Energy Audit of Fluid Catalytic Cracking Unit of an Oil Refinery

By

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08MMET17

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

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Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Mechanical Engineering (Thermal Engineering)

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

- Rabadia Chirag D.

Certificate

This is to certify that the Major Project entitled "Energy Audit of Fluid Catalytic Cracking Unit of an Oil Refinery" submitted by Rabadia Chirag Dhirajlal (08MMET17), towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) of Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of our knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

Energy conservation is a viable tool to promote economic efficiency especially in energy intensive industries such as oil refining. It has proven to be effective tool for overcoming the problem of scarcity of energy resources, and the ever-growing demand on them during the various stages of economic development. Energy conservation promotes production efficiency and enhances the international competitiveness in a world that is now oriented towards a new international economic order, with more liberal and free trade. At least 25 % of the operating cost of an oil refinery is attributed to energy consumption. Therefore, over the last two decades, refineries have taken a hard look at the efficiency of energy utilization of their technologies and equipment.

The energy audit of FCCU of an oil refinery is carried out. Objective of this audit was to assess performance of pump, compressors, fans, compressed air system, steam distribution system, insulation system and waste heat recovery system accordingly, appropriate recommendations is to be suggested for increasing energy efficiency of the plant.

It is evident that 52% of the total consumed energy can be saved by installing VFD and there is a possibility to save total Rs.374.57 Lacks by incorporating the modifications suggested, with maximum payback period of only 17 months. It is noticed that around 7-10 % of the total energy consumed can be saved in compressed air system by reducing discharge pressure, hence 1151539 kWh/annum of energy and Rs.60.45 Lacks can be saved immediately. In case of steam system, total savings in HP steam, MP steam and LP steam will be Rs.12.96 Lacks, Rs.25.8 Lacks and Rs.10.93 Lacks respectively, by replacing all damaged steam traps, with maximum payback period of only 3 months. It is also evident that total Rs.181.36 Lacks can be saved by applying detachable insulation covers on valves, valve flanges and steam tracing lines. It is also noticed that total Rs.31.69 Lacks can be saved by reducing 15 ^{o}C exhaust

gas temperature of flue gas cooler. It is strongly recommended to install gas turbine immediately in exhaust CO gas line of Regenerator-I and hence Rs.1323 Lacks can be saved with payback period of 12.69 months. In case of FD fans, it is suggested to operate only one fan in fully rated capacity and hence Rs.62.6 Lacks can be saved.

Contents

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Nomenclature

34FD-103	Forced Draft Fan
34P-101 A	Blower Condensate Pump
34P-102 S	Blow Down Pump
34P-103 A	Blower Lube Oil Pump
35P-101 S	Lean Oil Pump
35P-102 S	LCO Pump Around
35P-103 A	LCO Product Pump
35P-104 A	HCO Pump Around
35P-105 B	Slurry Pump Around
35P-108 A	Fresh Feed Pump
35P-109 A	Main Fractionator Reflux Pump
35P-110 A	Main Fractionator Distillate Pump
35P-111 A	Wash Water Pump
35P-113 A	Compressor Inter-Stage Condensate Pump
35P-115 A	Absorber Reflux Pump
35P-118 A	Gasoline Splitter Reflux Pump
35P-119 A	Gasoline Splitter Bottom Pump
35P-120 A	Rich Amine Pump
35P-121 S	Sour Water Pump
35P-122 A	Medium Gasoline Pump
35P-123 A	Slurry Oil Pump
35P-128 A	LPG Product Pump
35P-132 S	Condensate Discharge Pump
35P-136 S	Stripper Feed Pump
35P-137 A	Debutanizer Reflux Pump

35P-138 A	Supplemental Lean Oil Recycle Pump
35P-220	Rich Amine Pump
86K-101	Air Compressor
A	Surface area, m^2
C_p	Specific heat, k Cal/kg^{o}C
FAD	Free air delivery, m3/hr
FSA	Flash steam available, %
g	Gravitational acceleration, m/s^2
H	Total head, m
h	Heat transfer coefficient, W/m^2K
H_{Loss}	Surface heat loss, Watts
H_1	Specific enthalpy at inlet, kJ/kg
H_2	Specific enthalpy at outlet, kJ/kg
I	Current, amp
IP	Isothermal power, kW
L_2	Latent heat of flash steam at lower pressure).
P_1	Absolute intake pressure kg/ cm_2
P_{in}	Power input, kW
PL	Plume Length, m
Q	Flow rate of fluid, m^3/s
Q_{Leak}	Steam leak quantity, kg/hr
Q_1	Free air delivered m^3/hr
Q_{Heat}	Total heat available in flue gas, kCal/hr
r	Pressure ratio, P_2/P_1
S_1	Sensible heat of higher pressure condensate
S_2	Sensible heat of the steam at lower pressure
T_a	Average ambient temperature, ^{o}C
T_h	Hot surface temperature (for hot fluid piping), ^{o}C
V	Voltage, Volt
V_{Flow}	Flow rate, m^3/hr

V_s	Swept volume, m^3/hr
ϕ	Power factor
ΔT	Temperature difference, ^oC
η_p	Pump efficiency
$\eta_{\ isothermal}$	Isothermal efficiency
$\eta_{\ Volumetric}$	Volumetric efficiency
ρ	Density of fluid, kg/m^3

Acronyms

BPT	Balanced Pressure Type
CDU	Crude Distillation Unit
FAD	Free Air Delivery
FCCU	Fluid Catalytic Cracking Unit
FGC	Flue Gas Cooler
FSA	Flash Steam Available
HP	High Pressure
IP	Isothermal Power
LP	Low Pressure
LPG	Liquefied Petroleum Gas
MMTPA	Million Metric Tonne per Annum
MP	Medium Pressure
NHT-CCR	Naphtha Hydro Treater and Continuous Catalytic Reformer Unit
PL	Plume Length
SGU	Saturated Gas Unit
SH	Super Heated
TD	Thermodynamic
UGS	Unsaturated Gas Separation
VBU	Visbreaker Unit
VDU	Vacuum Distillation Unit
VFD	Variable Frequency Drive
VLCC	Very Large Crude Carriers

Chapter 1

Introduction

1.1 Introduction

In the recent years, India has emerged as one of the fastest growing economies of the world necessitating equally rapid increase in modern energy consumption. With an imminent global climate change threat, India will have difficulties in continuing with this rising energy use towards achieving high economic growth. It will have to follow an energy-efficient pathway in attaining this goal. In terms of energy intensity, India occupies a relatively high position of 9 among the top 30 energy consuming countries of the world [1]. Energy efficiency is one of the most important measures, among others, to address these challenges. Energy efficiency makes available additional energy resources, which can partially address the issues of inadequacy and equity. Energy efficiency also reduces energy consumption as well as carbon intensity, which is a necessary condition for addressing climate change. India will have to follow an energy-efficient pathway to address the above three challenges [2]. Energy Conservation Act, 2001 made provisions for setting up of the Bureau of Energy Efficiency, a body corporate incorporated under the Act, for supervising and monitoring the efforts on energy conservation in India [2], which is also responsible for formulating various policies related to energy conservation in India. To formulate it, one needs to know the contours of energy requirements and options. As per these policies, energy efficiency emerges as a major option with a potential to reduce energy requirement by as much as 17% [3].

Industrial energy efficiency has emerged as one of the key issues in India. The industrial sector uses about 40% of total energy in the country [4]. India accounts for 4.5% of industrial energy use worldwide [5]. According to the International Energy Agency (IEA) World Energy Outlook energy consumption in Indian industry is projected to more than double by 2030 and so increases its share of total final energy consumption to 31% [5].

A considerable amount of energy, in a refinery, is utilised in pump, fan, compressor operation, steam production and distribution, and therefore an energy performance assessment into pump, fan, compressor operation, steam production, distribution and waste heat recovery system would yield valuable information. Insulation of equipment and pipe work, heat recovery from processed fluids, etc., are all seen as an area where heat could be saved, which in turn saves fuel[6]. Similarly Fluid catalytic cracking (FCC) is the most important conversion process used in petroleum refineries [7], where long hydrocarbon compounds are chemically cracked into small chain compounds by catalytically cracking. The unit itself requires utilities such as compressed air, high pressure steam and various accessories such as pumps, compressors, blowers etc. So well designed and well maintained plant can save huge amount of energy. Although the FCC process continues to evolve, there is no doubt that it will continue to serve a central role in the future of the refining business.

An energy audit is a technique for identifying energy losses, quantifying them, estimating conservation potential, evolving technological options for conservation and evaluating techno-economics for the measures suggested. Though the objectives of an energy audit are universally accepted, the methodology is not standardized [8], but an attempt can be made to standardize the methodology of an energy audit by determining the overall efficiency of a whole system. By doing so, losses and efficiencies of each segment in the system can be determined independently. This would provide a clue as to where to act on improving the energy efficiency of the system [8].

1.2 Literature Review

To study about energy conservation in India as well as in other countries, the review of status has been carried out. The journals like "Energy", "Energy Policy", "Energy Conversion and Management", "Engineering Costs and Production Economics", "Renewable and Sustainable Energy Reviews", "Applied Energy" have been referred. Approximately 15 most appropriate papers have identified. The conclusion of review of status is as below:

Ample literature is available regarding energy conservation, but there is no standardize methodology followed by different authors. It is also felt that literatures related to energy audit of an oil refinery are very few. At the same time, there is unanimous belief that energy conservation is need of a day.

A systematic approaches, to monitor industrial-energy consumption and to pin-point sources of wastage, is known as energy audit [8]. An energy audit helps an organization to understand and analyze its energy utilization and identify areas where energy use can be reduced. It also helps to decide on how to budget energy use, plan and practice feasible energy conservation methods. These energy conservation methods will enhance energy efficiency, curtail energy wastage and substantially reduce energy costs. Different authors have studied about energy conservation in different areas like pumps, compressed air system, steam system, waste heat recovery system and fans.

1.2.1 Energy conservation in Pumps

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 [9]. 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 [10]. Old pumps generally consume more energy and hence energy audit of such pumps is essential. S. Kluman et al. [11] suggested that electricity use can be reduced by 50% in the old pumps by energy audit of such pumps.

1.2.2 Energy conservation in Compressed air system

Compressed air system utilizes about 10-20% of total input energy for useful work done and major energy lost takes place in the form of waste heat and through the leakage of compressed air. These are the potential areas where huge amount energy savings is possible [8].

1.2.3 Energy conservation in Steam system

Steam trap is an essential part of steam distribution system. Three important functions of steam traps are to discharge condensate as soon as it is formed, not to allow steam to escape and to remove air and other incondensable gases. Loss equivalent to 25% of total steam occurs due to malfunctioning of steam traps [6]. Such steam traps are to be replaced to avoid loss of live steam which conserves a lot of energy.

Insulation plays an important role in steam distribution system. Heat loss due to conduction and convection may greatly be saved by applying proper insulations. It is very important to optimize the thickness of insulation as the cost of insulation also increases with the insulation thickness. Rock wool insulation is generally used for reducing heat losses from industrial pipe lines as well as from vessels. Literature suggests that rock wool insulation can save energy up to 21 $/m^2 with payback periods of 1-1.7 years [12].

1.2.4 Energy conservation in Waste heat recovery system

Waste heat recovery steam generation (WHRSG) is well proven technique for energy conservation. Waste heat available in the plant may be used for either process heating or for power generation depending on the enthalpy of the said steam. Typical case study for a cement industry indicate that about 4.4 MW of electricity may be generated which leads to energy conservation of 42.88 MWh/year [13]. Another literature regarding the secondary kiln shell of the cement plant indicates that the use of waste heat can save up to 5.3MWof thermal energy, which is equivalent to 10.4% of the total input energy of plant [13]. This can save fuel consumption and energy efficiency of the unit increases by 5%.

Energy audit of dry type rotary kiln system has been reported by T. Engin et al. [14]. It indicates that the major heat loss sources are the kiln exhaust (19.15% of total input energy), cooler exhaust (5.61% of total input energy) and combined radiative and convective heat transfer from kiln surfaces (15.11% of total input energy). These are the probable areas where energy can be saved from heat losses. It is also reported in this literature that the total saving for the whole system of dry type rotary kiln is about 4 MW, which is equivalent to an energy recovery of 15.6% of the total input energy [14].

1.2.5 Energy conservation in Fans

It is known that variable speed drive improves the energy efficiency of a fan motor of boiler house [15]. Variable speed drive reduces stack gas temperature up to 50^{o}C and hence 2.5% boiler efficiency can be increased. It also reduces CO_2 emissions by more than 71 ton/yr. The typical payback period for such variable speed drive is about 18 months.

1.3 Problem Statement

There is a great potential of energy saving in an Oil Refinery. An Oil Refinery, with a capacity of 14 MMTPA, was selected for this energy audit. Energy audit was carried out in Fluid Catalytic Cracking Unit (FCCU), which is the most important unit of an oil refinery. Four main section of FCCU are Reactor/Regenerator Section, Main air blower and heat recovery section, Wet gas compressor section and Main Fractionator section. FCCU consumes 3.25 MW of electricity, 167 MT/hr steam from utility section and it can also generate 165 MT/hr steam. Energy audit has been carried out for various equipments of FCCU like pumps, forced draft fans, air compressors and waste heat recovery boiler.

1.4 Objective of the project

Objective of this project is

a. To carry energy audit in Fluid Catalytic Cracking Unit of an oil refinery for improving energy efficiency without affecting production and quality of the products.

b. To assess energy performance of pumps, compressors, fans, compressed air system, steam distribution system and waste heat recovery system for conserving as much energy as possible in FCCU.

1.5 Organization of thesis

The thesis has been organized in five chapters including conclusions and recommendations.

Chapter one is Introduction to the project work. This covers the overall picture of the project including motivation for the project work.

Chapter two is Methodology of the Energy Audit, which includes various methodology adopted for energy audit of pumps, fans, compressors, steam distribution system and waste heat recovery system.

Chapter three is Results and Discussion which includes results discussion of energy audit of pumps, fans, compressors, steam distribution system and waste heat recovery system. In this chapter, all the results obtained during the energy audit have been discussed in detail.

In chapter four is Conclusions and Recommendations which gives recommendations according to various system like energy audit of pumps, fans, compressors, steam distribution system and waste heat recovery system. Major conclusions/outcomes are also given in this chapter.

The thesis also includes resource of the references. This is followed by the Appendix section in which various tables of design details and actual performance details are given.

Chapter 2

Energy Audit Methodology

This energy audit was carried out in the Essar Oil Refinery, which is located at Vadinar in Jamnagar. The Refinery is operating at a capacity of 13.4 MMTPA with an investment of close to US $2.2 billion. Aviation Turbine Fuel, Kerosene Oil, High Speed Diesel, LPG, Gasoline and Transport Fuels conforming to Euro III, Euro IV and Euro V is some of the product of this world class refinery.

