, electric motor power and pump efficiency value have been determined by using of the offered pump efficiency, power, pressure and flow rate diagrams. Manufacturer company suggested two situation for point-1 pumps;first one is horizontal, second one is vertical position. Calculations of the existing and the offered pumps are given in Table 17.

a) Situation of horizontal position

As seen above, in the state of number 1,2,3 pumps are replaced with new ones, there will be an improvement between 9%-34%. In the result of replacement existing pumps with new ones, annual money saving, investment cost and payback is given in Table 18.

For Point-1 system pumps, only one pumps runs continuouslty and the other pumps are in spare. When efficiency and energy consuptions are taken into account, number 2 or number 3 pumps replaced with new onesand runned continuously and the other 2 pumps runned in spare calculations are given in Table 19. For the option given above, the payback period is given in Table 20 by the replacing the inefficient pumps without electric motors.

As seen in Table 20 from number 1,2,3 pumps, by the replacing and operating continuously of number 2 pump and number 1,3 pumps are runned spare, repaymment period is calculated 14,8 month. This result shows that, replacement and operation continuously of the pumps with low efficient and high electric consumption and running the other pumps in spare is more proper. It's seen from the comparison of Table 19 and Table 20 that it is proper to replace only the pump of number 2 pump+motor system. In the tables above, only own payback periods of the pumps and electiric motors are given. But after the total investment and changes in the operating conditions, when Point 1 pumps are taken into account as a complete system, we can see that the payback period is lower. Payback period of the Point 1 pump is given in Table 21. When total investment and total cost is taken into account, Point 1 pump system will redeem in 14,5 months and after this time it will save money annual 20.921 € in the operating costs of the company.

Table 17 Existing and offered pump pressure, flow rate, efficiency and electric motor power values.

Pump		Power transmitted to pump	Power transmitted to fluid	Pump efficiency
		[kW]	[kW]	[%]
Number 1	Existing Pump	69,29	48,35	69,78
	Offered Pump	41,45	34	82,1
Number 2	Existing Pump	71,43	52,48	73,47
	Offered Pump	41,45	34	82,1
Number 3	Existing Pump	59,70	28,43	47,62
	Offered Pump	41,45	34	82,1

Table 18 Annual saving, investment costs and payback periods of new and existing pumps.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment cost (Pump + Electric Motor) [€]	Payback Period [Month]
Number 1	76,79	44,42	32,37	1728	3.915,48 €	30.152,00 €	92,4
Number 2	79,15	44,42	34,73	4776	11.610,93 €	30.152,00 €	31,2
Number 3	66,15	44,42	21,73	2880	4.380,77 €	30.152,00 €	82,6

*1 kw/h electricity is taken 7 cent EURO.

Table 19 Annual saving, investment cost and payback period in state of replacement of the lowest efficiency pumps and electric motors.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment cost (Pump + Electric Motor) [€]	Payback Period [Month]
Number 2	79,15	44,42	34,73	8760	21.296,44 €	30.152,00 €	17,0
Number 3	66,15	44,42	21,73	8760	13.324,84 €	30.152,00 €	27,2

*1 kw/h electricity is taken 7 cent EURO.

Table 20 Annual saving, investment cost and payback period in state of replacement of the lowest efficiency pumps.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time[Hour]	Annual Saving* [€]	Investment cost (Pump + Electric Motor) [€]	Payback Period [Month]
Number 2	79,15	45,93	33,22	8760	20.370,50 €	25.175,00 €	14,8
Number 3	66,15	45,93	20,22	8760	12.398,90 €	25.175,00 €	24,4

*1 kw/h electric is taken 7 cent EURO.

Table 21 Payback period for the lowest cost.

