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ENERGY PERFORMANCE ASSESSMENT OF PUMPS AND COMPRESSED AIR SYSTEM IN FLUID CATALYTIC CRACKING UNIT OF AN OIL REFINERY

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ABSTRACT

The energy performance assessment in water supply systems and compressed air system should account for both actual energy consumed and how efficiently such energy is spent. This work represents the energy auditing of pumps and compressors used in Fluid catalytic cracking unit of an oil refinery. The main aim is to search for possible energy savings in pumps and compressed air system which would minimize energy consumption and maximize the energy efficiency. The energy performance of pumps and compressed system have been assessed and based on performance parameters recommendations have been given to enhance energy efficiency. One of the common problems found with pumping operation is throttling in pumps and high discharge pressure in compressors. Approximately Rs. 374.57 lacks can be saved in pumps and Rs. 60.45 lacks can be saved in compressors by implementing recommendations suggested from energy performance assessment.

KEYWORDS– Compressors, Energy audit, Energy conservation, Energy performance assessment, Energy savings, Pumps

NOMENCLATURE

FAD	Free air delivery, m^3/hr
FCCU	Fluid catalytic cracking unit
g	Gravitational acceleration, m/s^2
H	Total head, m
H1	Specific enthalpy at inlet, kJ/kg
H2	Specific enthalpy at outlet, kJ/kg

I	Current, amp
IP	Isothermal power, kW
N	Speed of the pump, rpm
P_1	Absolute intake pressure kg/ cm^2
P_{in}	Power input, kW
Q	Flow rate of fluid, m^3/s
Q_1	Free air delivered m^3/hr
r	compression ratio
V	Voltage, Volt
V_{Flow}	Flow rate, m^3/hr
VFD	variable frequency drive
Vs	Swept volume, m^3/hr
$\eta_{Isothermal}$	Isothermal efficiency
$\eta_{Volumetric}$	Volumetric efficiency
η_p	Pump efficiency
ρ	Density of fluid, kg/m^3
φ	Power factor

1. INTRODUCTION

The operation of Water Distribution Systems generally require high amounts of energy, which vary in relation to the characteristics of the served area, but also from design and management choices. The assessment of energy efficiency in water distribution systems is strongly influenced by the nature site-dependent of the water-energy nexus in pressurized networks [1]. Understanding this link requires a systematic energy analysis to evaluate separately the influence of pumping stations, network and water loss and can allow highlighting inconsistencies in the design and management that are reflected on the resources, water and energy.

In the studies that have been conducted for energy saving, it has been seen that one of the areas of high potential energy saving is pumping systems [2]. According to a study that the American Hydraulics Institute has made, 20% of the consumed energy has been consumed by pumps in developed countries [3]. It has been explained that 30% of this energy can be saved with good design of systems and choosing suitable pumps. This situation has caused new searches to be made to find more efficient systems in production and operation by producers and users of pumps [4]. Furthermore, some legal regulations have started to be enacted on this topic in some countries [5]. That pumps have high efficiency alone is not enough for a pump system to work in maximum efficiency. Working in maximum efficiency of a pump system depends not only on a good pump design but also a good design of the complete system and its working conditions. Otherwise, it is inevitable that even the most efficient pump in a system that has been wrongly designed and wrongly assembled is going to be inefficient [6].

Energy consumption by pumps in the developed countries is very high. It is estimated that about 20% of the total energy is being consumed by the pumps [7]. However, literature suggest that about 30% of this energy can be saved with good design of systems, by improving energy efficiency and choosing suitable size pumps. At part loads, variable frequency drive is also a promising option for energy saving by allowing pumps to run at slower speeds [8]. Old pumps generally consume more energy and hence energy audit of such pumps is essential. S. Kluman et al. [9] suggested that electricity use can be reduced by 50% in the old pumps by energy audit of such pumps.

Use of compressed air in industry and in service sectors is common as its production and handling are safe and easy. In most industrial facilities, compressed air is necessary to manufacturing. Compressed-air generation is energy intensive, and for most industrial operations, energy cost fraction of compressed air is significant compared with overall energy costs. Yet, there is a vacuum of reliable information on the energy efficiency of a typical compressed-air system [10].

As a general rule, compressed air should be used only if safety enhancements, significant productivity gains, or labor reduction, will result as it is very expensive. Greenough [11] also reported how to select compressed-air system for an industrial facility. Annual operating costs of air compressors, dryers, and supporting equipment, can account from 70% [12] to 90% [13] of the total electric bill.

