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ENERGY PERFORMANCE ASSESSMENT OF STEAM DISTRIBUTION SYSTEM AND HEAT RECOVERY SYSTEM IN FLUID CATALYTIC CRACKING UNIT OF AN OIL REFINERY

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ABSTRACT

This paper presents energy performance assessment of steam distribution system and heat recovery system in Fluid catalytic cracking unit of an oil refinery to save thermal energy and cost at the end in terms of money. The leakages and failure of steam traps are the main problems noted in steam distribution system. It has been found that there are three types of steams, high pressure steam, medium pressure steam and low pressure steam, used depending on their pressure and around 602.95, 1199.87 and 508.15 MT/annum of steam loss have been found. In addition, there is a great loss of exhaust gases in CO-oxidizer at high temperature has been observed and therefore, Rs.1323 lacks/annum can be saved with payback period of around 12 months by installing gas turbine in CO gas line.

KEYWORDS– Energy audit, Energy conservation and saving, Energy performance assessment, Heat recovery, Insulation system, Steam system

NOMENCLATURE

ΔT	Temperature difference, ^{o}C
CO	Carbon Monoxide
Cp	Specific heat, k Cal/kg ^{o}C
FCCU	Fluid Catalytic Cracking Unit
FSA	Flash Steam Available
HP	High Pressure

L_2	Latent heat of flash steam at lower pressure).
LP	Low Pressure
MP	Medium Pressure
PL	Plume length
Q_{Heat}	Total heat available in flue gas, kCal/hr
Q_{leak}	Quantity of steam leaked, kg/hr
S_1	Sensible heat of higher pressure condensate
S_2	Sensible heat of the steam at lower pressure
TPH	Tons per hour
V_{Flow}	Flow rate, m^3/hr
ρ	Density of fluid, kg/m^3

1. INTRODUCTION

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 [1]. India accounts for 4.5% of industrial energy use worldwide [2]. 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% [2].

A considerable amount of energy, in a refinery, is utilized 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 [3].

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 [4], 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 [4].

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 [5]. Such steam traps are to be replaced to avoid loss of live steam which conserves a lot of energy.

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 indicates that about 4.4 MW of electricity may be generated which leads to energy conservation of 42.88 MWh/year [7]. 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 [7]. This can save fuel consumption and energy efficiency of the unit increases by 5%.

The main aim of this paper is to save energy in steam distribution system, heat recovery system and insulation system. There are three different type of steams, high pressure (HP) steam (37.42 kg/cm^2), medium pressure (MP) steam (12.5 kg/cm^2) and low pressure steam (4 kg/cm^2), depending upon pressure variation. A steam leak survey of all these three types of steam has been carried out and total 16 numbers of HP steam traps, 18 numbers of MP steam traps and 7 numbers of LP steam traps have been found with leakages in it. Moreover, tremendous amount of heat energy can be recovered in CO-oxidizer unit of an FCCU.

2. ENERGY PERFORMANCE ASSESSMENT METHODOLOGY IN STEAM DISTRIBUTION SYSTEM

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 [8].

2.1.1 PERFORMANCE OF STEAM DISTRIBUTION SYSTEM

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

- Steam traps
- Heat loss from un-insulated surface

(a) 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 [8].

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

- Is the trap working correctly or not?
- 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 trap is concerned:

(a) 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 program 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 [9]. The following equation (1) can be used to assess the approximate quantity of steam leak.

$$Q_{Leak} = 2.5678 \times EXP(1.845 \times PL) \qquad (1)$$

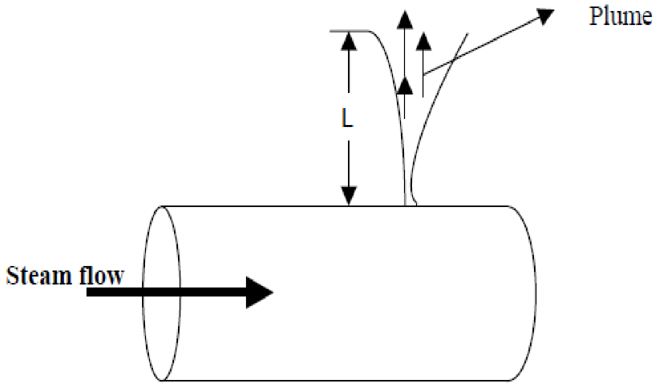

Figure 1: Plume length (L) of leaking steam

Figure 1 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.

(b) 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 [8].