Pumps	Total energy consumption before investment [kWh]	Total energy consumption after investment [kWh]	Annual energy consumption* [kWh]	Annual saving* [€]	Total investment cost [€]	Payback period [Month]
Point-1	701.225,52	402.346,80	298.878,72	20.921,51 €	25.175,00 €	14,44

*1 kw/h electricity is taken 7 cent EURO.

b) Situation of vertical position

Comparison offered and existing pumps are given in Table 22. As given above existing pumps replaced with the new ones, there is an improvement about %3-25 at the efficiency of the pumps. In case of the existing pumps and electric motors are replaced with new ones together, annual money savings, investment costs and payback periods are given in Table 23. In Point-1 Pump 3 system pumps are operated alternately to be 1 pump is operated continuously. By considering efficiency and energy consumption, calculations of replecement of number 2 pumps and electric motors and in the condition of operating continuously, number 1 and 3 are spare, are given Table 24. For the situation without replacing electiric motors, repaying periods are given in Table 25. As seen in the table, payback period after the replacement and operation of number 2 pump continuously and operation of number 1 and 3 pumps in spare is 23,3 month. This result shows that replacement of low efficient and high electric consuming pumps and operating continuously and operating the other in spare is more proper. Number 2 and 3 pumps system saving and operating condition comparisons are represented in Table 24 and Table 25. In the tables above, only own payback periods of the pumps and electiric motors are given. But after the total investment and changes in the operating conditions, when Point 1 pumps are taken into account as a complete system, we can see that the payback period is lower. Payback period of the Point 1 pump is given in Table 26. When total investment and total cost is taken into account, Central Pump will redeem in 22,5 months and after this time it will save money annual 16.064 € in the operating costs of the company.

Table 22 Comparison offered and existing pumps.

PUMP		Power Transmitted to Pump	Power Transmitted to Fluid	Pump Efficiency
		[kW]	[kW]	[%]
Number 1	Existing Pump	69,29	48,35	69,78
	Offered Pump	48,6	35,186	72,4
Number 2	Existing Pump	71,43	52,48	73,47
	Offered Pump	48,6	35,186	72,4
Number 3	Existing Pump	59,70	28,43	47,62
	Offered Pump	48,6	35,186	72,4

Table 23 Annual saving, investment costs and payback periods of new and existing pumps and electric motors.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment Cost(Pump + Motor) [€]	Payback Period [Month]
Number 1	76,79	52,1	24,69	1728	2.986,50 €	45.134,00 €	181,4
Number 2	79,15	52,1	27,05	4776	9.043,36 €	45.134,00 €	59,9
Number 3	66,15	52,1	14,05	2880	2.832,48 €	45.134,00 €	191,2

*1 kw/h electric is taken 7 cent EURO.

Table 24 Annual saving, investment costs and payback period in the state of replacement and operating continuously pumps and electric motors which have lowest efficiency.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment cost (Pump + Electric Motor) [€]	Payback Period [Month]
Number 2	79,15	52,1	27,05	8760	16.587,06 €	30.152,00 €	21,8
Number 3	66,15	52,1	14,05	8760	8.615,46 €	45.734,00 €	63,7

*1 kw/h electric is taken 7 cent EURO.

Table 25 Annual savings, investment costs and payback period in the state of replacement and operating continuously pumps which have lowest efficiency.

Pump	Existing Motor Network Power [kW]	Offered Motor Network Power [kW]	Hourly Energy Saving [kW]	Operating Time [Hour]	Annual Saving* [€]	Investment cost (Pump + Electric Motor) [€]	Payback Period [Month]
Number 2	79,15	53,85	25,3	8760	15.513,96 €	30.152,00 €	23,3
Number 3	66,15	53,85	12,3	8760	7.542,36 €	40.850,00 €	65,0

*1 kw/h electric is taken 7 cent EURO.

Table 26 Payback period for the lowest cost condition.

Pumps	Total energy consumption before investment [kWh]	Total energy consumption after investment [kWh]	Annual energy consumption* [kWh]	Annual saving* [€]	Total investment cost [€]	Payback Period [Month]
Point-1	701.225,52	471.726,00	229.499,52	16.064,97 €	30.152 €	22,52

*1 kw/h electric is taken 7 cent EURO.

5.2. The improvement of the existing pumps efficiencies

5.2.1. Central pumps

Central Pump efficiencies of number 6 and 7 has been determined in the same order as 71 % and 76% under operating conditions. The new pump offers have been taken from the pump suppliers for the mentioned pump that has the same pressure and flow rate capacities. To assure flow rate and pressure values at the measurements conditions, electric motor power and pump efficiency value have been determined by using of the new pump efficiency, power, pressure and flow rate diagrams. The calculations that have been belonged to the existing and the offered pump are showed in Table 27.