Compressed air accounts for as much as 10% of industrial electricity consumption in the European Union [13]. Compressed-air systems in China use 9.4% of China’s electricity. Compressed air is probably the most expensive form of energy in a plant, because only 19% of its power is usable. In the US, compressed-air systems account for about 10% of total industrial-energy use [14], as in Malaysia [15]. In South Africa, compressed air consumes about 9% of total energy consumption [16].

The main aim of this paper is to assess energy performance of 32 numbers of pumps and 4 numbers of compressors in fluid catalytic cracking unit of an oil refinery. Various parameters of pumps like efficiency, total savings and payback period for all 32 pumps have been calculated. Performance parameters of compressors such as efficiencies and power consumption have been calculated. Appropriate recommendations have been given to increase energy efficiency of pumps and compressors based on the performance parameters.

2. ENERGY PERFORMANCE ASSESSMENT METHODOLOGY

Methodology adopted for this energy performance assessment is as shown in Figure 1 in form of flow chart.

2.1 ENERGY AUDIT METHODOLOGY OF PUMPS

Pumping is the process of addition of kinetic and potential energy to liquid for the purpose of moving it from one point to another. This energy will cause the liquid to do work such as flow through a pipe or rise to a higher level. A centrifugal pump transforms mechanical energy from a rotating impeller into a kinetic and potential energy required by the system [17]. The most critical aspect of energy efficiency in a pumping system is matching of pumps to loads. Hence even if an efficient pump is selected, but if it is a mismatch to the system then the pump will operate at very poor efficiencies. In addition efficiency drop can also be expected over time due to deposits in the impellers. Performance assessment of pumps would reveal the existing operating efficiencies in order to take corrective action.

Purpose of the performance test of pumps is to determine the pump efficiency during operating condition and compare the same with design.

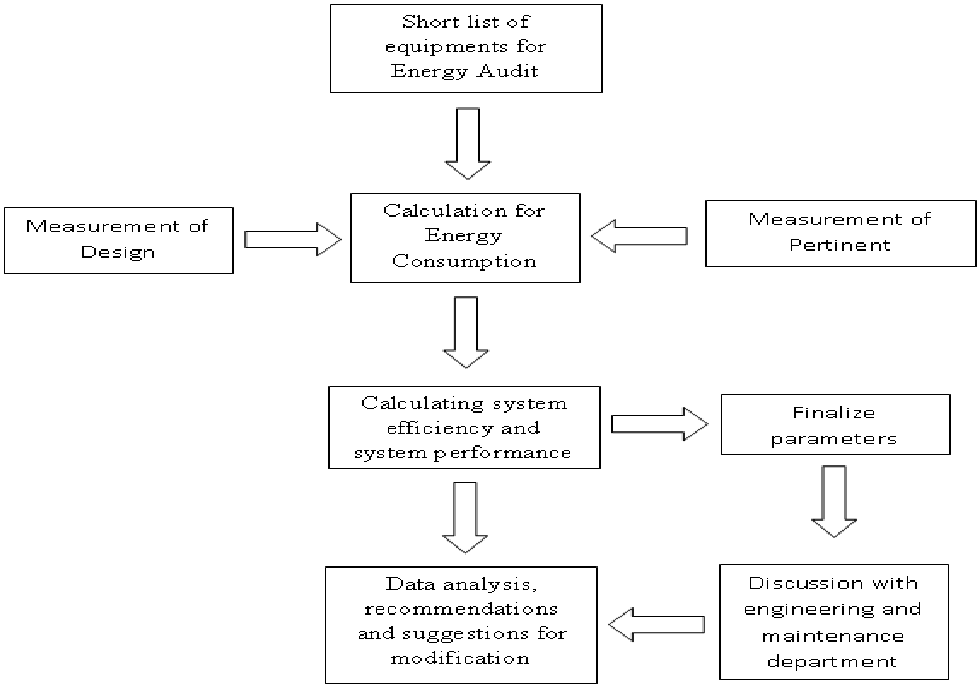

Figure 1: METHODOLOGY ADOPTED FOR ENERGY AUDIT OF FCCU

From measured pump efficiency, recommendations can be given for improving energy efficiency. The reasons for high power consumption in pumps may be improper selection and operation, throttling, overdesign, improper layout, old inefficient pump. Following Table 1 [18] shows symptoms that indicate potential opportunity for energy savings.