(c) 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:

- If steam blows out continuously in a blue stream, it is a leaking steam.
- If a steam floats out intermittently in a whitish cloud, it is a flash steam [8].

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) with the help of a steam table:

$$FSA = \frac{S_1 - S_2}{L_2} \qquad (2)$$

3. ENERGY PERFORMANCE ASSESSMENT METHODOLOGY IN 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 [10]. 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.

3.1. 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 utilized for steam production for three reasons:

- To recover the heat available in flue gases
- To convert CO into CO_2 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 CO_2. These equipments are not only boilers but also incinerators where residence time at high temperature is the key factor for the proper CO oxidation.

3.2 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 utilized 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 22°C reduction in temperature of flue gas)

3.3 ARRANGEMENT OF CO-OXIDIZER AND FLUE GAS COOLER IN FCCU

Figure 2 shows the detail arrangement of CO-oxidizer and Flue gas cooler used in FCCU.

3.4 CALCULATION OF TOTAL QUANTITY OF RECOVERABLE HEAT

The total heat recoverable at final exhaust temperature can be calculated by equation (3).

$$Q_{Heat} = V_{flow} \times \rho \times C_P \times \Delta T \qquad (3)$$

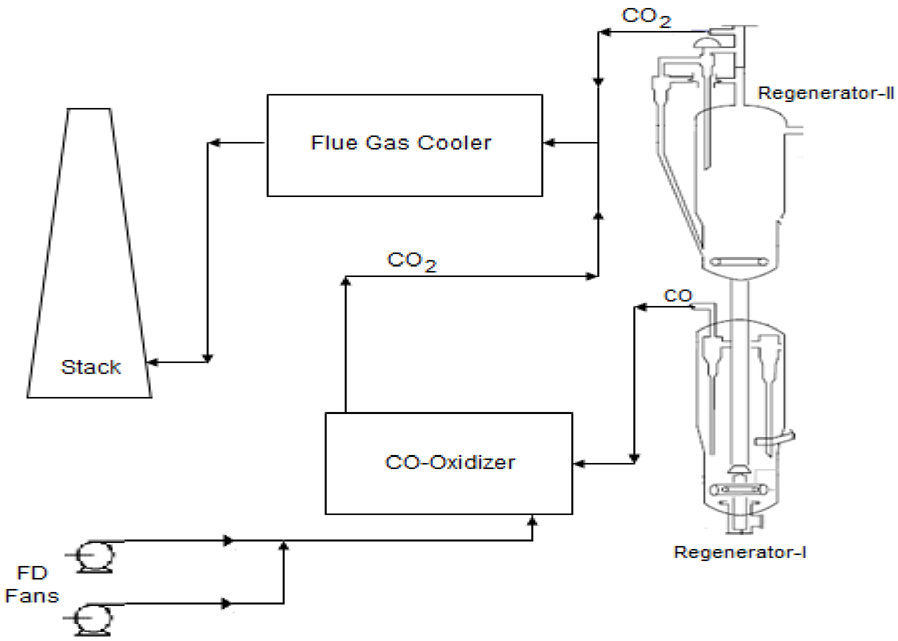

Figure 2: Arrangement of CO-Oxidizer and Flue gas cooler

4. RESULTS AND DISCUSSION

4.1 ACTUAL PERFORMANCE DETAILS 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:

- HP steam pressure (37.42 kg/cm^2)
- MP steam pressure (12.5 kg/cm^2)
- LP steam pressure (4 kg/cm^2)

4.1.1 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 1, Table 2 and Table 3 show the steam leaks quantity, total saving in Rs. and payback period of HP steam, MP steam and LP steam respectively. Figure 3, Figure 4 and Figure 5 show the steam leaks quantity, total saving in Rs. and Payback period, months of HP steam respectively, in form of charts. Figure 6, Figure 7 and Figure 8 show the steam leaks quantity, total saving in Rs. and Payback period, months of MP steam respectively, in form of charts. Figure 9, Figure 10 and Figure 11 show the steam leaks quantity, total saving in Rs. and Payback period, months of LP steam respectively, in form of charts.