Table 27 Existing and offered pump pressure, flow rate, efficiency and electric motor power values.

Pump		Power Transmitted to Pump	Power Transmitted to Fluid	Pump Efficiency
		[kW]	[kW]	[%]
Number 6	Existing Pump	114,80	82,33	71,77
	Offered Pump	99	84,6	85,5
Number 7	Existing Pump	123,94	94,38	76,14
	Offered Pump	99	84,6	85,5

As it could be seen above, existing pump has been operating approximately 9-13% less efficient than the new pumpss efficient comparing with the new pump. The efficiency rate can be increased about 5% by the maintenances like taking to the revision of the existing pump, blade coating, maintenance of the bearing etc. In this condition the calculations have been carried for out the annual money saving, the cost of investment and payback period of the investment cost and the results are given in Table 28.

5.2.2. *Tower pumps number 7 pump*

At Tower Pumps efficiency measurement has been determined as pumps efficiencies are 71% at the operation conditions. The new pump offers have been taken from the pump suppliers for the mentioned pump that has the same pressure and flow rate capacities. To assure flow rate and pressure values at the measurements conditions, electric motor power and pump efficiency value have been determined by using of the new pump efficiency, power, pressure and flow rate diagrams. The calculations that have been belonged to the existing and the offered pump are showed in Table 29. As it could be seen above, existing pump has been operating approximately 9-13% less efficient than the new pumps efficient comparing with the new pump. The efficiency rate can be increased about 5% by the maintenances like taking to the revision of the existing pump, blade coating, maintenance of the bearing etc. In this condition the calculations have been carried for out the annual money saving, the cost of investment and payback period of the investment cost and the results are given in Table 30.

Table 28 Annual savings, investment costs and payback periods after revision of existing pumps.

Pump	Existing Motor Network Power [kW]	Network Power After Revision [kW]	Hourly Energy Saving [kW]	Operating Time [hour]	Annual Saving* [€]	Investment Cost [€]	Payback Period [Month]
Number 6	127,33	120,9	6,36	2136	951,9	3000 €	37,8
Number 7	132,28	125,6	6,61	4392	2033	3000 €	17,7

*1 kw/h electricity is taken 7 cent EURO.

Table 29 Existing and offered pump pressure, flow rate, efficiency and electric motor power values.

Pump		Power Transmitted to Pump	Power Transmitted to Fluid	Pump Efficiency
		[kW]	[kW]	[%]
Number 7	Existing Pump	245,69	174,89	71,18
	Offered Pump	231,6	191,3	82,6

Table 30 Annual savings, investment costs and payback periods after revision of existing pumps.

Pump	Existing Motor Network Power [kW]	Network Power After Revision [kW]	Hourly Energy Saving [kW]	Operating Time [hour]	Annual Saving* [€]	Investment Cost [€]	Payback period [Month]
Number 7	262,16	249	13	7344	6738 €	3000 €	5,3

*1 kw/h electricity is taken 7 cent EUR

5.2.3 Point-1 pumps

At Point-1 pumps efficiencies has been determined as 69,78 and 73,47 % respectively while operating. The new pump offers have been taken from the pump suppliers for the mentioned pump that has the same pressure and flow rate capacities. To assure flow rate and pressure values at the measurements conditions, electric motor power and pump efficiency value have been determined by using of the new pump efficiency, power, pressure and flow rate diagrams. The calculations that have been belonged to the existing and the offered pump are showed in Table 31.

As it could be seen above, existing pump has been operating approximately 8-13% less efficient than the new pump. The efficiency rate can be increased about 5% by the maintenances like taking to the revision of the existing pump, blade coating, maintenance of the bearing etc. In this condition the calculations have been carried for out the annual money saving, the cost of investment and payback period of the investment cost and the results are given in Table 32.

Table 31 Existing and offered pump pressure, flow rate, efficiency and electric motor power values.