Crude Distillation Unit (CDU), Vacuum Distillation Unit (VDU), Visbreaker Unit (VBU), Fluid Catalytic Cracking Unit (FCCU), Saturated Gas Unit (SGU), Naphtha Hydro Treater and Continuous Catalytic Reformer Unit (NHT-CCR), Utility Unit and Environmental Units are the various units of this Oil refinery. Crude oil imported mostly from Gulf countries is brought by sea in Very Large Crude Carriers (VLCC). The processing of crude begins with a distillation operation in crude distillation unit. Thus the crude is separated into different components, which are also called fractions. LPG, Petrol and Naphtha are the light distillates and these distillates are used respectively in domestic use, transport and industry. Diesel, Kerosene and Aviation turbine fuel are the middle distillates and these distillates are used respectively in heavy transport, household fuel and in airbus fuel. Furnace oil comes in category of heavy distillates and is used in industry. Heavy distillates are further processed to produce more valuable middle distillates.

Fluid Catalytic Cracking Unit is the most important unit of Essar Oil refinery. Energy audit was carried out in this FCC unit. The FCC unit is designed for processing 2.93 MMTPA of feed which is obtained from processing of 70/30 Arab light/Arab heavy crude oil mix, in 8400 hours of operation. The feed containing Heavy Paraffin, Olefins, Naphthenes and Aromatics to FCC unit is cracked to give more valuable lighter products like LPG, Gasoline, Cycle oil and Fuel gas etc. Generally there are two types of cracking procedure followed for heavier hydrocarbons: Thermal Cracking and Catalytic Cracking. However most of the existing FCC unit is using catalytic cracking instead of thermal cracking. The vacuum gas oil is supplied from Vacuum Unit and Visbreaker Unit to FCCU. From this vacuum gas oil, LPG is produce in FCCU. The main objective of the FCCU is to maximize LPG production. The Unsaturated Gas Separation (UGS) unit is the part of the FCCU and objective of UGS is to separate the distillate and LPG from the FCC reactor outlet gas. This unit is designed to recover maximum C3's and C4's hydrocarbon chain from the unsaturated gas.

Various equipments of FCCU are Main Air Blower, Reactor, Regenerator-I Regenerator -II, Feed Heater, CO-Oxidizer and Flue Gas Cooler, Forced Draft Fans, Catalyst Handling Hoppers, Main Fractionators Column, and Other Post Processing Columns. Line diagram of FCCU is shown in Figure 2.1:

Main aim of this energy audit was to assess performance of pumps, compressors, fans, compressed air system, steam generation and distribution system for improving energy efficiency of FCCU. Methodology adopted for this energy audit is as shown in Figure 2.2 in form of flow chart:

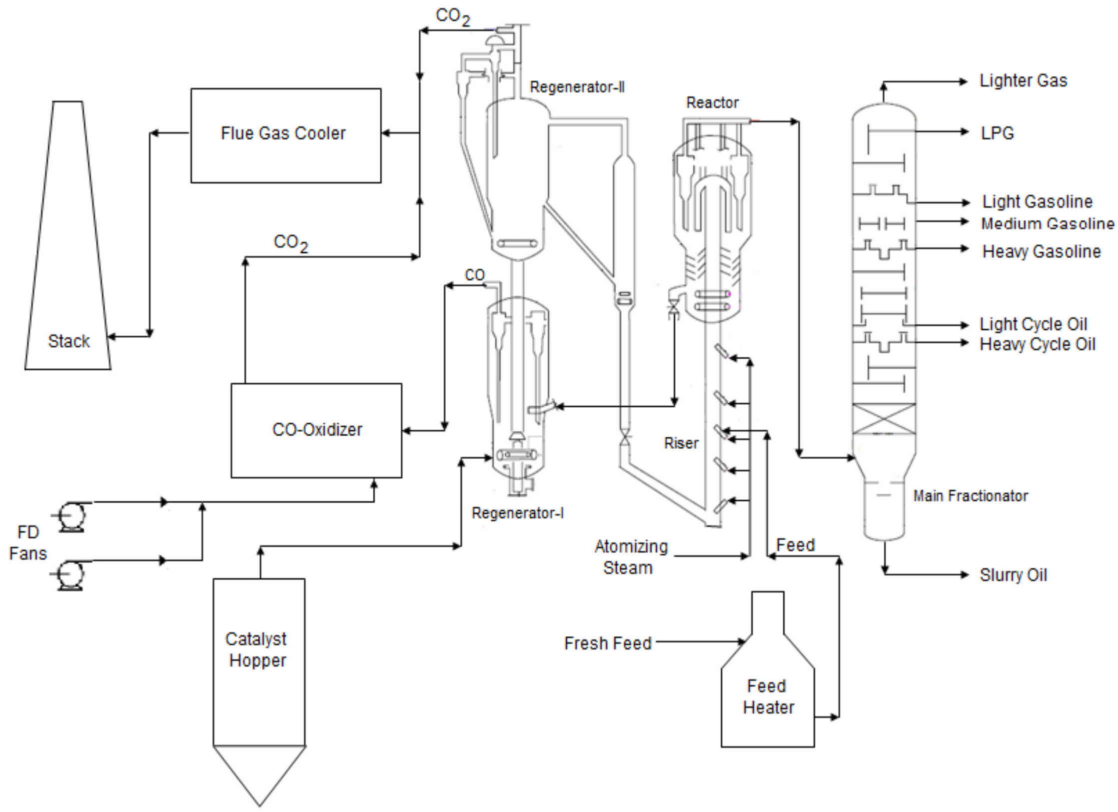

Figure 2.1: Line diagram of FCCU

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 [16]. 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.

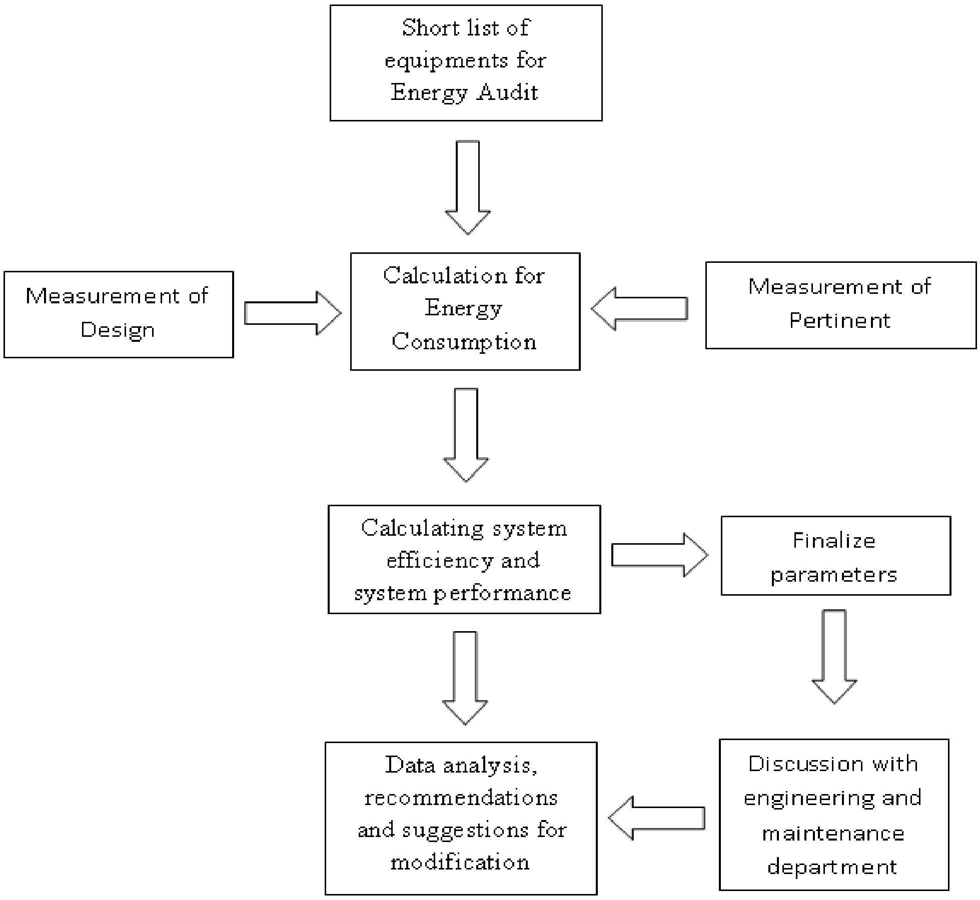

Figure 2.2: Methodology adopted for energy audit of FCCU

Purpose of the performance test of pumps is to determine the pump efficiency during operating condition and compare the same with design. 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 2.1 [17] shows symptoms that indicate potential opportunity for energy savings.

Table 2.1: Symptoms that Indicate Potential Opportunity for Energy Savings

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 far away 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 find out with the help of equation 2.1.

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

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

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

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

$$P_{in} = Q \times (H_1 - H_2) \tag{2.3}$$

2.1.2 Affinity laws of pumps

The equations relating rotodynamic 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:

$$Q \propto N \tag{2.4}$$

$$H \propto N^2 \tag{2.5}$$

$$P_m \propto N^3 \tag{2.6}$$

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 unusable heat energy and to a lesser extent lost in form of friction, misuse and noise [18].

Purpose of the performance test of compressor was to find out actual Free Air Delivery (FAD) of the compressor and to find out the isothermal power required and volumetric efficiency for improving energy efficiency. The actual performance of the plant is to be compared with design values for assessing the energy efficiency. Similarly discharge pressure also affect energy efficiency and hence it is essential to verify that the same is in accordance with required pressure for given application.

2.2.1 Compressor Efficiency

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

$$\eta_{Isothermal} = \frac{IP}{P_{Actual}} \tag{2.7}$$

$$IP = \frac{P_1 \times Q_1 \times log_e r}{36.7} \tag{2.8}$$

$$\eta_{Volumetric} = \frac{FAD}{V_s} \tag{2.9}$$

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/cm2 and loads at 6 kg/cm2. 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% [[19]].

2.3 Energy Audit Methodology of Steam Distribution System

Steam has been a popular mode of conveying energy since the industrial revolution. Steam is used for generating power and also used in process industries such as sugar, paper, fertilizer, refineries, petrochemicals, chemical, food, synthetic fibre and textiles [[20]]. The following characteristics of steam make it so popular and useful to the industry:

a. Highest specific heat and latent heat

b. Highest heat transfer coefficient

c. Easy to control and distribute

d. Cheap and inert

The steam distribution system is the essential link between the steam generator and the steam user. Steam with the right quality, correct pressure and in the right quantity is essential for an efficient steam distribution system [20].

2.3.1 Performance of Steam distribution system

There are two main areas where performance of steam distribution system can be assessed in FCCU:

a. Steam traps

b. Heat loss from un-insulated surface

Monitoring Steam Traps

The purpose of installing the steam traps is to obtain fast heating of the product and equipment by keeping the steam lines and equipment free of condensate, air and non-condensable gases. A steam trap is a valve device that discharges condensate and air from the line or piece of equipment without discharging the steam [20].

Steam trap performance assessment is basically concerned with answering the following two questions:

a. Is the trap working correctly or not?

b. If not, has the trap failed in the open or closed position?

There are two type of failure of steam traps: Open condition type and Close condition type. Traps that fail 'Open' result in a loss of steam and its energy. At a same time as condensate is not returned back to the circuit, the water is lost to atmosphere which is loss of energy. The result is significant economic loss, directly via increased boiler plant costs, and potentially indirectly, via decreased steam heating capacity. Traps that fail 'closed' do not result in energy or water losses, but can result in significantly reduced heating capacity and/or damage to steam heating equipment.

There are three energy saving opportunities as far as steam traps concerned:
Avoiding Steam Leakages:
Steam leaks on high-pressure mains are prohibitively costlier than on low pressure mains. Any steam leakage must be quickly attended to. In fact, the plant should consider a regular surveillance programme for identifying leaks at pipelines, valves, flanges and joints.

One method of identifying steam leak is to measure the plume length of the leaking steam from a spot [21]. The following equation 2.10 can be used to assess the approximate quantity of steam leak.

$$Q_{Leak} = 2.5678 \times EXP(1.845 \times PL) \tag{2.10}$$

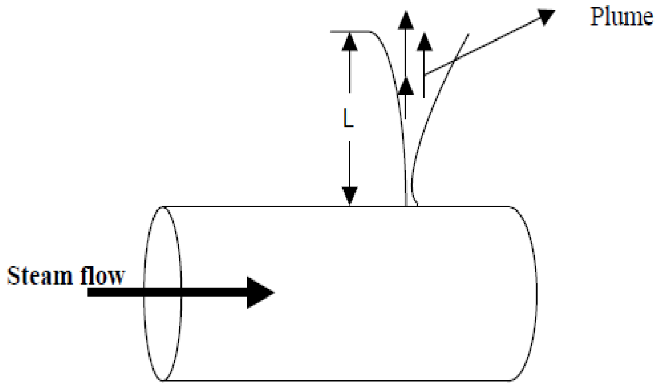

Figure 2.3: Plume length (L) of leaking steam

Figure 2.3 shows the layout of a pipe line carrying steam. Whenever any hole develops on the surface, steam will start leaking through it. The length of plume may be measured by a steel tape or a meter scale as accurate as possible.

Condensate Recovery:

The steam condenses after giving off its latent heat in the heating coil or the jacket of the process equipment. A sizable portion (about 25%) of the total heat in the steam leaves the process equipment as hot water. The percentage of energy in condensate to that in steam can vary from 18% at 1 bar to 30% at 14 bar; clearly the liquid condensate is worth reclaiming. If this water is returned to the boiler house, it will reduce the fuel requirements of the boiler. For every 60^o C rise in the feed water temperature, there will be approximately 1% saving of fuel in the boiler [20].

Flash Steam Recovery:

This shall not be mistaken for a steam leak through the trap. The users sometimes get confused between a flash steam and leaking steam. The flash steam and the leaking steam can be approximately identified as follows:

a. If steam blows out continuously in a blue stream, it is a leaking steam.

b. If a steam floats out intermittently in a whitish cloud, it is a flash steam [20].

Flash steam is produced when condensate at a high pressure is released to a lower pressure such steam can be used for low pressure heating. The higher the steam pressure and lower the flash steam pressure the greater the quantity of flash steam that can be generated. In many cases, flash steam from high pressure equipments is made use of directly on the low pressure equipments to reduce use of steam through pressure reducing valves. The flash steam quantity can be calculated by the equation 2.11 with the help of a steam table:

$$FSA = \frac{S_1 - S_2}{L_2} \tag{2.11}$$

Monitoring Un-Insulated Surfaces

A thermal insulator is a poor conductor of heat and has a low thermal conductivity. Insulation is used in buildings and in manufacturing processes to prevent heat loss or heat gain. Although its primary purpose is an economic one, it also provides more accurate control of process temperatures and protection of personnel. It prevents condensation on cold surfaces and the resulting corrosion. Such materials are porous, containing large number of dormant air cells. Thermal insulation delivers the following benefits:

a. Reduces over-all energy consumption

b. Offers better process control by maintaining process temperature.

c. Prevents corrosion

d. Provides fire protection to equipment

e. Absorbs vibration

Heat can be lost due to radiation from steam pipes if it is not insulated properly. As an example while lagging steam pipes, it is common to see some of the flanges remain uncovered. An uncovered flange is equivalent to leaving 0.6 m of pipe line unlagged. If a 0.15 m steam pipe diameter has 5 uncovered flanges, there would be a loss of heat equivalent to wasting 5 tons of coal or 3000 litres of oil a year [22]. This is usually done to facilitate checking the condition of flange but at the cost of considerable heat loss. The remedy is to provide easily detachable insulation covers, which can be easily removed when necessary. The various insulating materials used are cork, Glass wool, Rock wool and Asbestos.