Table 1: 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**	

Table 2: 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: 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**	

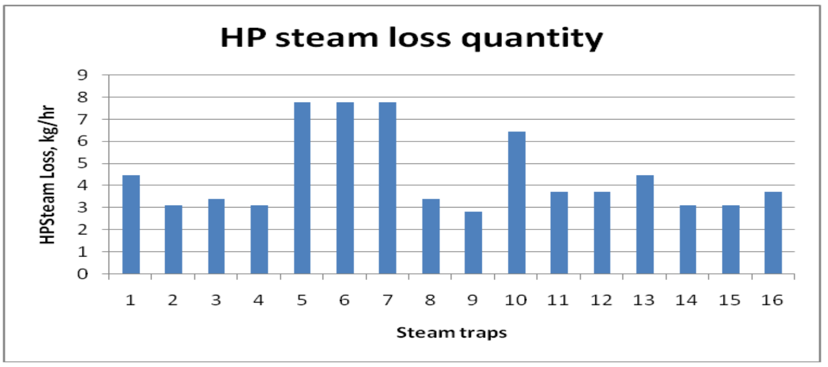

Figure 3: HP Steam Loss Quantity

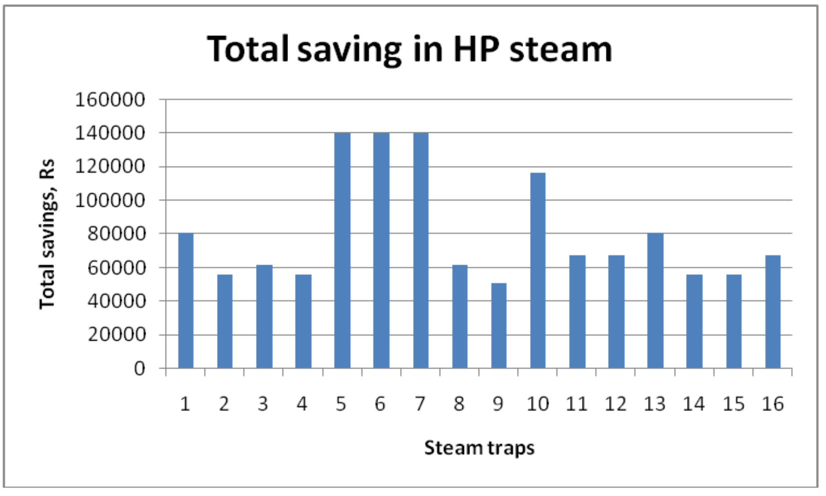

Figure 4: Total Saving in HP Steam

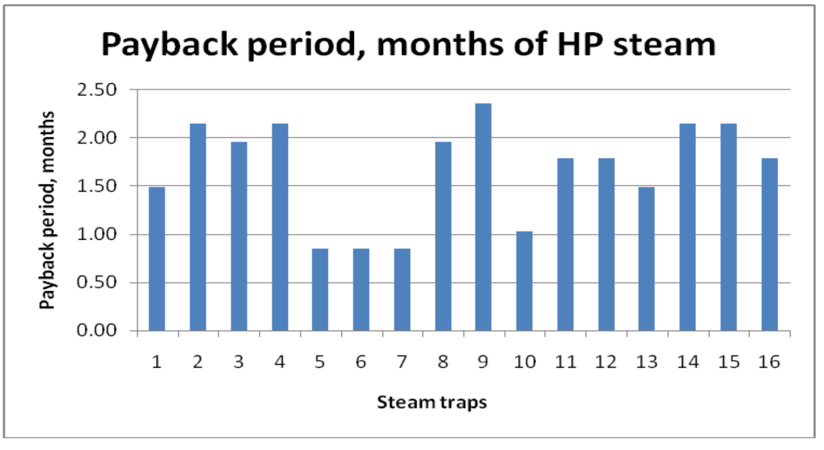

Figure 5: Payback Period of HP Steam

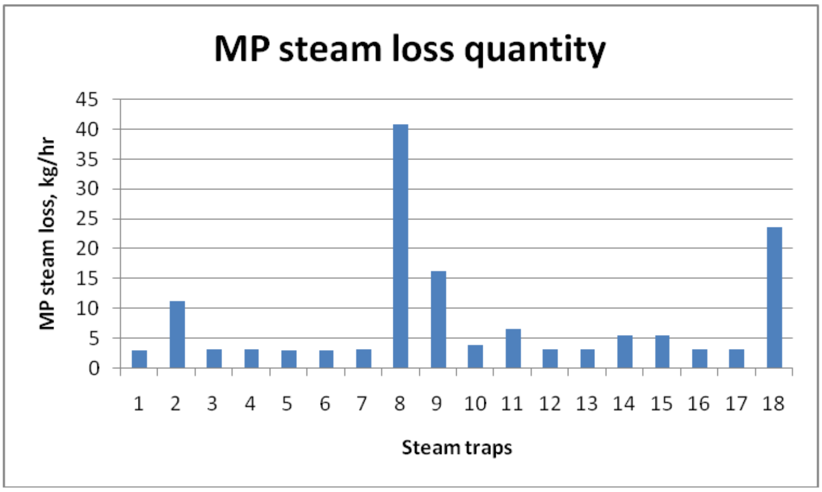

Figure 6: MP Steam Loss Quantity

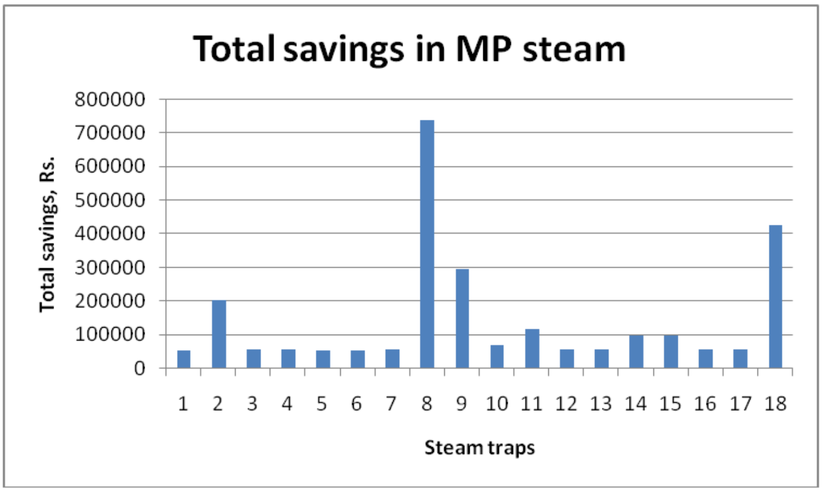

Figure 7: Total Saving in MP Steam

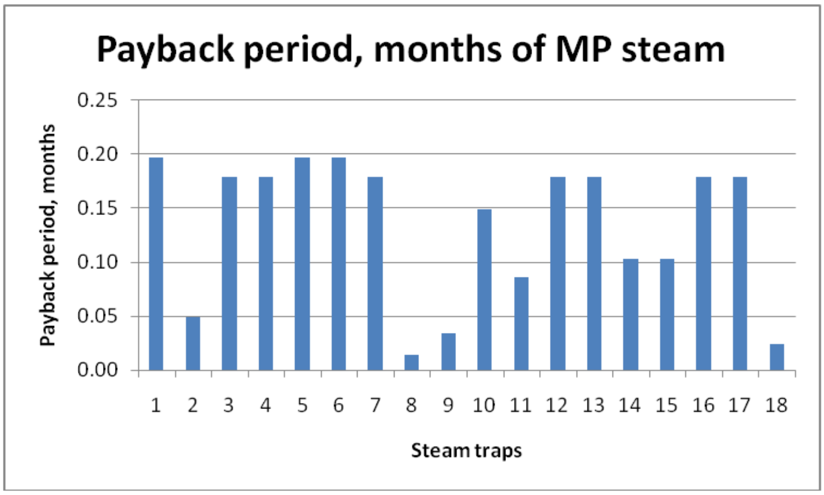

Figure 8: Payback Period of MP Steam

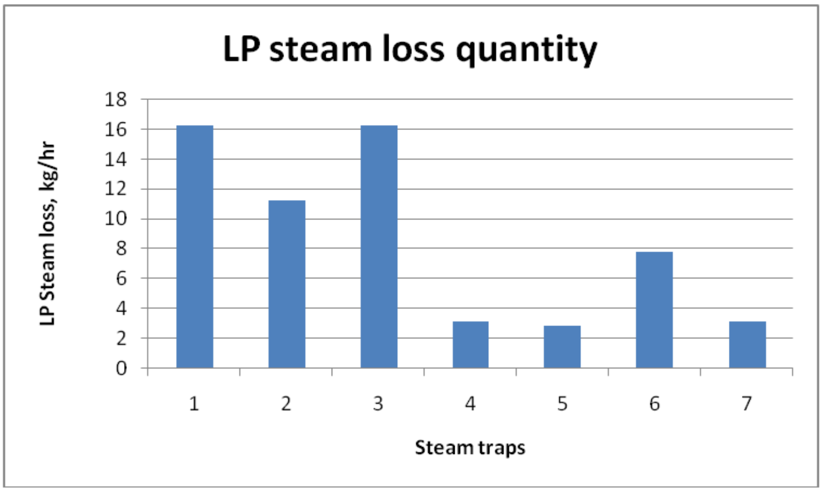

Figure 9: LP Steam Loss Quantity

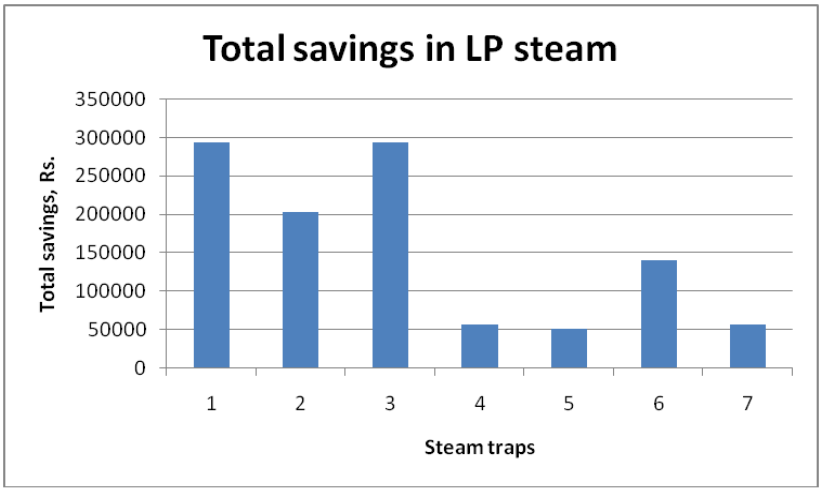

Figure 10: Total Saving in LP Steam

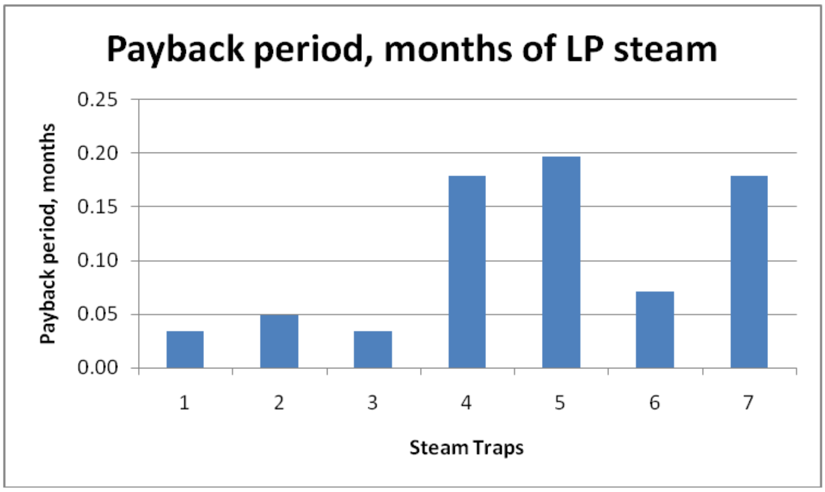

Figure 11: Payback Period of LP Steam

Steam loss quantity shown in Figure 3, Figure 6 and Figure 9 found due to failure of steam traps in Open condition. Payback period was calculated by taking steam trap cost as Rs.10, 000. Figure 5, Figure 8 and Figure 11 presents 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 4 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.