Pump		Power Transmitted to Pump	Power Transmitted to Fluid	Pump Efficiency
		[kW]	[kW]	[%]
Number 1	Existing Pump	69,29	48,38	69,78
	Offered Pump	41,45	34	82,1
Number 2	Existing Pump	71,43	52,48	73,47
	Offered Pump	41,45	34	82,1

Table 32 Annual saving, investment costs and payback periods after revision of existing pumps.

Pump	Existing Motor Network Power [kW]	Network Power After Revision [kW]	Hourly Energy Saving [kW]	Operating Time [hour]	Annual Saving* [€]	Investment Cost [€]	Payback period [Month]
Number 1	76,79	72,95	3,84	1728	464	3000 €	77,5
Number 2	79,15	75,19	3,96	4776	1323,9	3000 €	27,2

*1 kw/h electric is taken 7 cent EURO.

5.3. High efficient electric motor usage and energy saving

The energy saving potential of the pumps has been calculated for the condition the replacement of electric motors of pumps with highly efficient ones. It has been evaluated how much energy could be saved by the replacement of the motors with the higher efficient one while operating under same conditions.

Economical life period has been completed in the factory, considering the replacement because of their failure or as a result of the big revisions in the facility, when purchasing of a new compressor, HVAC and pump system electric motors are higher efficient than existing standard electric motors, this provides more efficient energy usage and so energy saving. The saved energy is by the replacement of the standard motor with a highly efficient new one can be determined with the help of this formula Eq.(7):

$$\text{Energy Saving} = MN * \text{Nominal Power} * OP * LC * UF * (1/\eta_{standard} - 1/\eta_{high\ efficient}) \quad (7)$$

Where; MN Motor number in the same power, OP operating period, LC loading coefficient, UF usage factor (for the motors that continuously in the circuit UF=1), $\eta_{standard}$ standard type motor efficient, $\eta_{high\ efficient}$ high efficient type motor efficient. The comparison of efficiencies of standard motor and high efficient motors are given in Table 33. As it can be seen from this table their nameplate power bigger than 224 kW (300 HP) the high efficient motors efficiencies are not known.

Note: these average values that belong to 8 firms are validated in the condition of when the motor at full load with the establishment of high efficient motor, monthly demand power saving for motors, is “DS”, monthly kWh energy usage saving is “US” can be calculated as in Eq.(8), Eq.(9) demonstrated below:

$$DS = \text{Nominal Power} * MN * LC * (1/\eta_{standard} - 1/\eta_{high\ efficient}) \quad (8)$$

$$US = DS * OP * UF \quad (9)$$

As an example, in a facility, the unit price of electricity is 0.07€/kWh, operating under full loading is 7000 h/year and continuously in the circuit, in the condition of the replacement of 36 motors that its nominal power is 45 kW with high efficient motors, Demand Energy Saving (DS) is:

DS = (45 kW * 36 *1) * [(1.0/0.936) - (1.0/0,954)]

DS = 32.656 kW/month

Usage saving (US):

US= (32656 kW/month) * (7000 hour/year)
US= 228.592 kWh/year

The money equal of the saving resourced annual usage (AUS) in Eq.(10) :

AUS= US *(the price of the average electricity unit usage) (10)

AUS = 228592 kWh/year * 0.07€/kWh
AUS 16.001,4 €/year

Nameplate power of the electric driven pump motors (kW), annual operating periods (OP), Loading coefficient (LC), and usage factor (UF) are given in Table 34. When nameplate powers of the motors that belong to the pumps are examined, there are only 3 pump motors that their powers are smaller than 224 kW. Because of the reason that the high efficient motors efficient values are not known that their powers are bigger than this, the calculations are only can be made for these 10 electric motors which their powers are smaller than 224 kW.

In the condition of the replacements of these motors with high efficient motors, the monthly demand saving (DS), usage saving (US) and the money equal of the saving resourced annual usage (AUS) are given in Table 35. As it is given in the table monthlydemand saving (DS) is 63 kW, annual energy usage saving (Total energy saving) is 257.330 kWh. When the replacement of the 10 motors that have been examined by accepting the unit price of energy is 0.07 €/kWh, with high efficient motors the money equal of the total saving amount that will be obtained in every year is 18.013 €/year.