- **Heat loss calculation methodology**

  According to Newton's law of cooling, heat loss from the pipe can be calculated by equation 2.12:

$$H = h \times A \times (T_h - T_a) \tag{2.12}$$

  For horizontal pipe, heat transfer coefficient can be calculated by equation 2.13:

$$h = (A_1 + 0.005(T_h - T_a)) \times 10 \tag{2.13}$$

  For vertical pipes, heat transfer coefficient can be calculated by equation 2.14:

$$h = (B_1 + 0.005(T_h - T_a)) \times 10 \tag{2.14}$$

  A_1 and B_1 are the constant coefficients [[22]]. The values of these constants for different surfaces are shown in Table 2.2.

Table 2.2: Values of co-efficient A_1 and B_1

Surface	A_1	B_1
Aluminium, Bright rolled	0.25	0.27
Aluminium, Oxidized	0.31	0.33
Steel	0.32	0.34
Galvanized sheet metal	0.53	0.55
Nonmetallic surfaces	0.85	0.87

2.4 Energy Audit Methodology of Waste Heat Recovery System

Waste heat is heat is generally generated in a process by way of fuel combustion or chemical reaction, and then dumped into the environment even though it could still be reused for some useful and economic purpose [23]. The essential quality of heat is not the amount but rather its value. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. CO-oxidizer and flue gas cooler are the equipments which are used for extracting waste heat comes from regenerator.

2.4.1 CO-oxidizer

Huge quantities of low pressure flue gases containing carbon monoxides (CO) are available in refineries as a by product of the catalyst regeneration process in fluid catalytic cracking (FCC) unit. This CO gas is being converted into CO2 by CO-oxidizer.This CO gas is utilised for steam production for three reasons:

a. To recover the heat available in flue gases

b. To convert CO into CO2 before discharging the flue gases to atmosphere

The flue gases are rich in carbon monoxide which is to be converted to carbon dioxide before its discharge to atmosphere. CO boiler design must take into consideration the three reasons mentioned above, i.e. recover the heat available and convert the CO to CO2. These equipments are not only boilers but also incinerators where residence time at high temperature is the key factor for the proper CO oxidation.

2.4.2 Flue Gas Cooler

Flue gas cooler is used in cases where little or no CO is present in the flue gases (when fully converted in the catalyst regeneration process). Flue gas coolers are heat recovery units where sensible heat contained in the flue gases is utilised to produce and superheat steam or to preheat process oil streams for energy conservation purposes in fluid catalytic cracking unit. The heat recovery section is composed either by horizontal or vertical bare tubes.

By installing flue gas cooler, heat can be recovered to pre-heat the combustion air and hence the fuel savings would be 33% (@ 1% fuel reduction for every 22C reduction in temperature of flue gas.

2.4.3 Arrangement of CO-oxidizer and Flue gas cooler in FCCU

Figure 2.4 shows the detail arrangement of CO-oxidizer and Flue gas cooler used in FCCU.

2.4.4 Calculation of total quantity of recoverable heat

The total heat recoverable at final exhaust temperature can be calculated by equation 2.15.

$$Q_{Heat} = V \times \rho \times C_P \times \triangle T \tag{2.15}$$

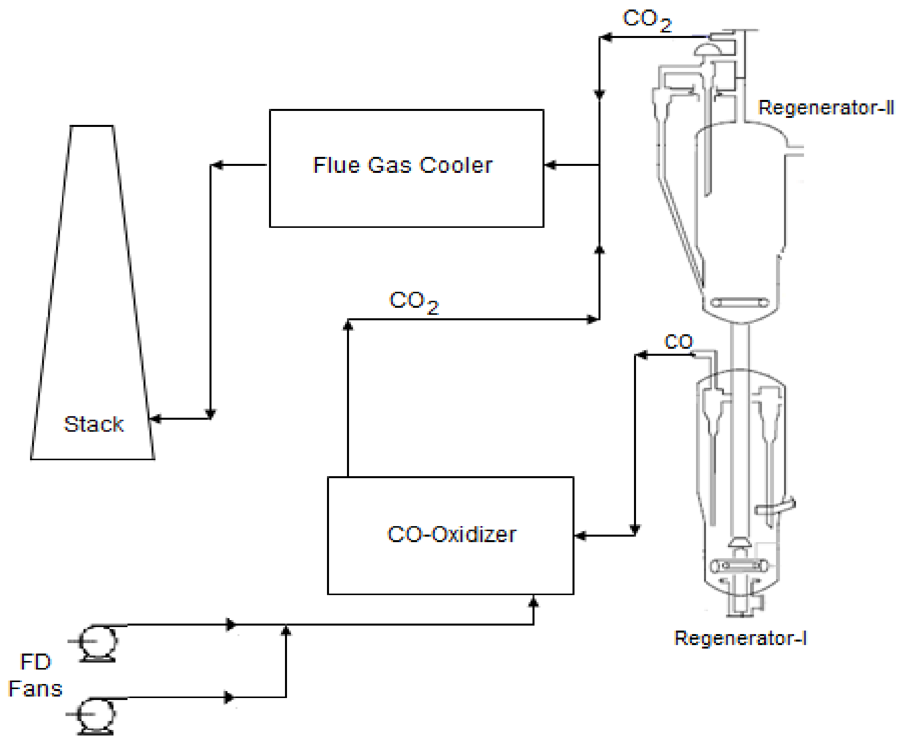

Figure 2.4: Arrangement of CO-Oxidizer and Flue gas cooler

2.5 Energy Audit Methodology of Fans

Fans provide air for ventilation and industrial process requirements. The purposes of energy audit of fan is to determine, the volume flow rate, the power input and the total pressure rise under a fuel operating condition [24]. From all these actual performance details, opportunity for energy conservation can be checked. There are two numbers of forced draft fans in FCCU which feed the air to CO-oxidizer.Efficiency of fans should be calculated with equation 2.16.

$$\eta_{Fan} = \frac{V \times P_r}{102 \times P_{in}} \tag{2.16}$$

After calculating efficiency of the fan, it is required to calculate the discharge of fan. From the calculated efficiency and discharge, a decision is to be made for number of fan required to put in operation and/or standby mode.

Chapter 3

Results and Discussion

Energy audit study was undertaken into energy conservation in Fluid Catalytic Cracking Unit (FCCU) in an oil refinery. Actual energy performance of Pumps, Compressors, Fans, Steam Distribution System and Waste Heat Recovery System has been assessed.

3.1 Results and Discussion 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.

3.1.1 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 is the better option where throttling of the discharge flow is taking place. Power consumed by variable frequency drive can be calculated from equation 2.4 and equation 2.6. 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 Rs. and investment cost. Design and actual measured parameters are shown in Annexure A and Annexure B respectively. Figure 3.1, Figure 3.2 and Figure 3.3 shows efficiency, total savings and pack back period of pumps in the form of charts.

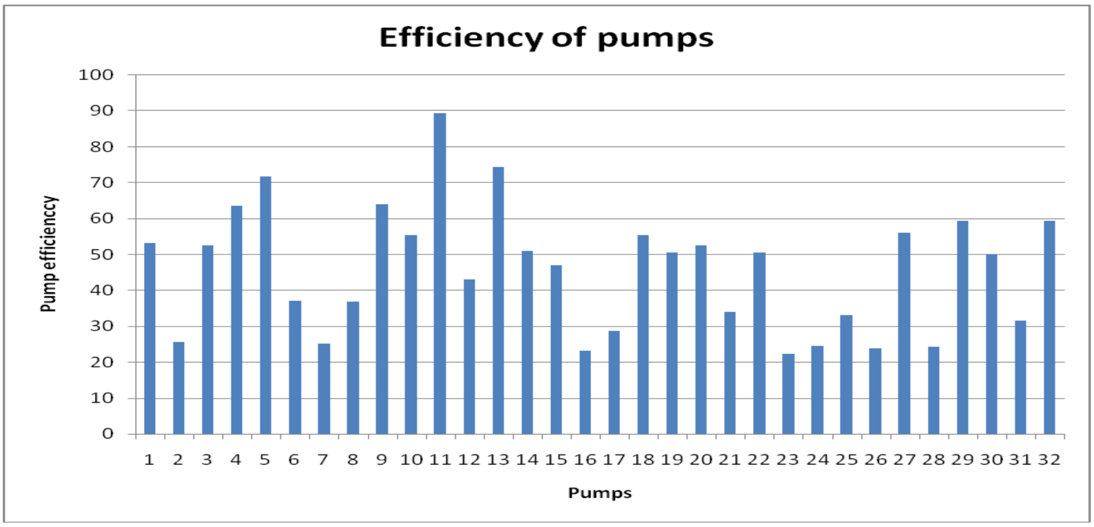

Figure 3.1: Efficiency of Pumps

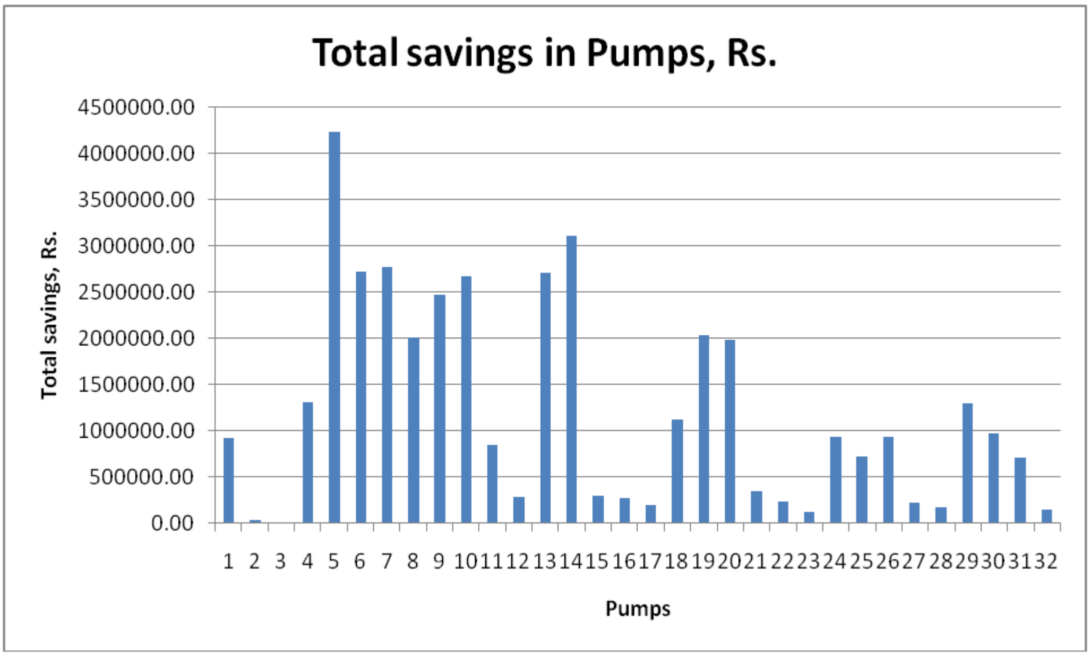

Figure 3.2: Total Savings in Pumps

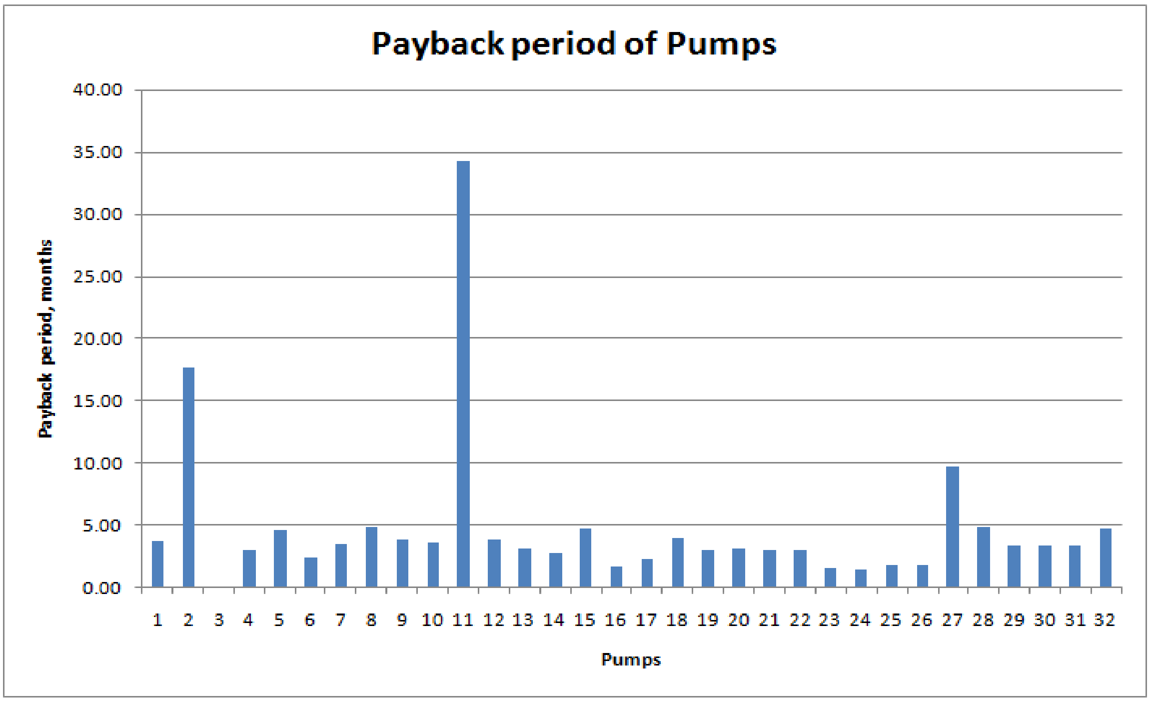

Figure 3.3: Proposed Payback Period of pumps

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 34P-103 A and 35P-108 A and hence it is not viable to install VFD in these pumps. From Figure 3.1, Figure 3.2 and Figure 3.3, it is suggested to install VFD in all the pumps mention above except 34P-103 A and 35P-108 A. Total Rs.374.57 Lacks can be saved by installing VFD with maximum payback period of only 17 months.

3.2 Results and Discussion 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.

3.2.1 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

Table 3.1: Actual Performance Details of Compressors

Description	**Units**	**86K101S**	**86K101A**	**86K101B**	**86K101C**
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 delivered	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

checking energy conservation opportunities.

Table 3.1 shows actual performance details of compressors. Figure 3.4, Figure 3.5 and Figure 3.6 shows actual power consumption, isothermal efficiency, and volumetric efficiency of compressors in the form of charts.