Table.1: SYMPTOMS THAT INDICATE POTENTIAL OPPORTUNITY FOR ENERGY SAVINGS IN PUMPS

Symptom generally observed	**Likely Reason**	**Best Solutions**
Throttle valve-controlled systems	Oversized pump	Trim impeller, smaller impeller, variable speed drive, two speed drive, lower rpm
Bypass line (partially or completely) open	Oversized pump	Trim impeller, smaller impeller, variable speed drive, two speed drive, lower rpm
Multiple parallel pump system with the same number of pumps always operating	Pump use not monitored or controlled	Install controls
Constant pump operation in a batch environment	Wrong system design	On-off controls
High maintenance cost (seals, bearings)	Pump operated faraway from BEP	Match pump capacity with system requirement

2.1.1 PUMP EFFICIENCY

Pump efficiency should be checked first for assessing actual performance of pump. Liquid horse power divided by the power input in the pump shaft is known as pump efficiency. Efficiency of the pump can be found with the help of equation 2.1.

$$\eta_p = \frac{\rho \times g \times Q \times H}{P_{in} \times 1000} \qquad (2.1)$$

For motor driven pumps, power consumption by motor can be calculated from equation 2.2.

$$P_{in} = \sqrt{3} \times V \times I \times cos\phi \qquad (2.2)$$

For turbine driven pump, power consumption by motor can be calculated from equation 2.3.

$$P_{in} = Q \times (H1 - H2) \qquad (2.3)$$

2.1.2 AFFINITY LAWS OF PUMPS

The equations relating roto-dynamic pump performance parameters of flow, head and power absorbed, to speed are known as the Affinity Laws shown in equation 2.4, equation 2.5 and equation 2.6:

$$Q \propto N \qquad (2.4)$$

$$H \propto N^2 \qquad (2.5)$$

$$P_{in} \propto N^3 \qquad (2.6)$$

As can be seen from the above affinity laws, doubling the speed of the centrifugal pump will increase the power consumption by 8 times. Conversely a small reduction in speed will result in drastic reduction in power consumption. This forms the basis for energy conservation in centrifugal pumps with varying flow requirements. Variable speed drive is used for varying the speed of the pump.

2.2 ENERGY AUDIT METHODOLOGY OF COMPRESSORS

The compressed air system is not only an energy intensive utility but also one of the least energy efficient. Over a period of time, both performance of compressors and compressed air system reduces drastically. The causes are many such as poor maintenance, wear and tear etc. All these lead to additional compressors installations leading to more in-efficiencies. A periodic performance assessment is essential to minimize the cost of compressed air. Air compressors account for significant amount of electricity used in Indian industries. Air compressors are used in a variety of industries to supply process requirements, to operate pneumatic tools and equipment, and to meet instrumentation needs. Only 10-30% of energy reaches the point of end-use, and balance 70-90% of energy of the power of the prime mover being converted to un- usable heat energy and to a lesser extent lost in form of friction, misuse and noise [19].

2.2.1. COMPRESSOR EFFICIENCIES

Isothermal power, Isothermal and volumetric efficiency can be calculated based on following equation 2.7, equation 2.8 and equation 2.9 respectively:

$$IP = \frac{P1\times Q1\times log_e r}{36.7} \qquad (2.7)$$

$$\eta_{isothermal} = \frac{IP}{Pactual} \qquad (2.8)$$

$$\eta_{Volumetric} = \frac{FAD}{V_S} \qquad (2.9)$$

2.2.2. PRESSURE SETTINGS FOR EFFICIENT OPERATION

Compressor operates between pressure ranges called as loading (cut-in) and unloading (cut-out) pressures. For example, a compressor operating between pressure setting of 6 - 7 kg/cm^2 means that the compressor unloads at 7 kg/cm^2 and loads at 6 kg/cm^2. Loading and unloading is done using a pressure switch. For the same capacity, a compressor consumes more power at higher pressure. They should not be operated above their optimum operating pressures as this not only wastes energy, but also leads to excessive wear, leading to further energy waste. A reduction in the delivery pressure by 1% in a compressor would reduce the power consumption by 6 - 10% [20].

3. ENERGY PERFORMANCE RESULTS OF PUMPS

There are total 76 numbers of centrifugal pumps in FCCU. Out of 76 numbers of Pumps, 32 numbers of pumps are in operating condition. 29 numbers of pumps are motor-driven pumps and 3 numbers of pumps are turbo-driven pumps. Main aim of the pump audit is to check pump performance and from this analysis energy conservation opportunity in centrifugal pumps can be checked and recommendations can be given accordingly.