Table 33 The comparison of the motor efficiencies.

Rated motor power (hp)	Rated motor power (kW)	Mean efficiency of standard type motors	Mean efficiency of high efficient motors
1	0,746	0.825	0.865
1,5	1,119	0.840	0.894
2	1,492	0.840	0.888
2.5	1,865	0.812	0.870
3	2,238	0.875	0.895
4	2,984	0.827	0.889
5	3,73	0.875	0.902
7.5	5,595	0.895	0.917
10	7,46	0.895	0.917
15	11,19	0.910	0.930
18	13,428	0.878	0.924
20	14,92	0.910	0.936
25	18,65	0.924	0.941
30	22,38	0.924	0.941
40	29,84	0.930	0.945
50	37,3	0.930	0.950
60	44,76	0.936	0.954
75	55,95	0.941	0.954
100	74,6	0.945	0.958
125	93,25	0.945	0.954
150	111,9	0.950	0.958
200	149,2	0.950	0.958
250	186,5	0.954	0.962
300	223,8	0.954	0.962

Table 34 Operating periods of electric motors.

Motor	Number of Motor (MN)	Label Power (kW)	Nameplate Power That the Motor Draws (kW)	Operating Period (OP)	Loading Coefficient (LC)	Usage Factor
Central Pump number 1	1	210	124,92	4584	53,63	1
Central Pump number 2	1	210	135,05	3840	57,98	1
Central Pump number 3	1	210	217,05	4128	93,18	1
Central Pump number 4	1	115	135,29	5664	102,06	1
Central Pump number 5	1	120	123,45	3264	91,94	1
Central Pump number 6	1	210	127,33	3136	54,67	1
Central Pump number 7	1	132	132,28	4392	93,90	1
Tower Pump number 1	1	400	262,16	6432	61,42	1
Tower Pump number 2	1	400	279,32	4632	65,44	1
Tower Pump number 3	1	400	269,78	8136	63,21	1
Tower Pump number 4	1	400	270,74	6120	63,43	1
Tower Pump number 5	1	400	268,78	7224	63,21	1
Tower Pump number 6	1	400	262,16	1392	61,42	1
Tower Pump number 7	1	400	76,79	7344	92,39	1
Poin-1 Pump number 1	1	75	79,15	1728	95,23	1
Poin-1 Pump number 2	1	75	66,15	4776	79,60	1
Poin-1 Pump number 3	1	75	124,92	2880	53,63	1

Table 35 Energy saving by operating high efficient electric motors.

Pump	DS (kW/month)	US (kWh)	AUS (€/year)	Cost of Investment ($)*
Central Pump number 1	6,9	31.814,96	2.227,05	500 €
Central Pump number 2	7,5	28.789,35	2.015,25	500 €
Central Pump number 3	12,1	49.763,55	3.483,45	500 €
Central Pump number 4	11,8	66.950,93	4.686,57	500 €
Central Pump number 5	7,3	23.948,18	1.676,37	500 €
Central Pump number 6	7,0	21.927,64	1.534,93	500 €
Central Pump number 7	1,8	7.874,07	551,19	500 €
Poin-1 Pump number 1	3,6	6.210,96	434,77	500 €
Poin-1 Pump number 2	3,0	14.275,22	999,27	500 €
Poin-1 Pump number 3	2,0	5.775,10	404,26	500 €
Total	63	257.330	18.013	5000 €

*Investment cost: Average cost difference in case of the selection of high efficient electric motor.

Payback period of the price difference that will be paid when purchasing high efficient motor instead of standard motor can be found the price difference of the high efficient motor from the standard motor. The price difference has been taken as approximately 600$ for the motor of 110 kW. Payback period can be calculated with Eq.(11).

Payback period= (The cost of investment)/(Annual money saving) (11)

Payback period= (5000$) / (18.013€/year) *12 month/year

Payback period= 3,3 month

After payback period 257.330 kWh/year energy saving or 18.013€/year money saving will be obtained in every year.