Figure 3.6 shows that volume delivered by each compressor is good. From the pertinent parameters given by operation department of Essar Oil Limited, it is noticed

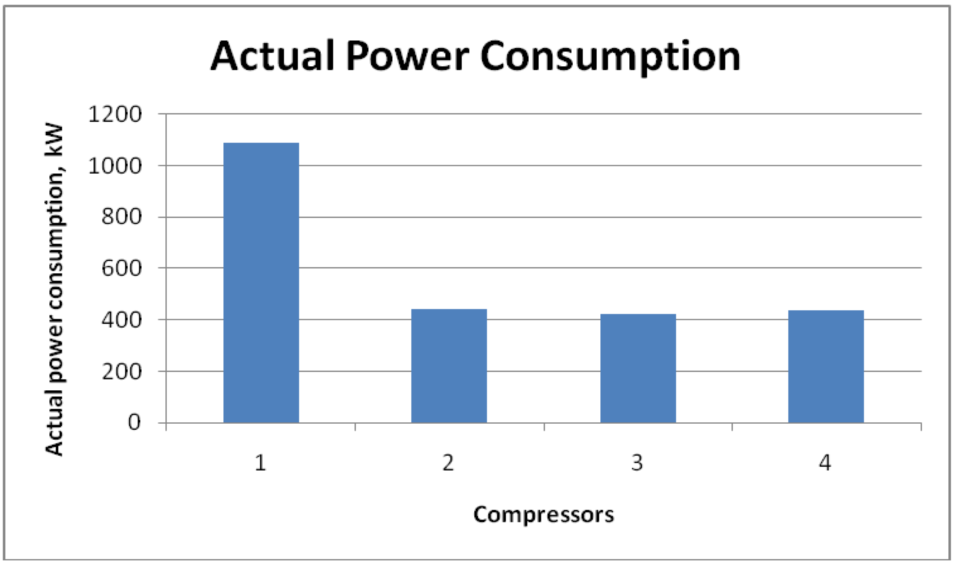

Figure 3.4: Power Consumption of Compressors

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.

3.3 Results and Discussion of Steam distribution system

Fluid Catalytic Cracking Unit (FCCU) is one of the major steam consuming units in Essar oil refinery. Steam leak survey as well as survey of heat loss through un-insulated surface has been undertaken in FCCU. There are three types of steam used in FCCU:

a. HP steam pressure (37.42 kg/cm^2)

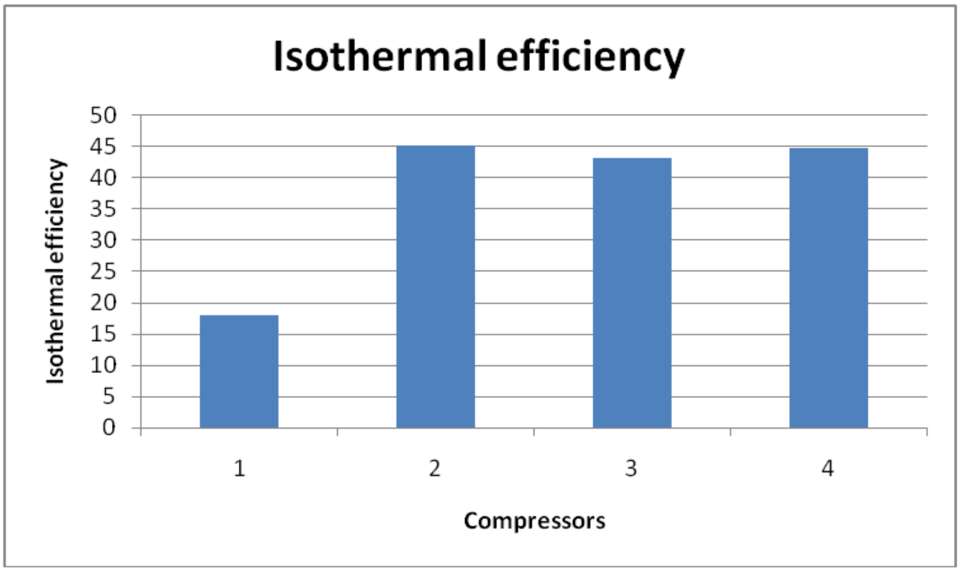

Figure 3.5: Isothermal Efficiency of Compressors

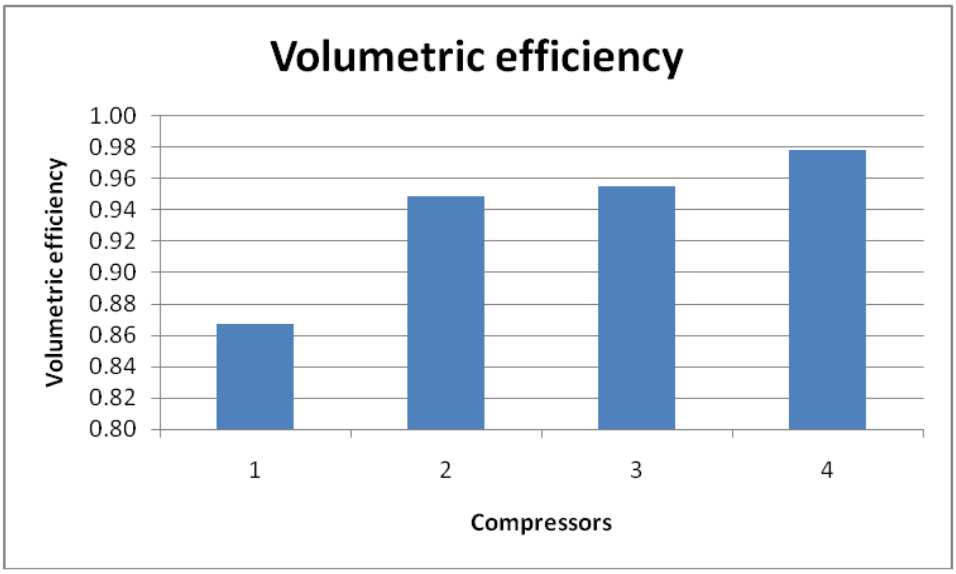

Figure 3.6: Volumetric Efficiency of Compressors

b. MP steam pressure (12.5 kg/cm^2)

c. LP steam pressure (4 kg/cm^2)

3.3.1 Steam leak survey

Most of steam traps, used in FCCU, are Thermodynamic (TD) type and Thermostatic (Balanced Pressure-BPT) type. Steam leak quantity was calculated in FCCU by plume length method. Plume length measured by visual inspection with the steel scale. Table 3.2, Table 3.3 and Table 3.4 show the steam leaks quantity, total saving in Rs. and payback period of HP steam, MP steam and LP steam respectively. Figure 3.7, Figure 3.8 and Figure 3.9 show the steam leaks quantity, total saving in Rs. and Payback period, months of HP steam respectively, in form of charts. Figure 3.10, Figure 3.11 and Figure 3.12 show the steam leaks quantity, total saving in Rs. and Payback period, months of MP steam respectively, in form of charts. Figure 3.13, Figure 3.14 and Figure 3.15 show the steam leaks quantity, total saving in Rs. and Payback period, months of LP steam respectively, in form of charts.

Table 3.2: Actual Performance Details of HP Steam leakages from the steam traps

Sr. no.	**Steam trap no.**	**Plume length, m**	**Steam loss, kg/hr**	**Total steam loss, MT/annum**	**Total Saving, Rs.**	**Payback Period, Months**
1	TD-62	0.3	4.47	37.52	80,698.02	1.49
2	TD-63	0.1	3.09	25.94	55,796.66	2.15
3	FL-491	0.15	3.39	28.45	61,188.79	1.96
4	TD-64	0.1	3.09	25.94	55,796.66	2.15
5	TD-536	0.6	7.77	65.25	1,40,360.49	0.85
6	TD-533	0.6	7.77	65.25	1,40,360.49	0.85
7	TD-537	0.6	7.77	65.25	1,40,360.49	0.85
8	TD-539	0.15	3.39	28.45	61,188.79	1.96
9	TD-08	0.05	2.82	23.65	50,879.70	2.36
10	PV-07	0.5	6.46	54.26	1,16,712.55	1.03
11	PV-08	0.2	3.71	31.2	67,102.01	1.79
12	TD-63	0.2	3.71	31.2	67,102.01	1.79
13	TD-69	0.3	4.47	37.52	80,698.02	1.49
14	TD-71	0.1	3.09	25.94	55,796.66	2.15
15	TD-120	0.1	3.09	25.94	55,796.66	2.15
16	TD-124	0.2	3.71	31.2	67,102.01	1.79
Total steam loss, kg/hr				**602.95**	**12,96,940.05**	

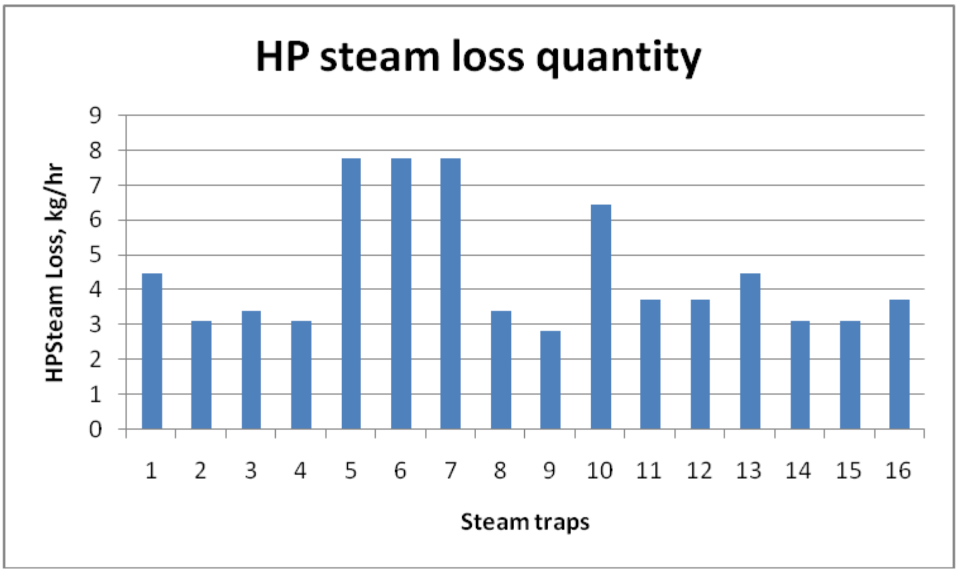

Figure 3.7: HP Steam Loss Quantity

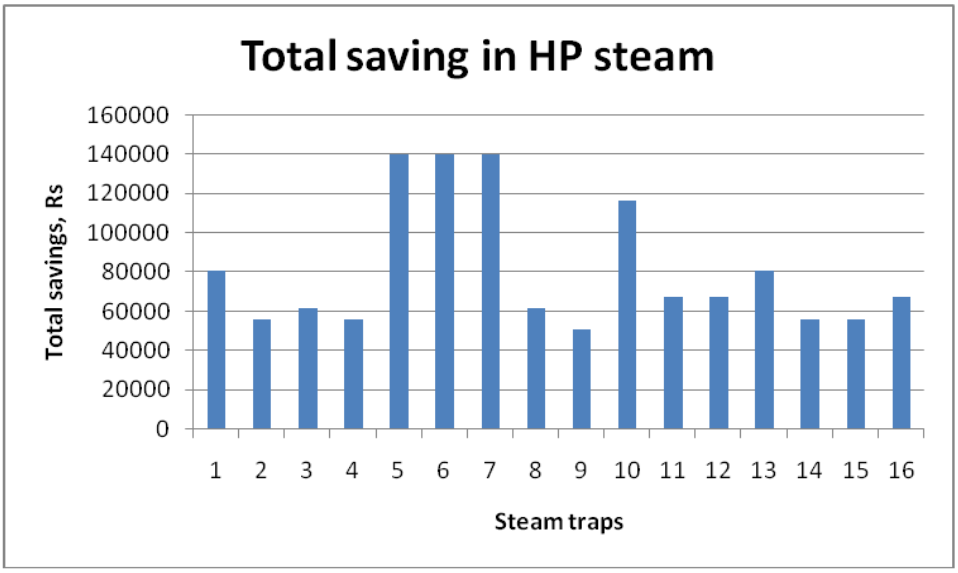

Figure 3.8: Total Saving in HP Steam

Table 3.3: Actual Performance Details of MP Steam leakages from the steam traps

Sr. no.	**Steam trap no.**	**Plume length, m**	**Steam loss, kg/hr**	**Total steam loss, MT/annum**	**Total Saving, Rs.**	**Payback Period, Months**
1	TD-450	0.05	2.82	23.65	50,879.70	0.2
2	TD-495	0.8	11.24	94.38	2,03,001.64	0.05
3	TD-457	0.1	3.09	25.94	55,796.66	0.18
4	TD-462	0.1	3.09	25.94	55,796.66	0.18
5	TD-465	0.05	2.82	23.65	50,879.70	0.2
6	BPT-431	0.05	2.82	23.65	50,879.70	0.2
7	BPT-434	0.1	3.09	25.94	55,796.66	0.18
8	BPT-435	1.5	40.88	343.36	7,38,568.65	0.01
9	PV-409	1	16.25	136.49	2,93,598.76	0.03
10	PV-411	0.2	3.71	31.2	67,102.01	0.15
11	PV-412	0.5	6.46	54.26	1,16,712.55	0.09
12	PV-414	0.1	3.09	25.94	55,796.66	0.18
13	TD-47	0.1	3.09	25.94	55,796.66	0.18
14	TD-48	0.4	5.37	45.12	97,048.81	0.1
15	TD-49	0.4	5.37	45.12	97,048.81	0.1
16	TD-579	0.1	3.09	25.94	55,796.66	0.18
17	TD-580	0.1	3.09	25.94	55,796.66	0.18
18	TD-581	1.2	23.5	197.41	4,24,628.24	0.02
Total steam loss, kg/hr				**1199.87**	**2580925.21**	

Table 3.4: Actual Performance Details of LP Steam leakages from the steam traps

Sr. no.	**Steam trap no.**	**Plume length, m**	**Steam loss, kg/hr**	**Total steam loss, MT/annum**	**Total Saving, Rs.**	**Payback Period, Months**
1	BPT-438	1	16.25	136.49	2,93,598.76	0.03
2	BPT-506	0.8	11.24	94.38	2,03,001.64	0.05
3	BPT-476	1	16.25	136.49	2,93,598.76	0.03
4	BPT-478	0.1	3.09	25.94	55,796.66	0.18
5	TD-393	0.05	2.82	23.65	50,879.70	0.2
6	BPT-480	0.6	7.77	65.25	1,40,360.49	0.07
7	BPT-127	0.1	3.09	25.94	55,796.66	0.18
Total steam loss, kg/hr				**508.15**	**10,93,032.67**	

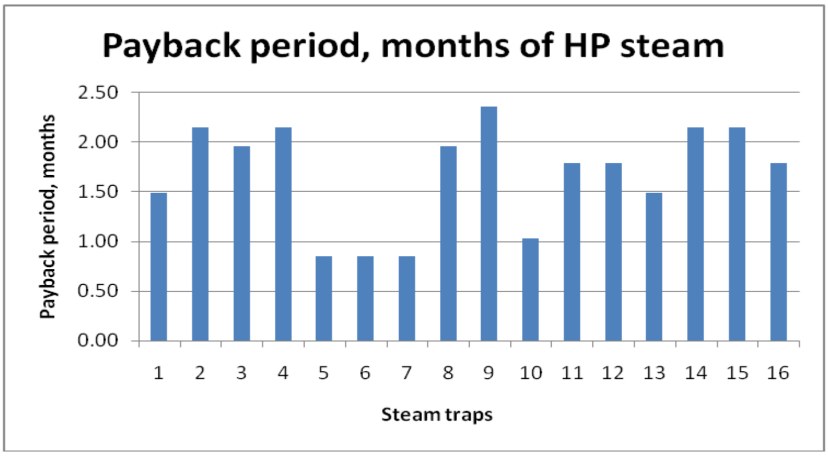

Figure 3.9: Payback Period of HP Steam

Steam loss quantity shown in Figure 3.7, Figure 3.10 and Figure 3.13 found due to failure of steam traps in Open condition. Payback period was calculated by taking steam trap cost as Rs.10,000. Figure 3.9, Figure 3.12 and Figure 3.15 show the payback period which is not more than 3 months. It is recommended to replace all steam traps mentioned above, hence total savings in HP steam, MP steam and LP steam will be Rs.12.96 Lacks, Rs.25.8 Lacks and Rs.10.93 Lacks respectively, by incorporating the modifications suggested. Condensate recovery system and Flash steam separator exist in FCCU but these equipments are not utilized properly. Table 3.5 is prepared based on steam leak readings taken in FCCU, which shows total steam loss, total savings and payback period of HP steam, MP steam and LP steam.