3.1 ACTUAL PERFORMANCE RESULTS OF PUMPS

Design parameters of 32 numbers of pumps have been collected from operation and maintenance manual which is given by the manufacturer of the pump. Pertinent parameters like pressure, flow rate and power consumption have been measured for calculating actual efficiency of each pump. Actual efficiency is to be compared with design efficiency for checking energy saving opportunities. It was found that majority of pumps were operated at part load keeping discharge valve partly closed, leading to throttling and energy loss. Literature says that throttling of the discharge flow is general reason found for getting low efficiency. Throttling increases the head requirement of the pump and energy is wasted in developing that extra head. Efficiency comes low due to discharge flow throttling. Variable frequency drive (VFD) is the better option where throttling of the discharge flow is taking place. Power consumed by variable frequency drive can be calculated from equation 2.2. Total energy savings was calculated from subtraction of actual measured power consumption and power consumed by variable frequency drive. Investment cost has been taken from procurement department of the Essar Oil Limited. Simple payback period has been calculated from the investment cost and total energy savings in Indian national rupees and investment cost.

It is found from the measured parameters of pumps that flow of all the pumps is being throttled (from 26% to 98%) to control the flow rate. Decision has to be made, from calculated total savings and payback period, for installing VFD. Total savings comes low for pumps no. 2 and 11 and hence it is not viable to install VFD in these pumps. From Figure 2, Figure 3 and Figure 4, it is suggested to install VFD in all the pumps mention above except pump no. 2 and 11. Total Rs.374.57 Lacks can be saved by installing VFD with maximum payback period of only 17 months.