6. CAVITATION

Generated small and largely empty cavities expands to large size and then rapidly collapse with a sharp sound in a fluid. Cavitation can occurs in pumps propellers, impellers, and etc. When a liquid is subjected to a low pressure above a threshold value it ruptures and forms vaporous cavities. This phenomenon is determined as cavitation. When local environment pressurefalls below the vapor pressure of liquid at a point in the liquid, the liquid changes phase, creating largely empty bublesas called cavitation bubbles. When the bubbles explode, they focus liquid energy to very small volumes. Thereby, they generate spots of high temperature and creates shock waves which are the source of noise.The eplosion of cavities creates very high energies, and can cause major damages. Cavitation can damage all part of systems where occured. Collapse of cavities produces great wear on components and shorten a propeller or pump's lifetime.

As a result, cavitation is, in many cases, an undesirable occurrence. In pumps and propellers, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency (Kovats and Desmur, 1964).

According to the operating conditions of the pumps and fluid temperatures that have been measured, the cavitation calculations and their related results are given in Table 36 at the facility.

While calculating the cavitation follwing formulas Eq.(12) and Eq.(13) used.

$$h_{e\,max}=(P_m/\rho g)-(P_{sat}/\rho g)-NPSH-h_{loss} \quad (12)$$

$$Ps= \rho gh \quad (13)$$

The formula which is given above has been used for calculation of cavitation. In this fomula; Pm the medium pressure of the pump that established in the region (N/m^2), P_{sat} the saturation pressure of the pump that related to the inlet water temperature (N/m^2), Ps The suction NPSH Net Positive Suction Head (m), $H_{loss}$the pressure losses in suction pipes and local components (m), H_{smax} the maximum head of suction line (m).

P_s value should be smaller than P_{inlet} (P_1) value for the pump operation without cavitation. Otherwise pump will operate with cavitation.According to Table 36 there is no cavitation in the measured pumps.

7. EXERGETIC EFFICIENCY

Exergy has become an increasingly important tool for the design and analysis of systems. The importance developing thermal systems that effectively use energy resourses such oil natural gas and coal is apperant. Effective use is determined with both the first and second laws thermodynamics, Energy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is accounted for in the products and by-products. Energy can not be destroyed a first law consept. The idea that something can be destroyed is useful in the design and analysis of thermal systems. This idea does not to apply to energy, however but to exergy (availability) a second lae consept. Moreover, it is exergy and nor energy that properly gauges the quality (usefullness) of, say, 1 kJ of electricity generated by a power plant versus 1 kJ of energy in the plant cooling water stream. Electricity clearly has the greater quality and not incidentally, the greater economic value (Bejan et al. 1996).

7.1. Exergetic efficiency in Compressors, Pumps or Fans

In a compressor, pump or a fan, for gas or liquid is caused to flow in the direction of increasing pressure and/or elevation by means of a mechanical power input.

As the exergy of stream increases, we consider the product to be the exergy increase between inlet and outlet. So exergetic efficiency in Compressors, Pumps or Fans can be expressed as Eq.(14);

$$\varepsilon = (E_2 - E_1)/W \qquad (14)$$

According to the operation conditions of the pumps and fluid temperatures that have been measured, the exergy where W is power input taken as positive in the direction (Cengel and Boles, 1996).

The flow exergy change of a fluid stream can be expressed as Eq.(15) (Cengel and Boles, 1996);

$$\Psi_1 - \Psi_2 = (h_1 - h_2) - T_0 (S_2 - S_1) + (V_2^2 - V_1^2)/2 + g(z_2 - z_1) \qquad (15)$$

efficiency calculations and their related results are given in Table 37 at the facility.

Table 36 Cavitation calculation results of the pumps.