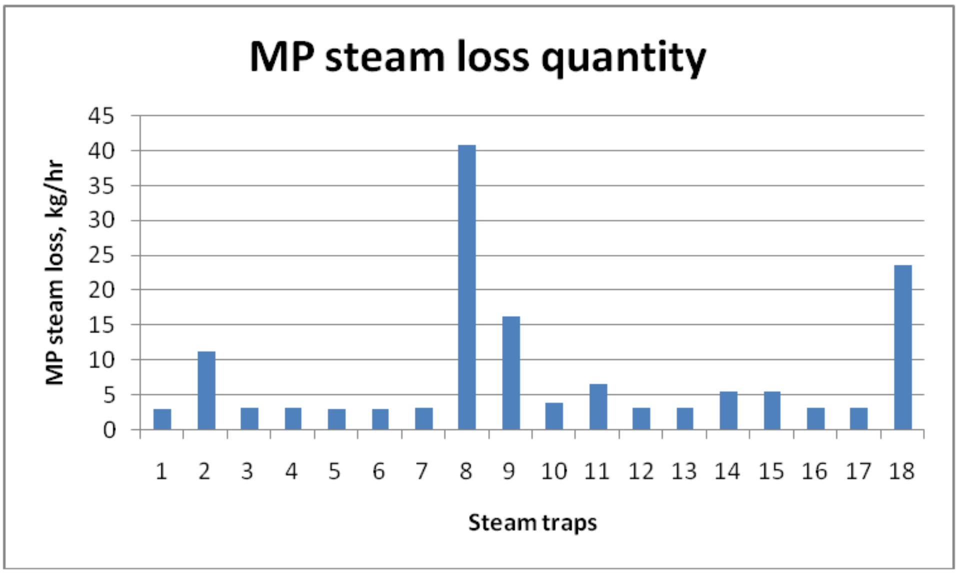

Figure 3.10: MP Steam Loss Quantity

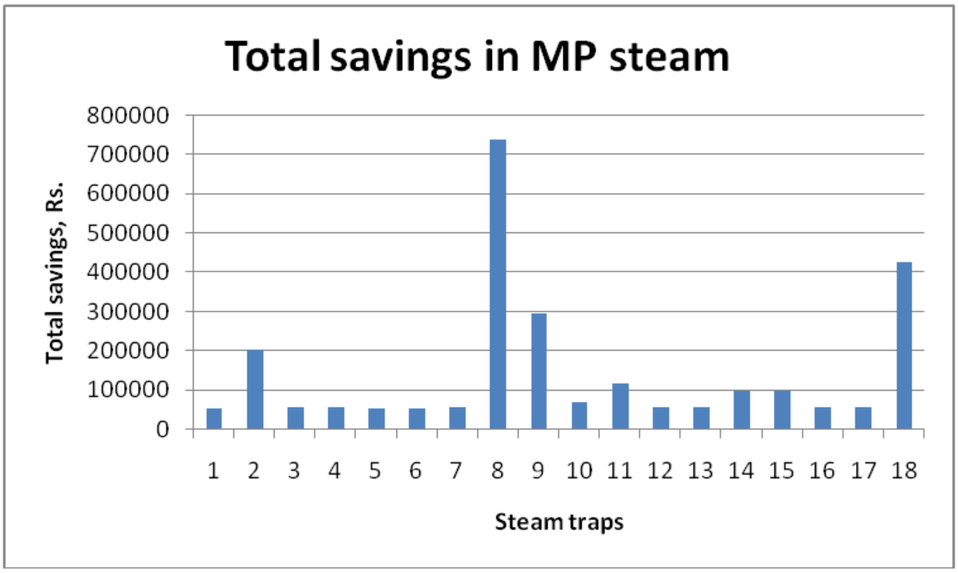

Figure 3.11: Total Saving in MP Steam

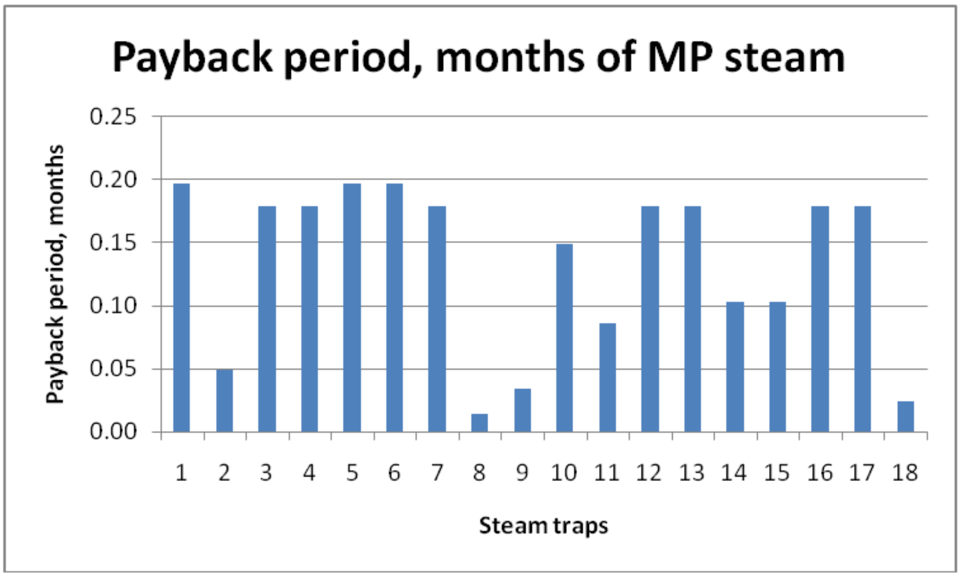

Figure 3.12: Payback Period of MP Steam

3.3.2 Heat loss calculation from Un-Insulated surface

Valves, flanges, steam tracing lines are common to see without insulation lagging in refinery. But this heat loss which occurs from un-insulated can't be ignored. Heat loss is calculated using methodology mention in 2.3.1.2. Actual measured parameters are shown in Annexure B. Figure 3.16, Figure 3.17 and Figure 3.18 show the total heat loss, energy saving and payback period of Un-Insulated surfaces respectively. Figure 3.19, Figure 3.20 and Figure 3.21 show the total heat loss, energy saving and payback period of Un-Insulated pipe surfaces respectively.

Majority of valves flanges and steam tracing lines found without insulation in FCCU. Figure 3.16 and Figure 3.19 show the total heat loss from un-insulated surfaces and

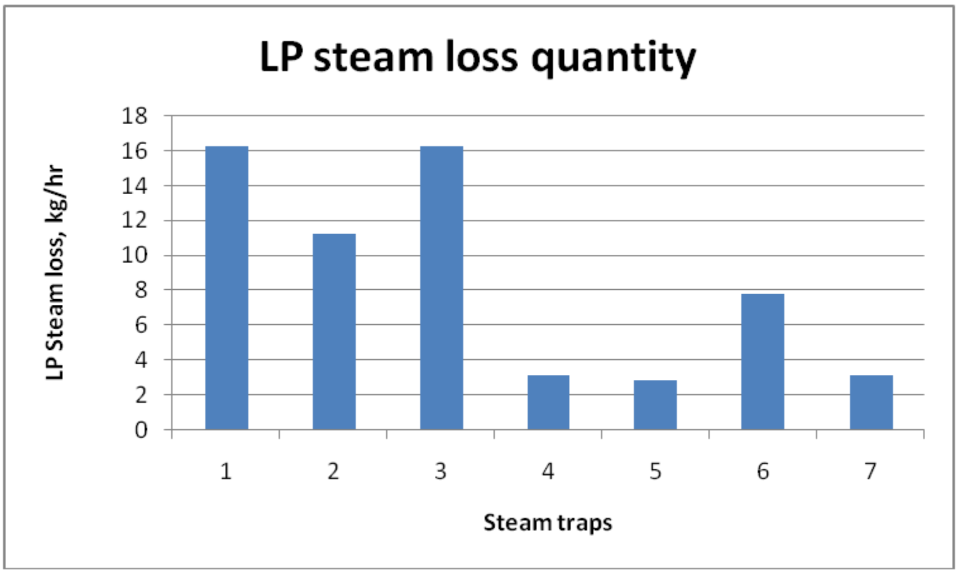

Figure 3.13: LP Steam Loss Quantity

un-insulated pipe surfaces. Total 411.26 kW/hr of heat loss has been calculated from un-insulated surfaces and hence total saving with Rs.181.36 Lacks can be saved. It is recommended to apply detachable insulation covers on valves, flanges and steam tracing lines.

3.4 Results and Discussion of Waste heat recovery system

Huge quantity of waste heat from CO gas is being recovered in CO-Oxidizer and Flue gas cooler in FCCU. CO-oxidizer converts CO gas into CO_2 and Flue gas cooler generates steam from that CO_2 gas. Actual performance details of CO-Oxidizer and Flue gas cooler are given below:

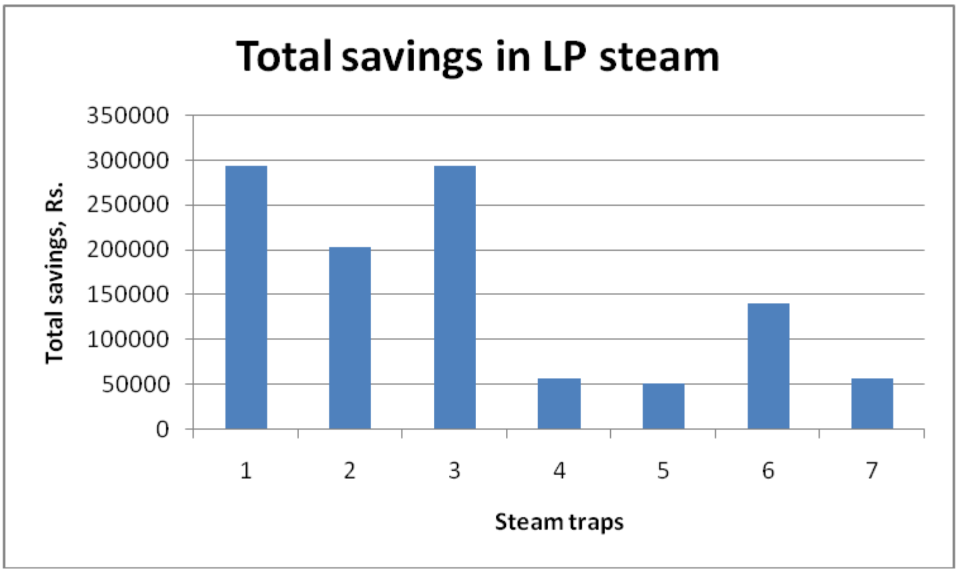

Figure 3.14: Total Saving in LP Steam

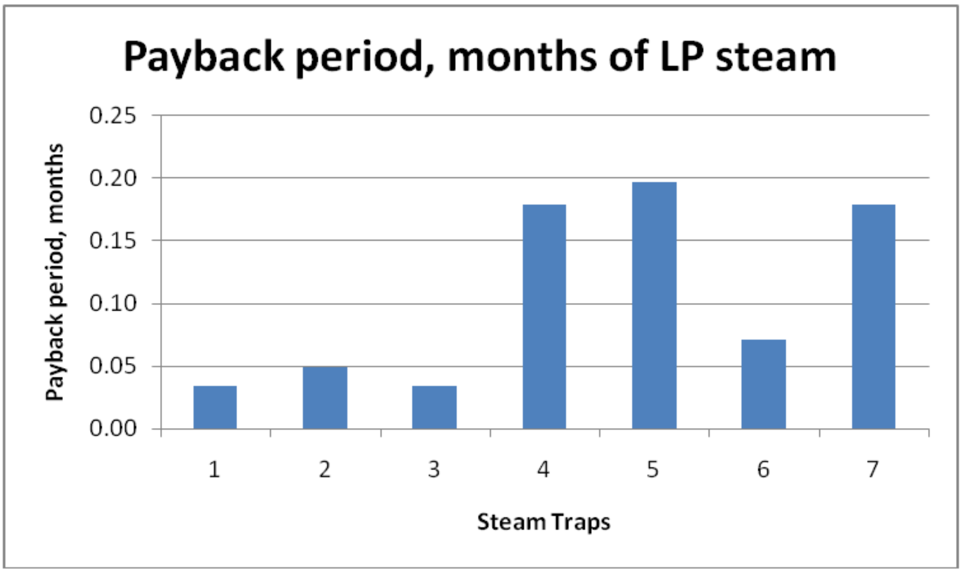

Figure 3.15: Payback Period of LP Steam

Table 3.5: Proposed saving calculation of steam leaks

Description	**HP steam**	**MP steam**	**LP steam**
Total steam loss, MT/annum	602.86	1199.87	508.15
Total saving, Rs. Lacks	12.96	25.8	10.93
Investment, Rs./Steam trap	10000	10000	10000
Payback period, months	Up to 3	Up to 1	Up to 1

3.4.1 Actual performance details of CO-Oxidizer and Flue gas cooler in FCCU

Design parameters of CO-oxidizer and flue gas cooler have been collected from operation and maintenance manual which is given by the manufacturer of the equipment. Pertinent parameters of like pressure, temperature, flow rate of CO gas have been measured at the inlet and exhaust for calculating actual efficiency of the the equipment. Same pertinent parameters have also been measure for boiler feed water, saturated steam and superheated steam. Energy can be saved by decreasing exhaust gas temperature. Performance details of CO-Oxidizer are given in Table 3.6. Performance details of Flue gas cooler are given in Table 3.7 Total available heat in flue gas has been calculated by equation 2.15. So total available heat in flue gas,

$$Q = 216287.9 \times 1.16 \times 0.31 \times (895 - 313) = 45266288.98 kCal/hr \tag{3.1}$$