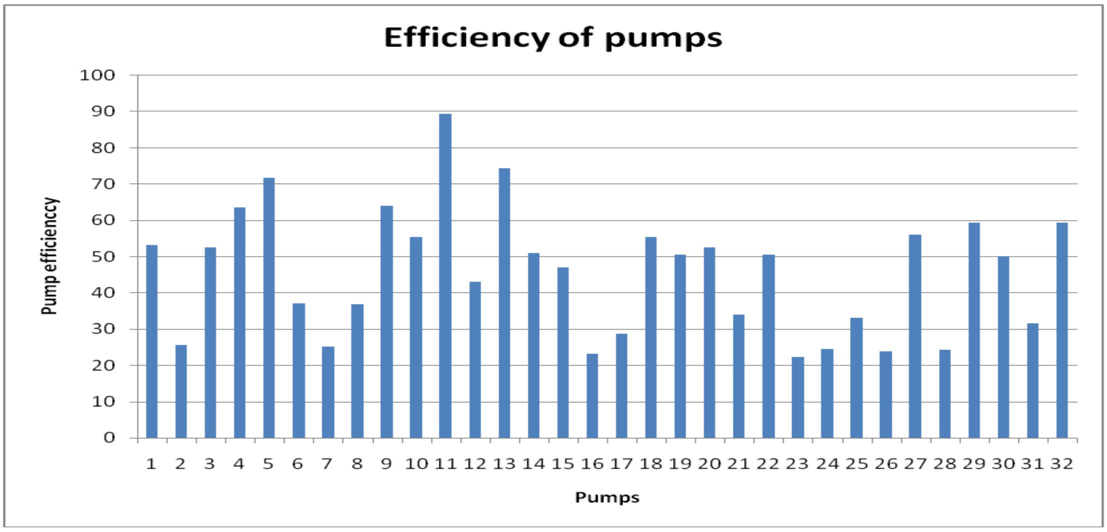

Figure 2: EFFICIENCY OF PUMPS

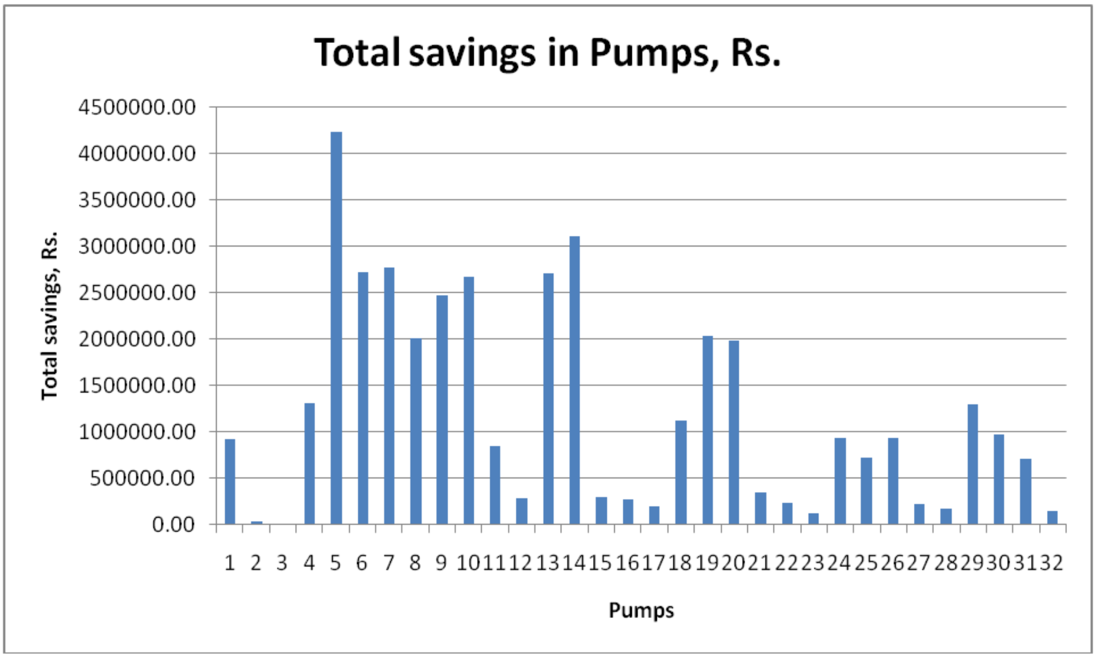

Figure 3: TOTAL SAVINGS IN PUMPS

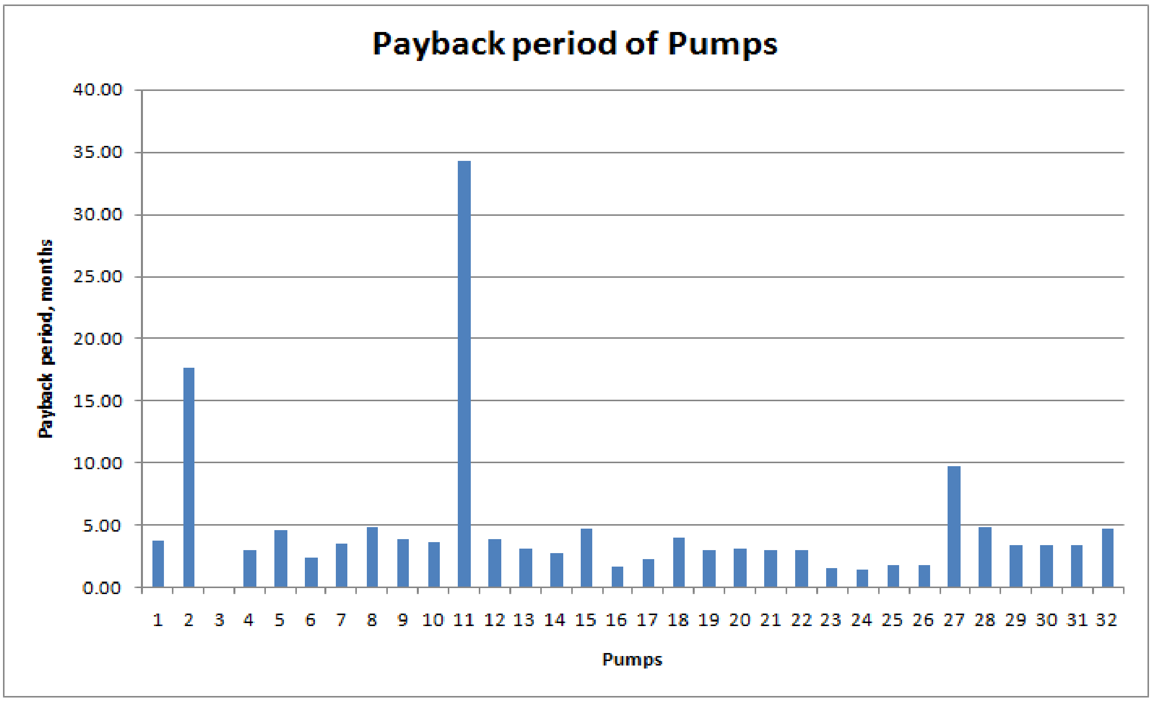

Figure 4: PROPOSED PAYBACK PERIOD OF PUMPS

4. ENERGY PERFORMANCE RESULTS OF COMPRESSORS

There are four numbers of three stage centrifugal compressors in Utility section. All compressors are running continuously. Out of four compressors, one compressor is in stand by condition. Three numbers of Compressors are motor driven type while one compressor is turbine driven type. Compressed air from utility section is being distributed to other units. There are two categories of compressed air used in FCCU: Plant air and Instrument air. Instrument air is pure dry air which doesn't contain moisture while plant air may have some moisture particles. Most of the flow rate of plant air is used for service purpose like purging, aeration etc. Instrument air is used only for the purpose of control valve operation.

4.1 ACTUAL PERFORMANCE DETAILS OF COMPRESSORS

Design parameters of all compressors have been collected from operation and maintenance manual which is given by the manufacturer of the compressor. Pertinent parameters like pressure, flow rate, throttling