Table 4: 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

4.2 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 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 5. Performance details of Flue gas cooler are given in Table 6 Total available heat in flue gas has been calculated by equation (4) So total available heat in flue gas,

$$Q_{Heat} = 216287.9 \times 1.16 \times 0.31 \times (895 - 313) = 45266288.98 \text{ kCal/hr} \quad (4)$$

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 895oC and 313oC respectively and hence total 45266288.98 kCal/hr of available heat in flue gas is calculated from Table 5 and Table 6. 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.

Table 5: 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 6: 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

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 624.9oC and 2.06kg/cm2. Then CO gas passes through the orifice chamber and is sent into the CO oxidizer at 0.7 kg/cm2, which burns the CO gas and flue gas sent out of the CO oxidizer at 910oC. The energy in CO gas exhausted at 2 kg/cm2 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 7 below.

Table 7: 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 7 shows proposed total savings per annum, investment and payback period. It is recommended to install gas turbine and so Rs.1323 lacks can be saved.

5. CONCLUSION

Energy conservation is prime important for any of the plant. Energy can be conserved in FCCU by routine check-up of plant equipments, proper operation and maintenance work of the plant. Following recommendations should be implemented for saving huge amount of energy in steam distribution and heat recovery system.

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.

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 45266288.98 kCal/hr of available heat in flue gas is calculated with the help of equation (4). 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.1323 Lacks can be saved with payback period of 12.69 months.

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