It is noticed that HP superheated steam, HP saturated steam and MP superheated steam is generated and exported to various units. Boiler feed water and MP saturated steam feed to flue gas cooler. Flue gas inlet and outlet temperatures are observed 895^{o}C and 313^{o}C respectively and hence total 4,52,66,288.98 kCal/hr of available heat

Table 3.6: Performance details of CO-Oxidizer

Sr. no.	Description	Unit	Actual Value
1	Flue gas inlet temperature-CO Oxidizer	^{o} C	605
2	Flue gas flow rate-CO Oxidizer	m^3/hr	216287.9
3	Flue gas inlet pressure	kg/cm^2	0.215
4	Flue gas outlet pressure	kg/cm^2	0.161
5	Fuel gas(FG) supply quantity	kg/hr	425
6	Flue gas outlet temperature	^{o} C	898

Table 3.7: Performance details of Flue gas cooler

Sr. no.	Description	Unit	Actual Value
1	Flue gas flow rate-FGC	m^3/hr	216287.9
2	Flue gas flow rate-FGC	kg/hr	250893.96
3	Flue gas inlet temperature-FGC	^{o} C	895
4	Flue gas outlet temperature-FGC	^{o} C	313
5	Flue gas inlet Pressure-FGC	kg/cm^2	0.161
6	Flue gas outlet Pressure-FGC	kg/cm^2	0.094
7	Boiler feed water inlet temperature	^{o} C	188
8	Boiler feed water inlet pressure	kg/cm^2	44
9	Boiler feed water inlet flow rate	T/hr	111
10	Economizer outlet temperature	^{o} C	220
11	Saturated HP steam outlet temperature	^{o} C	250
12	Saturated HP steam outlet pressure	kg/cm^2	40
13	Saturated HP steam outlet flow rate	T/hr	27
14	Superheated HP steam outlet temperature	^{o} C	390
15	Superheated HP steam outlet pressure	kg/cm^2	38.89
16	Superheated HP steam outlet flow rate	T/hr	60
17	Saturated MP steam inlet temperature	^{o} C	194
18	Saturated MP steam inlet pressure	kg/cm^2	13.6
19	Saturated MP steam inlet flow rate	T/hr	20.8
20	Superheated MP steam outlet temperature	^{o} C	299
21	Superheated MP steam outlet pressure	kg/cm^2	13
22	Superheated MP steam outlet flow rate	T/hr	20.8

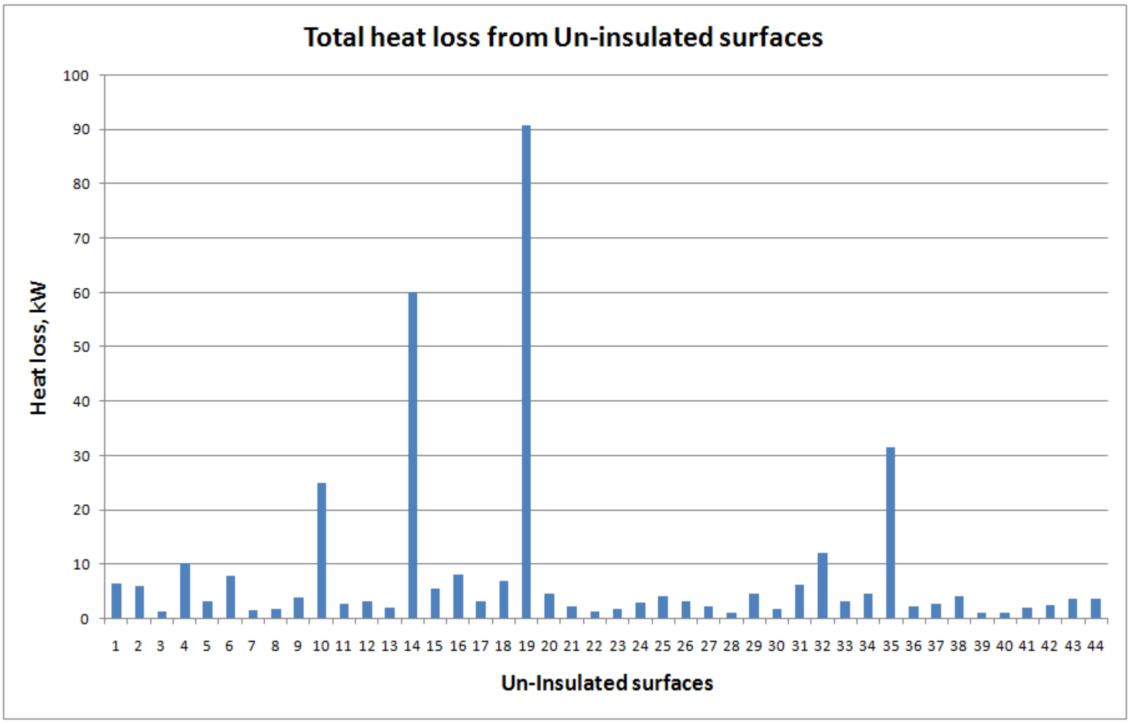

Figure 3.16: Total Heat Loss from Un-insulated Surfaces

in flue gas is calculated from Table 3.6 and Table 3.7. It is noticed that still more heat can be recovered by reducing flue gas outlet temperature. Reductions of 15 ^{o}C in Flue gas outlet temperature can be possible. Therefore total 184.58 MT/annum of fuel can be saved and so Rs.31.69 Lacks can be saved in Flue gas cooler.

It is also recommended to install gas turbine in the exhaust CO gas line of Regenerator-I. At present the CO gas from Regenerator-I exhausted at 624.9^{o}C and 2.06kg/cm^2. Then CO gas passes through the orifice chamber and is sent into the CO oxidizer at 0.7 kg/cm^2, which burns the CO gas and flue gas sent out of the CO oxidizer at 910^{o}C. The energy in CO gas exhausted at 2 kg/cm^2 could be used to drive a gas turbine and the gas turbine connected to a generator could produce electrical energy. Literature says that similar project successfully carried out in one of the plant in china [25]. Cost benefit analysis of such a system is given in the Table 3.8 below.

Table 3.8: Cost benefit analysis of Gas Turbine

Description	**Units**	**Values**
Actual parameters		
CO	TPH	3
Proposed parameters		
Turbine generation	kW	3,000
Hours of operation of plant per annum	hrs/annum	8,400
Cost of unit energy	Rs./kWh	5.25
Energy saved per annum	kWh/annum	2,52,00,000
Total Savings per annum	**Rs. Lacks**	**1,323**
Investment	Rs. Lacks	1,400
Payback Period	Months	12.69

Table 3.8 shows proposed total savings per annum, investment and payback period. It is recommended to install gas turbine and so Rs.1,323 Lacks can be saved.

3.5 Results and Discussion of Fans

Two numbers of continuous running forced draft fan supplies combustion air to CO-Oxidizer. Design parameters of 2 numbers of fans have been collected from operation and maintenance manual which is given by the manufacturer of the fan. Pertinent parameters like pressure, flow rate, throttling percentage, temperature of air and power consumption have been measured for calculating actual efficiency of the each fan. Actual performance details of forced draft fans are shown in below Table 3.9:

It is noticed that air flow rate is controlled by Inlet Guide Vanes. It is noticed from Table 3.9 that any one fan can also handle the total flow rate requirement. Hence it is suggested to operate only one fan in fully rated capacity and another fan has to be in standby mode. Total 11,92,800 kWh of energy saving was calculated and so Rs. 62.6 Lacks can be saved.

Table 3.9: Performance details of FD fans

Description	**34FD-103A**	**34FD-103S**
Total Pressure, mmWC g	1510	1505
Discharge flow, Nm^3/hr	23932	21378
Discharge flow, m^3/sec	7.77	6.94
Total Discharge pressure, kg/cm^2 a	1.18	1.18
Actual current, amp	21	20
Volt	6600	6600
Motor power consumption, kW	149.22	142.11
Inlet guide vane (IGV) open, %	8.15	7.28
Discharge air temperature,^{o} C	58.03	58.03
Density, kg/m^3	1.16	1.16
Mechanical Efficiency, %	77.16	72.13