percentage, temperature of air and power consumption have been measured for calculating actual efficiency of the each compressor. Actual volumetric efficiency is to be compared with design efficiency for checking energy conservation opportunities.

Table 2 shows actual performance details of compressors. Figure 5, Figure 6 and Figure 7 shows actual power consumption, isothermal efficiency, and volumetric efficiency of compressors in the form of charts.

Table 2: ACTUAL PERFORMANCE DETAILS OF COMPRESSORS

Description	**Units**	**1**	**2**	**3**	**4**
Model		Centrifugal	Centrifugal	Centrifugal	Centrifugal
Make		Elliott	Elliott	Elliott	Elliott
Design capacity	Nm^3/hr	3200	3200	3200	3200
Motor rated capacity	kW	450	450	450	450
Design pressure	kg/cm^2	9.7	9.7	9.7	9.7
No. of stages		3	3	3	3
Gas handled		Air	Air	Air	Air
Type of driven		Turbine	Motor	Motor	Motor
Discharge Pressure	kg/cm^2	9	9	9	9.1
Dynamic Pressure	mmWC	38.75	46.3	47	49.4
Velocity	m/s	25.7	28.11	28.3	29
Area	m^2	0.03	0.03	0.03	0.03
Actual air deleivered	m^3/hr	2,776	3,036	3,056	3,132
Actual power consumption, kW	kW	1090.3	443.9	422.6	439.1
Isothermal power	kW	173.2	191.1	189.92	173.2
Isothermal efficiency	%	18.01	45.22	43.25	44.74
Volumetric efficiency	%	0.87	0.95	0.96	0.98