Pump	P_m [Pa]	P_{sat} [Pa]	Q [ton/h]	N [r/m]	h_{loss} [m]	h_{emax} [m]	P_e [bar]	P_{input} (P1) [bar]	Result
Central Pump number 1	97000	3169	-	725	-	-	-	-	-
Central Pump number 2	97000	3169	-	725	-	-	-	-	-
Central Pump number 3	97000	3169	2285	725	6,05	2,51	-0,25	0,50	Not Exist
Central Pump number 4	97000	3169	1805	970	7,63	0,94	-0,09	0,35	Not Exist
Central Pump number 5	97000	3169	2011	730	5,61	2,95	-0,29	0,50	Not Exist
Central Pump number 6	97000	3169	2280	730	6,10	2,46	-0,24	0,50	Not Exist
Central Pump number 7	97000	3169	2265	650	5,20	3,36	-0,33	0,50	Not Exist
Tower Pump number 1	97000	3169	4025	960	12,84	-4,27	0,42	0,50	Not Exist
Tower Pump number 2	97000	3169	3147	960	10,90	-2,33	0,23	0,50	Not Exist
Tower Pump number 3	97000	3169	3240	960	11,11	-2,54	0,25	0,50	Not Exist
Tower Pump number 4	97000	3169	3607	960	11,93	-3,37	0,33	0,50	Not Exist
Tower Pump number 5	97000	3169	3416	960	11,51	-2,94	0,29	0,50	Not Exist
Tower Pump number 6	97000	3169	-	960	-	-	-	-	-
Tower Pump number 7	97000	3169	3148	960	10,90	-2,33	0,23	0,50	Not Exist
Poin-1 Pump number 1	97000	3169	1055	970	5,33	3,23	-0,32	0,50	Not Exist
Poin-1 Pump number 2	97000	3169	1145	970	5,63	2,93	-0,29	0,50	Not Exist
Poin-1 Pump number 3	97000	3169	890	1470	8,29	0,28	-0,03	0,50	Not Exist

Table 37 Exergetic efficiencies of the pumps.

Pump	Z_1	Z_2	V_1	V_2	S_1	S_2	T_0	h_1	h_2	Ψ_2-Ψ_1	η
Central Pump number 3	-2	10	2,67	3,99	1,09	1,49	298	340,54	490,55	35,2	0,23
Central Pump number 4	-2	10	2,11	3,15	1,09	1,51	298	340,54	497,53	34,9	0,22
Central Pump number 5	-2	10	1,97	2,35	1,09	1,49	298	340,54	490,55	32,2	0,21
Central Pump number 6	-2	10	2,24	2,66	1,09	1,49	298	340,54	490,55	32,4	0,22
Central Pump number 7	-2	10	1,42	2,22	1,09	1,53	298	340,54	504,51	35,1	0,21
Tower Pump number 1	-2	20	3,95	3,95	1,09	1,63	298	340,54	529,49	28	0,15
Tower Pump number 2	-2	20	3,09	3,09	1,09	1,63	298	340,54	529,49	28	0,15
Tower Pump number 3	-2	20	3,18	3,18	1,09	1,53	298	340,54	504,21	33,75	0,20
Tower Pump number 4	-2	20	3,54	3,54	1,09	1,57	298	340,54	512,71	29,71	0,17
Tower Pump number 5	-2	20	3,35	3,35	1,09	1,63	298	340,54	546,16	44,27	0,21
Tower Pump number 7	-2	20	3,09	3,09	1,09	1,60	298	340,54	535,35	41,44	0,21
Poin-1 Pump number 1	-2	10	0,76	1,04	1,09	1,55	298	340,54	514,31	36,3	0,21
Poin-1 Pump number 2	-2	10	0,83	1,12	1,09	1,55	298	340,54	514,31	36,3	0,21
Poin-1 Pump number 3	-2	10	1,97	3,49	1,09	1,46	298	340,54	479,06	31,8	0,23

8. CONCLUSION

This study has been carried out for the estimation and enhancement of energy and exergy efficiency of the pumps in big industrial facility. By using measurement data; existing pump and electric motor energy and exergy efficiencies has been calculated. As a result of this study main saving opportunities are determined as; the replacement of the existing low efficient pumps with higher efficient ones, the maintenance of the pumps that their efficiencies started to decline at certain range, the replacements of the electric motors that had been chosen in high power with electric motors that have suitable power, the usage of high efficient electric motors. For each saving opportunities that is mentioned above, their investment costs, and payback periods are given. Authors hope that the represented results motivates the manufacturers and engineers for energy efficiency investments.

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