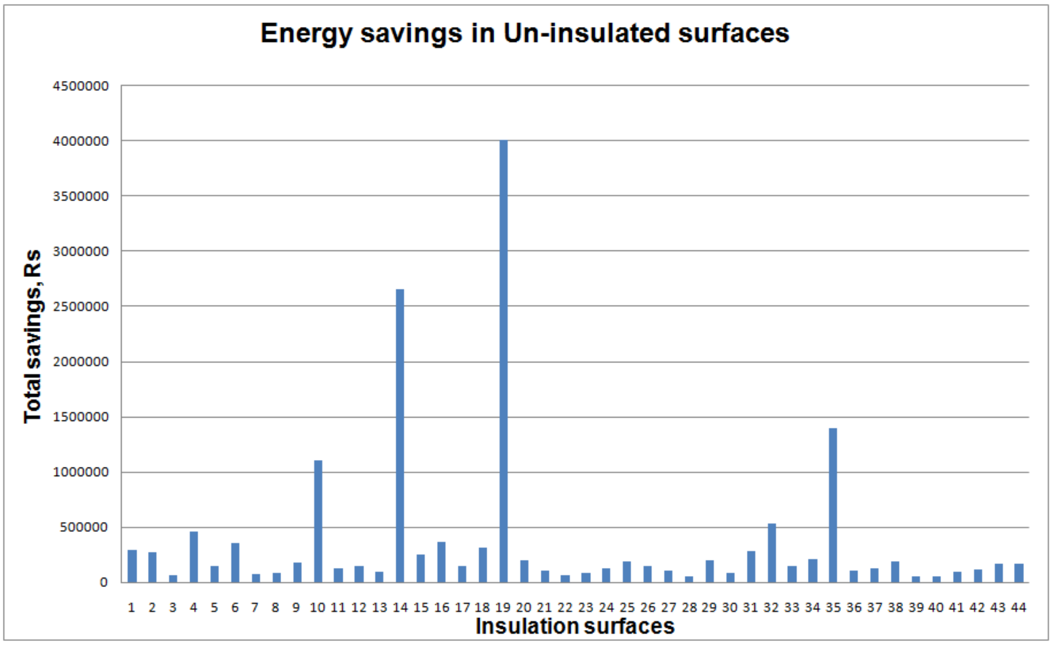

Figure 3.17: Energy Savings in Un-insulated Surfaces

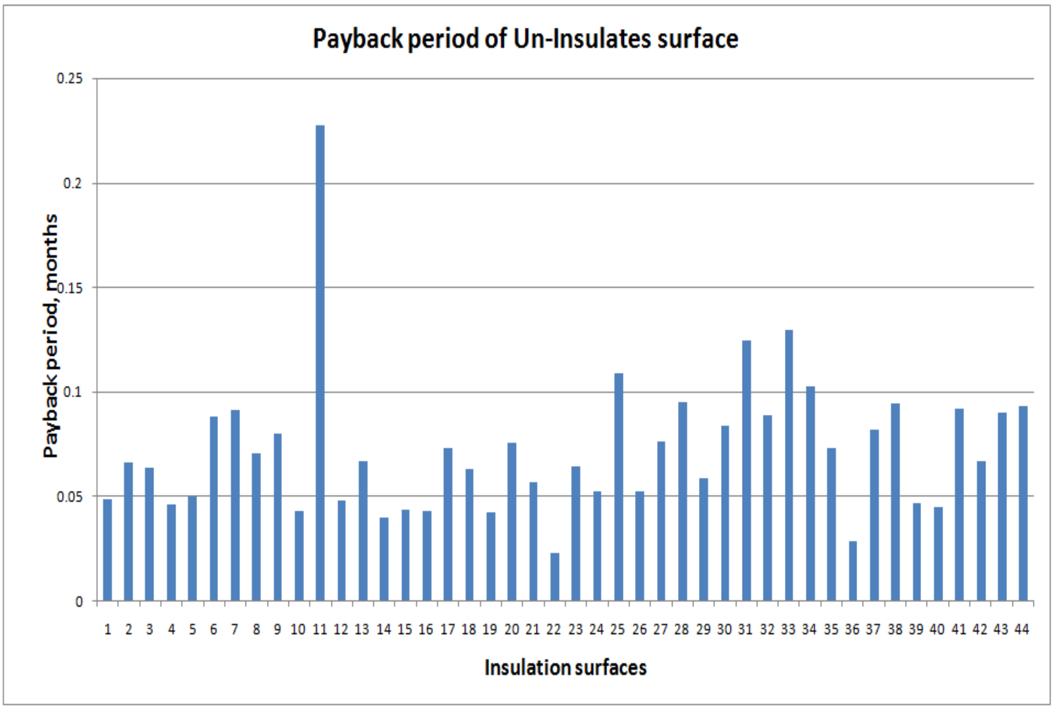

Figure 3.18: Payback Period of Un-insulated Surfaces

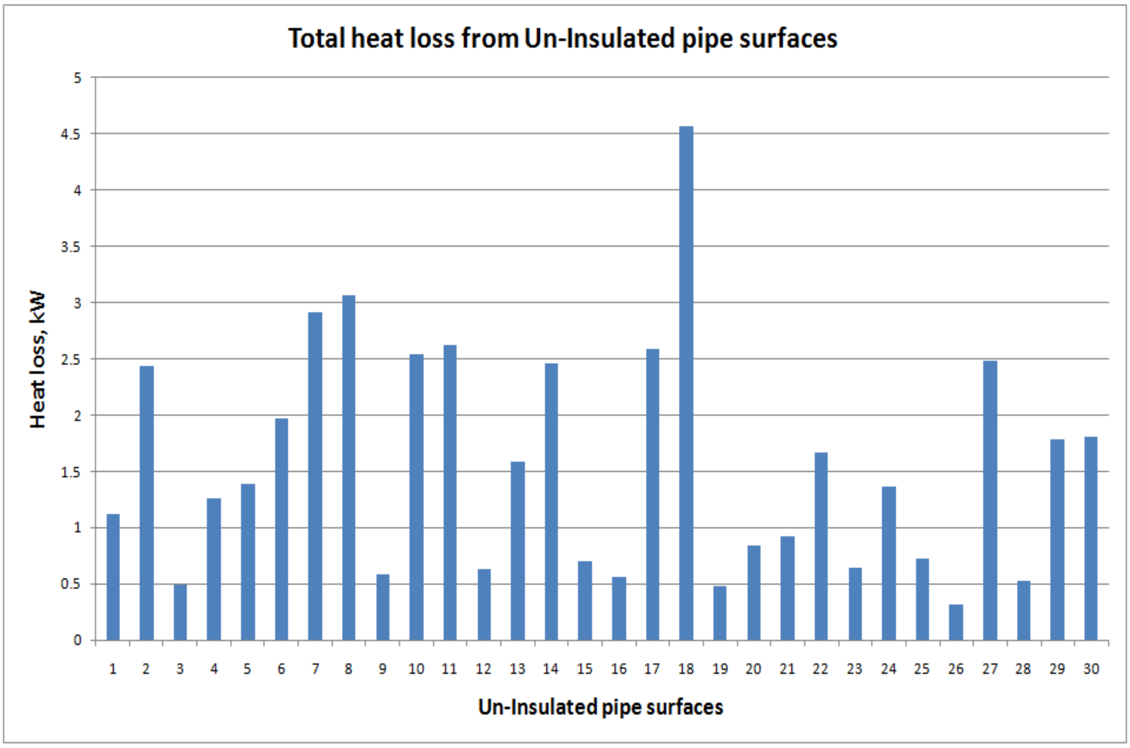

Figure 3.19: Total Heat Loss from Un-insulated Pipe Surfaces

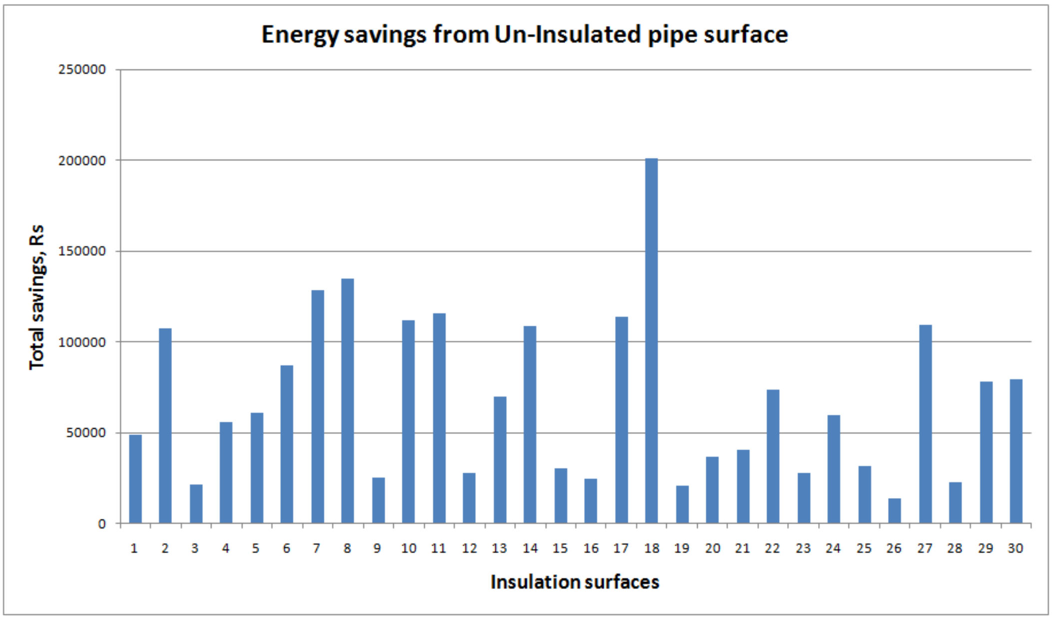

Figure 3.20: Energy Savings in Un-insulated Pipe Surfaces

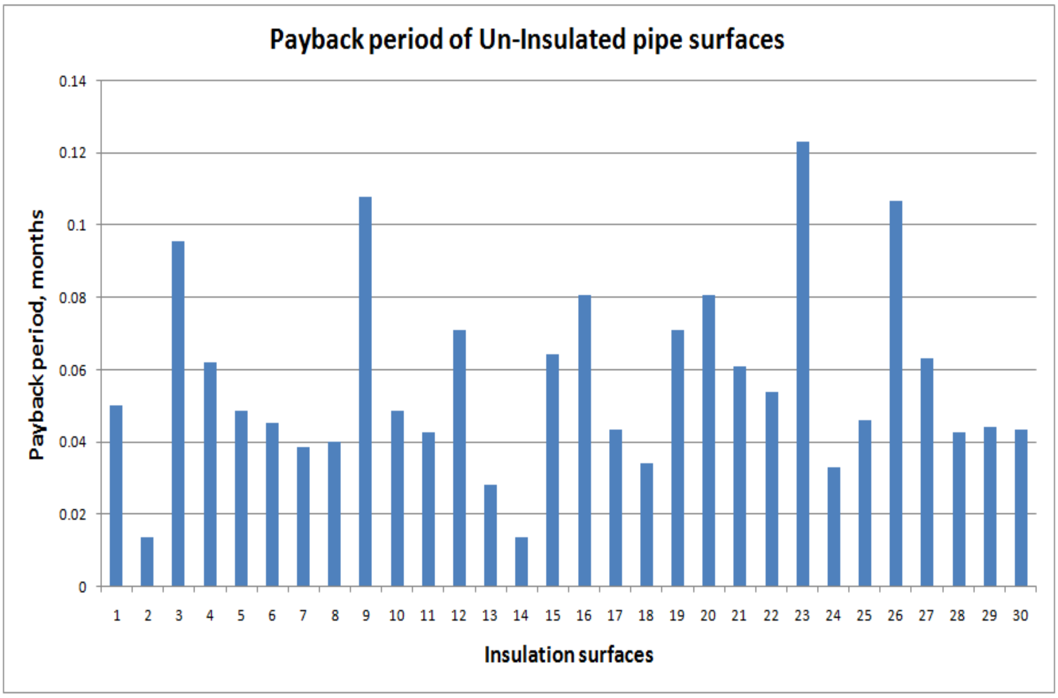

Figure 3.21: Payback Period of Un-insulated Pipe Surfaces

Chapter 4

Conclusion and Recommendations

4.1 Conclusions and Recommendations

Energy conservation is prime important for any of the plant. Energy can be conserved in FCCU by routine checkup of plant equipments, proper operation and maintenance work of the plant. Following recommendations should be implemented for saving huge amount of energy.

In case of pumps, it is 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 VFD. 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/cm^2 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.

It is found in steam distribution system that most of the steam traps fail in open condition hence steam leaks found from those failed traps. It is recommended to replace all the steam traps mentioned in section 3.3.1. Total savings in HP steam, MP steam and LP steam will be Rs.12.96 Lacks, Rs.25.8 Lacks and Rs.10.93 Lacks respectively by incorporating the modifications suggested, with maximum payback period of only 3 months. It is also suggested to utilize existing condensate recovery system and flash steam separator properly in FCCU.

Majority of valves, valve flanges and steam tracing lines found without insulation in FCCU. Total 411.26 kW/hr of heat loss has been calculated from un-insulated surfaces with help of methodology suggested in section 2.3.1. Total Rs.181.36 Lacks can be saved by applying detachable insulation covers on valves, flanges and steam tracing lines.

Flue gas inlet and outlet temperatures are observed as 895 ^{o}C and 313 ^{o}C respectively, in case of CO-oxidizer and Flue gas cooler. Hence total 4,52,66,288.98 kCal/hr of available heat in flue gas is calculated with the help of equation (2.15). It is noticed that still more heat can be recovered by reducing flue gas outlet temperature. Reduction in flue gas outlet temperature by 15 ^{o}C has been recommended and if this recommendation is implemented, total 184.58 MT/annum of fuel can be saved and so Rs.31.69 Lacks can be saved in Flue gas cooler. It is also recommended to install gas turbine immediately in CO line and hence Rs.1,323 Lacks can be saved with payback period of 12.69 months.

In case of forced draft fan, it is noticed that any one fan can also handle the total flow rate requirement. Hence it is suggested to operate only one fan in fully rated capacity and another fan has to be in standby mode. Total 11,92,800 kWh of energy and so Rs. 62.6 Lacks can be saved by incorporating the modification suggested.

4.2 Future Scope

This energy audit has been carried out only in FCCU. Similarly Energy audit can be carried out in other units like CDU, VDU, VBU, DHDS, NHT-CCR and Captive power plant of Essar Oil Refinery. There are so many pumps, compressors, heat exchangers, fans, furnaces, steam distribution system and compressed air systems in all these units and hence there is a huge amount of scope for saving energy.

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Appendix A

Design details

A.1 Design details of Pumps

Following Table A.1 and Table A.2 show the design details of pumps.

A.2 Design details of Fans

Following Table A.3 shows design details of Fans

A.3 Design details of CO-Oxidizer and Flue gas cooler

Following Table A.4 and Table A.5 show the design details of CO-Oxidizer and Flue gas cooler.

Table A.1: Design Details of Pumps-Part(a)

Sr No.	**Equipment Tag No.**	**Design Pressure Difference, kg/cm^2**	**Density, kg/m^3**	**Design Flow rate, m^3/ hr**	**Design power consumption, kW**	**Design Efficiency, %**
1	34P-101 A	8.5	990	119	52	63
2	34P-102 S	5.97	965	8.4	9.3	46.5
3	34P-103 A	12	781	32	29	64
4	35P-101 S	14.8	729	84.8	58.8	68
5	35P-102 S	6.5	766.9	878.2	292.1	83
6	35P-103 A	9.4	728.5	236.6	94.7	78.5
7	35P-104 A	5.4	784.6	262.2	144.3	80
8	35P-104 S	5.4	784.6	262.2	144.3	80
9	35P-105 B	7.4	813.5	373.3	141.6	70
10	35P-105 S	7.4	813.5	373.3	141.6	70
11	35P-108 A	25.5	857.8	427.4	443.2	81
12	35P-109 A	5.7	718	57.6	16.7	64.5
13	35P-110 A	21.5	718	125.3	126.5	69
14	35P-110 S	21.5	718	125.3	126.5	69
15	35P-111 A	18.5	992.9	24.6	21.4	62
16	35P-113 A	13.2	636.4	10.5	6.7	59

Table A.2: Design Details of Pumps-Part(b)

Sr No.	**Equipment Tag No.**	**Design Pressure Difference, kg/cm^2**	**Density, kg/m^3**	**Design Flow rate, m^3/ hr**	**Design power consumption, kW**	**Design Efficiency, %**
17	35P-113 S	13.2	636.4	10.5	6.7	59
18	35P-115 A	6.5	691.1	201	67.1	76.5
19	35P-118 A	10.9	622.5	162.8	90.7	61
20	35P-118 S	10.9	622.5	162.8	90.7	61
21	35P-119 A	6.1	655.8	56.9	15.5	60.5
22	35P-120 A	4.6	1032.5	47.7	10.3	68.5
23	35P-121 S	2.25	975.5	26.1	2.8	64
24	35P-122 A	9.5	639.6	41.8	18.7	43
25	35P-122 S	9.5	639.6	41.8	18.7	43
26	35P-123 A	6.2	902.9	86.7	25.3	39
27	35P-128 A	9	518.5	72.7	32.3	69
28	35P-132 S	8.5	955	14	12.7	41
29	35P-136 S	3.5	857.8	521	64.3	68
30	35P-137 A	4.5	747	226	48.7	64.5
31	35P-138 A	10	729	43	36	43
32	35P-220	5.5	1032.5	41	10.3	68.5

Table A.3: Design details of Fans

Description	**34FD-103A**	**34FD-103S**
Design power, kW	450	450
FLC	49	49
Rated Power, hp	446	446
Volt	6600	6600
Rated speed, rpm	1460	1460
Total pressure, mmWC	1626	1626
Inlet air temperature, ^{o}C	38.9	38.9
Inlet capacity, m^3/min	880.48	880.48
Mass flow, kg/hr	57762	57762

Table A.4: Design details of CO-Oxidizer

Sr. no.	Description	Unit	Design value
1	Flue gas inlet temperature-CO Oxidizer	^oC	621
2	Flue gas flow rate-CO Oxidizer	m^3/hr	287865
3	Flue gas inlet pressure	kg/cm^2	0.22
4	Flue gas outlet pressure	kg/cm^2	0.155
5	Fuel gas(FG) supply quantity	kg/hr	1188
6	Flue gas outlet temperature	^oC	982

Table A.5: Design details of Flue gas Cooler

Sr. no.	Description	Unit	Design value
1	Flue gas flow rate-FGC	m^3/hr	287865
2	Flue gas flow rate-FGC	kg/hr	333923
3	Flue gas inlet temperature-FGC	^oC	882
4	Flue gas outlet temperature-FGC	^oC	291
5	Flue gas inlet Pressure-FGC	kg/cm^2	0.155
6	Flue gas outlet Pressure-FGC	kg/cm^2	0.091
7	Boiler feed water inlet temperature	^oC	216
8	Boiler feed water inlet pressure	kg/cm^2	41.3
9	Boiler feed water inlet flow rate	T/hr	113.7
10	Economizer outlet temperature	^oC	265
11	Saturated HP steam outlet temperature	^oC	251
12	Saturated HP steam outlet pressure	kg/cm^2	40.2
13	Saturated HP steam outlet flow rate	T/hr	36.95
14	Superheated HP steam outlet temperature	^oC	400
15	Superheated HP steam outlet pressure	kg/cm^2	39
16	Superheated HP steam outlet flow rate	T/hr	70.05
17	Saturated MP steam inlet temperature	^oC	199
18	Saturated MP steam inlet pressure	kg/cm^2	13.85
19	Saturated MP steam inlet flow rate	T/hr	19.95
20	Superheated MP steam outlet temperature	^oC	275
21	Superheated MP steam outlet pressure	kg/cm^2	13
22	Superheated MP steam outlet flow rate	T/hr	19.95

Appendix B

Actual performance details

B.1 Actual performance details of Pumps

Following Table B.1, Table B.2, Table B.3, Table B.4, Table B.5 and Table B.6 show the actual performance details of 32 numbers of Pumps.

B.2 Actual performance details of Un-Insulated Surfaces

Table B.7, Table B.8, Table B.9, Table B.10, Table B.11, and Table B.12 show the actual performance of un-insulated surfaces.