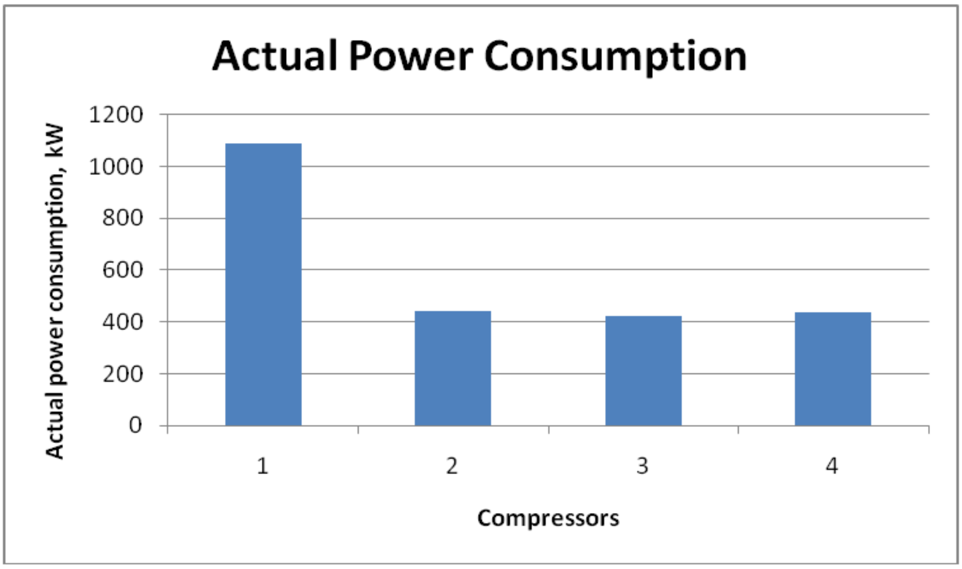

Figure 5: Power Consumption of Compressors

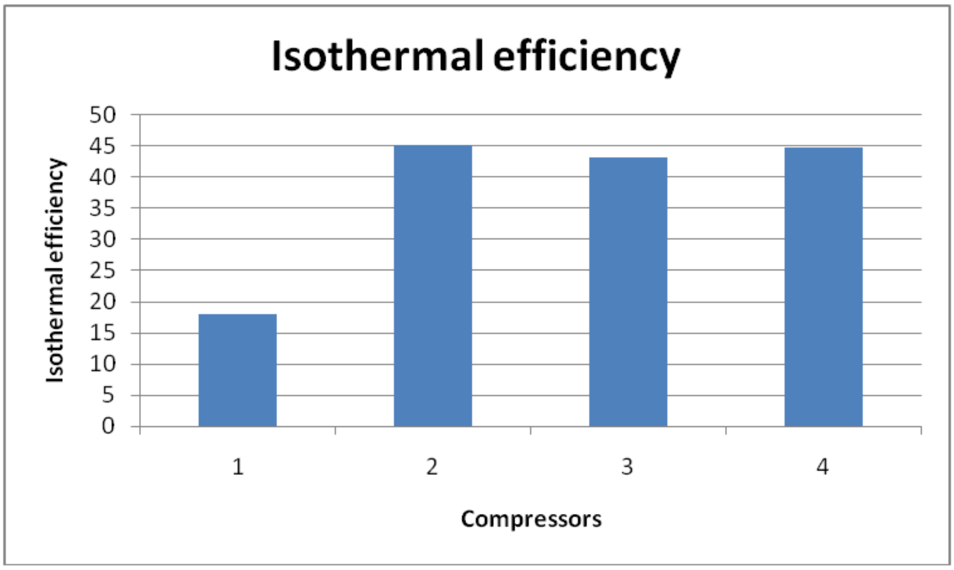

Figure 6: Isothermal Efficiency of Compressors

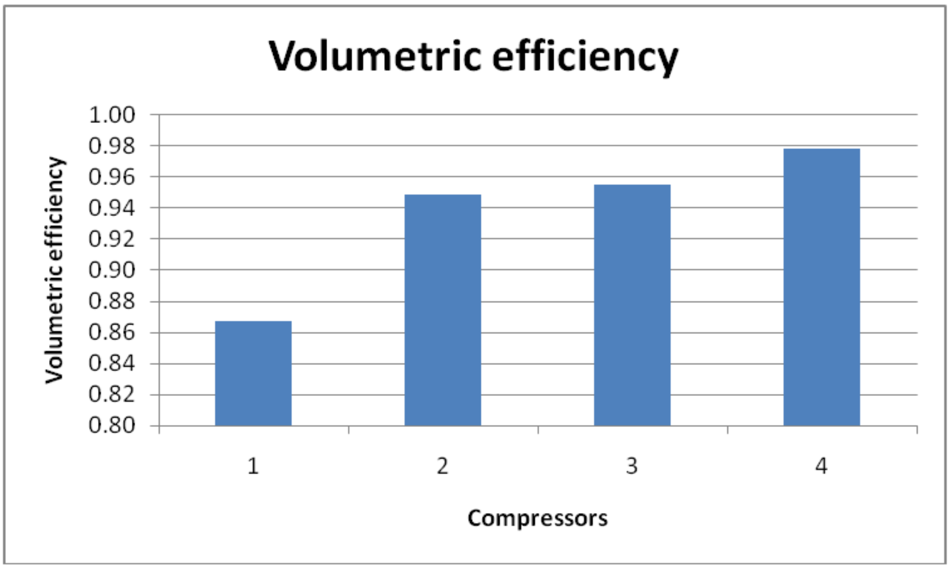

Figure 7: Volumetric Efficiency of Compressors

Figure 7 shows that volume delivered by each compressor is good. From the pertinent parameters given by operation department of Essar Oil Limited, it is noticed that the pressure requirement is only 6.5 kg/cm^2, while as per Table 3.1, which shows that compressor discharge pressure is around 9 kg/cm^2. Hence there is a pressure reducing valves placed at each section. Literature suggests that reduction in pressure directly reduces the energy required for compressing the air. It is suggested to reduce the outlet pressure of the compressor to 7.5 kg/cm^2. By reducing discharge pressure from 9 kg/cm^2 to 7.5 kg/cm^2, 11,51,539 kWh/annum and so Rs.60.45 Lacks can be saved immediately.