Table B.1: Actual Performance Details of Pumps-Part (a)

Equipment Tag No.	**34P-101 A**	**34P-102 S**	**34P-103 A**	**35P-101 S**	**35P-102 S**
Actual Pre. Diff., kg/cm^2	8	6.8	11	17.5	7
Actual Flow rate, m^3/ hr	90	8	32	57	685
Throttling, %	70/30	37	100	43	18
Actual power consumption, kW	37	5.8	18.3	42.89	182.62
Actual Efficiency, %	53.1	25.56	52.51	63.49	71.68
Power drwan by VFD, kW	16.00	5.01	18.3	13.02	86.66
Energy saved/hr(kWh)	20.99	0.79	0	29.86	95.96
Total Energy saved (kWh/annum)	176347.88	6633.83	0	250862	806029
Total savings, Rs.	925826.37	34827.6	0	1317026	4231651
Investment, Rs.	286000	51150	159500	323400	1606550
Payback period, Years	0.31	1.47	0	0.25	0.38
Payback period, months	3.71	17.62	0	2.95	4.56

Table B.2: Actual Performance Details of Pumps-Part (b)

Equipment Tag No.	**35P-103 A**	**35P-104 A**	**35P-104 S**	**35P-105 B**	**35P-105 S**
Actual Pre. Diff., kg/cm^2	8.4	4.75	5	7.5	7
Actual Flow rate, m^3/ hr	112	152	157	247	240
Throttling, %	33	60	60	98	98
Actual power consumption, kW	69.25	78.19	58.08	79.11	82.66
Actual Efficiency, %	37.08	25.21	36.89	63.92	55.49
Power drwan by VFD, kW	7.34564	15.2329	12.4689	22.9165	21.9662
Energy saved/hr(kWh)	61.9	62.96	45.61	56.19	60.69
Total Energy saved (kWh/annum)	519997	528839	383133	472025	509828
Total savings, Rs.	2729982	2776406	2011450	2478133	2676596
Investment, Rs.	520850	793650	793650	778800	778800
Payback period, Years	0.19	0.29	0.39	0.31	0.29
Payback period, months	2.29	3.43	4.73	3.77	3.49

Table B.3: Actual Performance Details of Pumps-Part (c)

Equipment Tag No.	**35P-108 A**	**35P-109 A**	**35P-110 A**	**35P-110 S**	**35P-111 A**
Actual Pre. Diff., kg/cm^2	25	4.5	29.4	22.3	18
Actual Flow rate, m^3/ hr	418.6	45.55	89	82	21.8
Throttling, %	60	51	51	51	70/30
Actual power consumption, kW	319.76	13	95.93	98.06	22.78
Actual Efficiency, %	89.35	43.04	74.47	50.91	47.01
Power drwan by VFD, kW	300.413	6.42896	34.3773	27.484	15.8532
Energy saved/hr(kWh)	19.35	6.57	61.55	70.58	6.93
Total Energy saved (kWh/annum)	162518	55196.7	517043	592838	58184.8
Total savings, Rs.	853217	289783	2714476	3112401	305470
Investment, Rs.	2437600	91850	695750	695750	117700
Payback period, Years	2.86	0.32	0.26	0.22	0.39
Payback period, months	34.28	3.8	3.08	2.68	4.62

Table B.4: Actual Performance Details of Pumps-Part (d)

Equipment Tag No.	**35P-113 A**	**35P-113 S**	**35P-115 A**	**35P-118 A**	**35P-118 S**
Actual Pre. Diff., kg/cm^2	11	12	5.5	11.5	11.75
Actual Flow rate, m^3/ hr	7.5	8.5	135	115	117
Throttling, %	53	53	30/60	65	65
Actual power consumption, KW	9.69	9.69	36.63	71.49	71.49
Actual Efficiency, %	23.23	28.72	55.33	50.5	52.5
Power drwan by VFD, kW	3.53134	5.14059	11.0981	25.1986	26.5363
Energy saved/hr(kWh)	6.16	4.55	25.53	46.29	44.95
Total Energy saved (kWh/annum)	51732.7	38215.1	214468	388848	377611
Total savings, Rs.	271597	200629	1125955	2041453	1982460
Investment, Rs.	36850	36850	369050	498850	498850
Payback period, Years	0.14	0.18	0.33	0.24	0.25
Payback period, months	1.63	2.2	3.93	2.93	3.02

Table B.5: Actual Performance Details of Pumps-Part (e)

Equipment Tag No.	**35P-119 A**	**35P-120 A**	**35P-121 S**	**35P-122 A**	**35P-122 S**	**35P-123 A**
Actual Pre. Diff., kg/cm^2	5	4.5	2	9.7	10.3	6.4
Actual Flow rate, m^3/ hr	47.7	34	12.9	28	29	30.5
Throttling, %	35	41	51	60	22	43
Actual power consumption, kW	19.21	8.26	3.17	30.38	24.57	22.34
Actual Efficiency, %	33.89	50.53	22.2	24.4	33.18	23.95
Power drwan by VFD, kW	11.3174	2.99131	0.38274	9.13131	8.20484	0.97258
Energy saved/hr(kWh)	7.89	5.27	2.79	21.25	16.37	21.37
Total Energy saved (kWh/annum)	66298.1	44257	23413	178489	137467	179486
Total savings, Rs.	348065	232349	122918	937067	721703	942303
Investment, Rs.	85250	56650	15400	102850	102850	139150
Payback period, Years	0.24	0.24	0.13	0.11	0.14	0.15
Payback period, months	2.94	2.93	1.5	1.32	1.71	1.77

Table B.6: Actual Performance Details of Pumps-Part (f)

Equipment Tag No.	**35P-128 A**	**35P-132 S**	**35P-136 S**	**35P-137 A**	**35P-138 A**	**35P-220**
Actual Pre. Diff., kg/cm^2	9	8	3	4	9.5	5
Actual Flow rate, m^3/ hr	78.5	12	405	164	30	34
Throttling, %	27	42.5	48	46	26	56
Actual power consumption, kW	34.4	10.81	55.85	35.74	24.57	7.81
Actual Efficiency, %	56.06	24.24	59.39	50.1	31.66	59.36
Power drwan by VFD, kW	29.4206	6.80746	26.2346	13.6572	8.34379	4.45386
Energy saved/hr(kWh)	4.98	4	29.62	22.08	16.23	3.36
Total Energy saved (kWh/annum)	41827.3	33621.3	248769	185496	136300	28191.6
Total savings, Rs.	219593	176512	1306037	973853	715576	148006
Investment, Rs.	177650	69850	353650	267850	198000	56650
Payback period, Years	0.81	0.4	0.27	0.28	0.28	0.38
Payback period, months	9.71	4.75	3.25	3.3	3.32	4.59

Table B.7: Actual Performance Details of Un-Insulated Surfaces Part (a)

Sr. no.	**Heat loss Description**	**Appr. area, m^2**	**Hot surface Temp, ^oC**	**Heat loss from surface, kW**	**Total savings, Rs**	**Investment**	**Payback period, month**
1	10” HP SH steam (2 nos. of flanges)	1.52	294	6.56	2,89,211.2	1,179.0	0.05
2	10” MP SH steam (3 nos. of flanges)	2.29	232	6.10	2,68,806.7	1,483.6	0.07
3	8” MP saturated steam (1 no. of flange)	0.61	214	1.38	60,842.4	322.5	0.06
4	10” HP SH steam (3 nos. of Valve flanges)	2.29	301	10.31	4,54,881.6	1,768.4	0.05
5	10” HP SH steam (1 no. of flange)	0.76	290	3.19	1,40,667.2	589.5	0.05
6	8” BFW (9 nos. of Valve flanges)	5.49	173	8.04	3,54,638.6	2,606.0	0.09
7	8” BFW (2 nos. of flanges)	1.22	170	1.72	76,026.1	579.1	0.09
8	10” MP SH steam (1 no. of flange)	0.76	225	1.91	84,203.7	494.9	0.07
9	8” MP saturated steam to FGC (1 no. of valve)	2.44	181	3.92	1,72,929.9	1,157.3	0.08
10	3” CBD line (2 nos. of valves+1.5m pipe length)	15.96	179	25.09	11,06,623.8	3,979.7	0.04
11	8” BFW (2 nos. of valves)	4.88	110	2.77	1,22,158.0	2,315.5	0.23

Table B.8: Actual Performance Details of Un-Insulated Surfaces Part (b)

Sr. no.	**Heat loss Description**	**Appr. area, m^2**	**Hot surface Temp, ^oC**	**Heat loss from surface, kW**	**Total savings, Rs**	**Investment**	**Payback period, month**
12	10” HP SH steam (1 no. of flange)	0.76	293	3.26	1,43,615.9	578.6	0.05
13	10” MP SH steam (1 no. of flange)	0.76	231	2.01	88,820.9	494.9	0.07
14	8” HP SH steam (2 nos. of flanges+0.5m pipe length)	13.78	296	60.13	26,51,637.4	8,837.8	0.04
15	4” MP SH steam (2 nos. of valves+1 no. of flange)	2.74	205	5.69	2,50,872.2	918.1	0.04
16	4” MP SH steam (3 nos. of valves+1 no. of flange)	3.96	206	8.30	3,65,979.3	1,326.2	0.04
17	8” MP SH steam (2 nos. of valve flanges+1 no. of flange)	1.83	189	3.21	1,41,698.2	867.4	0.07
18	6” MP SH steam (2 nos. of valves+1 no. of flange)	4.11	187	7.07	3,11,961.6	1,644.7	0.06
19	3” MP SH steam (6 nos. of valves+6m pipe length)	62.02	173	90.91	40,09,230.9	14,284.2	0.04
20	6” MP SH steam (6 nos. of valve flanges+1 no. of flange)	3.20	171	4.58	2,01,989.1	1,279.2	0.08
21	4” MP SH steam (1 no. of valve+ 1no. of flange)	1.52	174	2.26	99,683.5	472.3	0.06
22	6” MP SH steam (2 nos. of valve flanges)	0.91	171	1.31	57,711.2	110.3	0.02

Table B.9: Actual Performance Details of Un-Insulated Surfaces Part (c)

Sr. no.	**Heat loss Description**	**Appr. area, m^2**	**Hot surface Temp, ^{o}C**	**Heat loss from surface, kW**	**Total savings, Rs**	**Investment**	**Payback period, month**
23	3” MP SH steam (2 nos. of valves)	1.83	142	1.78	78,585.4	421.2	0.06
24	4” MP SH steam (1 no. of valve+ 2 nos. of flange)	1.83	181	2.94	1,29,697.4	566.7	0.05
25	8” MP SH steam (6 nos. of valve flanges)	3.66	156	4.33	1,91,043.9	1,734.8	0.11
26	3” MP SH steam (3 nos. of valves)	2.74	156	3.25	1,43,282.9	631.8	0.05
27	3” MP SH steam (3 nos. of valves)	2.74	131	2.26	99,580.7	631.8	0.08
28	10” MP SH steam (1 no. of flange)	0.76	185	1.28	56,513.9	447.4	0.10
29	10” HP SH steam (2 no. of flange)	1.52	246	4.58	2,01,786.5	989.8	0.06
30	6” HP saturated steam (3 nos. of valve flanges)	1.37	163	1.78	78,437.2	548.2	0.08
31	14” HP SH steam (3 nos. of valve flanges)	3.20	200	6.31	2,78,323.4	2,893.5	0.12
32	10” HP SH steam (2 nos. of valves)	6.10	201	12.14	5,35,556.9	3,959.4	0.09
33	14” HP SH steam (2 nos. of flanges)	2.13	176	3.24	1,42,868.9	1,542.4	0.13

Table B.10: Actual Performance Details of Un-Insulated Surfaces Part (d)

Sr. no.	**Heat loss Description**	**Appr. area, m^2**	**Hot surface Temp, ^{o}C**	**Heat loss from surface, kW**	**Total savings, Rs**	**Investment**	**Payback period, month**
34	10” HP SH steam (1 no. of valve)	3.05	178	4.74	2,08,883.7	1,789.8	0.10
35	18” HP SH steam (6 valve flanges)	8.23	278	31.63	13,95,085.1	8,536.6	0.07
36	3” HP SH steam (1 no. of valve)	0.91	226	2.31	1,01,957.8	247.0	0.03
37	8” MP SH steam (3 nos . of flanges)	1.83	179	2.87	1,26,777.9	867.4	0.08
38	10” HP SH steam (3 nos . of flanges)	2.29	195	4.28	1,88,796.8	1,484.8	0.09
39	3” MP SH steam (1 no. of valve)	0.91	165	1.22	53,622.2	210.6	0.05
40	3” MP SH steam (1 no. of valve0	0.91	169	1.28	56,332.1	210.6	0.04
41	6” MP SH steam (1 no. of valve)	1.83	156	2.17	95,522.0	731.0	0.09
42	6” MP SH steam (3 nos. of valve flanges)	1.37	198	2.65	1,16,862.0	654.1	0.07
43	3” MP SH steam (6 nos. of valves0	5.49	121	3.82	1,68,433.7	1,263.5	0.09
44	3” MP SH steam (6 nos. of valves)	5.49	119	3.69	1,62,578.5	1,263.5	0.09
45	3/4” steam line	1.47	126	1.12	49,243.2	205.7	0.05

Table B.11: Actual Performance Details of Un-Insulated Surfaces Part (e)

Sr. no.	**Heat loss Description**	**Appr. area, m^2**	**Hot surface Temp, ^{o}C**	**Heat loss from surface, kW**	**Total savings, Rs**	**Investment**	**Payback period, month**
46	3/4" steam line	0.88	236	2.44	1,07,540.2	123.41	0.01
47	1 1/2" steam line	0.88	109	0.49	21,697.7	172.26	0.10
48	3/4" steam line	2.06	114	1.26	55,741.4	287.96	0.06
49	3/4" steam line	1.76	128	1.39	61,086.4	246.82	0.05
50	3/4" steam line	2.35	132	1.97	86,892.4	329.10	0.05
51	3/4" steam line	2.94	143	2.91	1,28,399.7	411.37	0.04
52	3/4" steam line	3.23	140	3.06	1,35,133.0	452.51	0.04
53	1 1/2" steam line	1.17	103	0.58	25,595.5	229.69	0.11
54	3/4" steam line	3.23	128	2.54	1,11,991.8	452.51	0.05
55	3/4" steam line	2.94	136	2.62	1,15,627.9	411.37	0.04
56	3/4" steam line	1.17	107	0.63	27,797.9	164.55	0.07
57	3/4" steam line	1.17	166	1.59	69,937.7	164.55	0.03
58	3/4" steam line	0.88	237	2.46	1,08,465.5	123.41	0.01
59	3/4" steam line	1.17	112	0.70	30,667.9	164.55	0.06
60	3/4" steam line	1.17	101	0.56	24,525.5	164.55	0.08

Table B.12: Actual Performance Details of Un-Insulated Surfaces Part (f)

Sr. no.	**Heat loss Description**	**Appr. area, m^2**	**Hot surface Temp, ^{o}C**	**Heat loss from surface, kW**	**Total savings, Rs**	**Investment**	**Payback period, month**
61	3/4" steam line	2.94	135	2.58	1,13,855.3	411.37	0.04
62	3/4" steam line	4.12	151	4.56	2,01,285.4	575.92	0.03
63	3/4" steam line	0.88	107	0.47	20,848.4	123.41	0.07
64	3/4" steam line	1.76	101	0.83	36,788.2	246.82	0.08
65	3/4" steam line	1.47	115	0.92	40,565.2	205.69	0.06
66	3/4" steam line	2.35	122	1.67	73,594.6	329.10	0.05
67	1 1/2" steam line	1.47	97	0.64	28,059.6	287.11	0.12
68	3/4" steam line	1.17	154	1.36	59,902.1	164.55	0.03
69	3/4" steam line	0.88	131	0.73	32,068.4	123.41	0.05
70	3/4" steam line	0.88	89	0.32	13,906.1	123.41	0.11
71	3/4" steam line	4.12	113	2.48	1,09,401.1	575.92	0.06
72	3/4" steam line	0.58	136	0.52	23,125.6	82.27	0.04
73	3/4" steam line	2.06	134	1.78	78,467.0	287.96	0.04
74	3/4" steam line	2.06	135	1.81	79,698.7	287.96	0.04
			Total	**411.26**	**1,81,36,629**		