5. CONCLUSION

The energy performance assessment of pumps and compressed air system has been carried out in fluid catalytic cracking unit of an oil refinery.

In case of pumps, it has been found from the measured parameters that flow of all the pumps is being throttled (from 26% to 98%) to control the discharge flow rate. It is evident that 52% of the total consumed energy can be saved by installing variable frequency drive. It is possible to save total Rs.374.57 Lacks by incorporating the modifications suggested, with maximum payback period of only 17 months.

In Compressed air system, it is noticed that the pressure requirement of air is only 6.5 kg/cm^2, while compressor discharge pressure is around 9 kg/cm^2. A reduction in the delivery pressure by 1 kg/cm2 in a compressor would reduce the power consumption by 7-10 %. So it is suggested to reduce the outlet pressure of the compressor to 7.5 kg/cm^2 by regulating the pressure setting switch. By reducing discharge pressure from 9 kg/cm^2 to 7.5 kg/cm^2, 11,51,539 kWh/annum and so Rs.60.45 Lacks can be saved immediately.

REFERENCES

[1] Lenzi, C., Bragalli, C., Bolognesi A., Artina S., From energy balance to energy efficiency indicators including water losses, *Water Science and Technology: Water Supply, 13(4)* 2013.

[2] Yig˘it KS, CallıI, So¨zbir N, Sarac_ H_I, Brawn DM., Experimental investigation of optimum centrifugal pumps speeds. *In: Second international conference on pumps and fans, vol. II,* Beijing, China, October 1995.

[3] Erto¨z AO¨ , *Energy efficiency in pumps*. In: 6th national installations engineering and congress, Istanbul; 2003.

[4] The pump terms guide. *Published by POMSAD, Turkey, no. 2*; 1997.

[5] Cuha D., *The presentation of energy economy in centrifugal pumps and centrifugal pump systems*. Hotel Dedeman Istanbul, Turkey, 9th June 2005.

[6] Lifelong cost in pumps: lifelong cost for plants that using pumps. Published by *POMSAD, no. 12*; 2001.

[7] D. Kaya, E. A. Yagmur, K. S. Yigit, F. C. Kilic, A. S. Eren, and C. Celik, Energy efficiency in pumps," *Energy Conversion and Management, vol. 49, 2008,* pp. 1662-1673.

[8] F. W. Pumps, Variable speed pumps-are they worth the money?," *Elsevier science limited publisher, pp. 26-29,* 2001.

[9] S. Klugman, M. Karlsson, and B. Moshfegh, A scandinavian chemical wood- pulp mill. part-1. energy audit aiming at efficiency measures," *Applied Energy, vol. 84, pp. 326-339*, 2007.

[10] Joseph B., Industrial compressed air supply system efficiency. *California energy commission pier program, consultant report; 2004.*

[11] Greenough G. Selecting a compressed air system. *Metal Finishing; 98 (6):* 2000, 398–400.

[12] Kaya D, Phelan P, Chau D, Sarac HI., Energy conservation in compressed-air systems. *International Journal of Energy Research; 26:* 2002, 837–49.

[13] Radgen P., Efficiency through compressed air energy audits. *Energy Audit Conference, www.audit06.fi; 2006.*

[14] Senniappan AP., Baselining a compressed air system—an expert systems approach. *MS thesis, Morgantown, West Virginia University, USA; 2004.*

[15] Saidur R, Rahim NA, Masjuki HH, Mekhilef S, Ping HW, Jamaluddin MF. Enduse energy analysis in the Malaysian industrial sector. *Energy;34(February (2)):* 2009, 153–158.

[16] Marais J, Increased energy savings through a compressed air leakage documentation system. *ICUE, SA, 11* June; 2009.

[17] BEE, *Energy Performance Assessment of water Pumps.* New Delhi, India: Ministry of Environment and Forests, Ministry of Power, Government of India, 2007.

[18] BEE, *Pumps and Pumping System.* New Delhi, India: Ministry of Environment and Forests, Ministry of Power, Government of India, 2007.

[19] BEE, *Compressors.* New Delhi, India: Ministry of Environment and Forests, Ministry of Power, Government of India, 2007.

[20] BEE, *Compressed air system.* New Delhi, India: Ministry of Environment and Forests, Ministry of Power, Government of India, 2007.