Design and Function of Condensate Heat Recovery System

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Abstract: Energy is an important material basis for human survival and development, per capita consumption of energy, the composition of energy, usage of energy is often used as a measure of the degree of modernization of a country. With the development of society and industry, the worldwide energy crisis has become urgent, the relationship between human life and death big problem.. Experts estimate that, if you do not change the current energy consumption structure and speed, not the development of new energy, after 200 to 300 years ago, all the energy in the world will be depleted. Thus, effective energy conservation has become one of the core research of global energy issues.

During our time spent in the industry, we came across such a problem.

In this research, I have included all the information regarding the Condensate Heat Recovery System which was created by us during our final year college project, which recycles the heat that is being sent to the waste reservoir and thereby increases the overall efficiency of the boiler.

It not only increases the profit of the organization but also decreases the thermal pollution and thus the system is eco-friendly.

Keywords: Condensate, Steam, Heat, Eco-friendly, Waste, Water

I. INTRODUCTION

Nowadays, usage of energy is at its peak by the industries. In the meantime we took one small initiate to reduce the amount of energy used by a particular industry. We include all the calculations and observation tables to depict an idea about the system which we have designed. Condensate Heat Recovery is a system in which the waste steam pipes are connected so that the wastage of energy shall be reduced by connecting that system to the Boiler. The temperature and the amount of steam energy which was wasted is mentioned in this research paper. Efficiency before the installation and after installation is figured. Designed model including evaluation with Economic analysis are shown further. In this paper, we have also discussed the basic boiler system and how the heat from it is being utilized in process heating. A boiler is an enclosed vessel that provides a means for combustion and transfers heat to water until it becomes hot water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment and should be treated carefully. Liquid when heated up to the gaseous state this process is called evaporation. The heating surface is any part of the boiler; hot gases of combustion are on one side and water on the other. Any part of the boiler metal that contributes to making steam is heating surface. The amount of heating surface of a boiler is expressed in square meters. The larger the heating surface a boiler has, the more efficient it becomes.

II. DEVELOPMENT OF CONDENSATE RECOVERY SYSTEM

In this chapter, we have discussed the components & materials & their specification required to increase the efficiency of the Fire-tube boiler. We have also shown the circuit system & arrangement of the main components on the cycle in the best possible way.

A. Fire Tube Boiler

In a fire tube boiler, there are six main parts. They are 1) Burner 2) Combustion space 3) Convection section 4) Stack 5) Air fans 6) Controls and accessories

1) *Wet Back Designs:* Have a water wall at the back of the boiler in the area where combustion gases reverse direction to enter tubes.
2) *Dry Back Designs:* The Refractory is used at the back, instead of a water wall. Internal maintenance is simplified, but refractory replacement is expensive, and overheating, gauging, and cracking of tube ends at the entrance to return gas passages often cause problems.
3) *Advantages*

Lower initial cost

a) Few controls
b) Simple operation
4) *Disadvantages*

Drums exposed to heat, increasing the risk of explosion

a) Large water volume, resulting in poor circulation
b) Limited steam pressure and evaporation

B. What is Condensate?

Condensate is the liquid formed when steam passes from the vapor to the liquid state. In a heating process, condensate is the result of steam transferring a portion of its heat energy, known as latent heat, to the product, line, or equipment being heated.
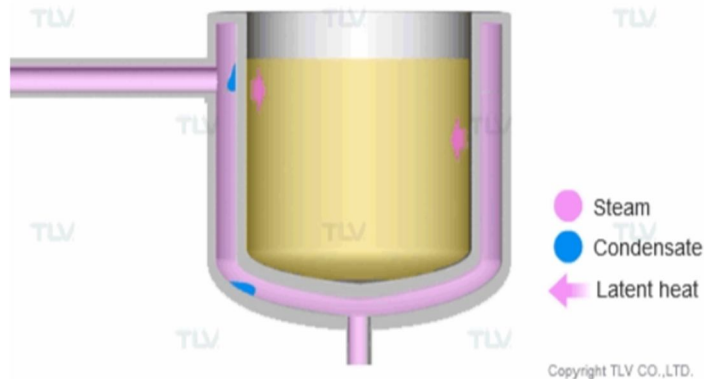
C. Latent Heat vs. Sensible Heat

In steam-using industries, Latent Heat refers to the energy required to transform water into steam, also known as the Enthalpy or Heat of Vaporization. By absorbing this Latent Heat, water becomes steam, and by releasing it, steam reverts to high-temperature water (condensate). When steam condenses, at the threshold or instant of phase change, the condensate temperature is the same as steam because only the latent heat has been lost, and the full amount of sensible heat remains. This condition is known as "Saturated Water". Not wasting, but rather recovering and reusing as much of this sensible heat as possible is one of the main reasons behind condensate recovery.
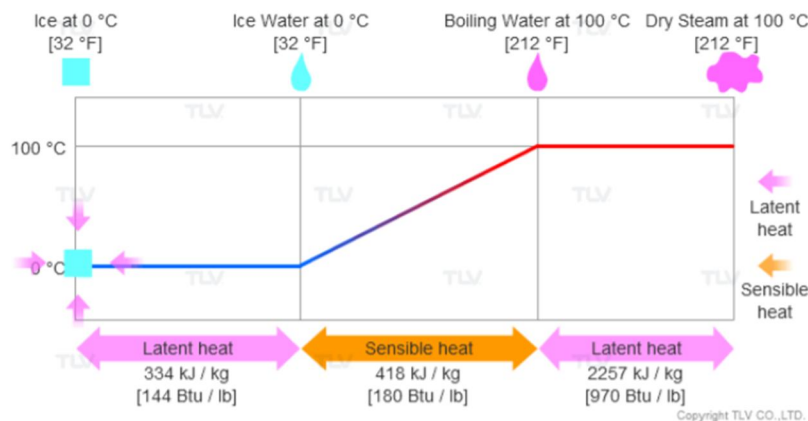
D. What is Condensate Recovery?

If 1 t/h of steam is supplied to equipment for a heating process, then the same amount of condensate (1 t/h) needs to be discharged from the equipment. Condensate recovery is a process to reuse the water and sensible heat contained in the discharged condensate. Recovering condensate instead of throwing it away can lead to significant savings of energy, chemical treatment, and make-up water.

Condensate can be reused in many different ways, for example:

1) As heated feedwater, by sending hot condensate back to the boiler's deaerator
2) As pre-heat, for any applicable heating system
3) As steam, by reusing flash steam
4) As hot water, for cleaning equipment or other cleaning application

E. The Benefits of Condensate Recovery

Reusing hot condensate can lead to considerable savings in terms of energy and water resources, as well as improve working conditions and reduce your plant's carbon footprint.

1) *Reduced Fuel Costs:* Condensate contains a significant amount of sensible heat that can account for about 10% to 30% of the initial heat energy contained in the steam. Feeding the boiler with high-temperature condensate can maximize boiler output because less heat energy is required to turn water into steam. When efficiently recovered and reused, it can even be possible to reduce boiler fuel needs by up to 10 to 20%.
2) *Lower Water-related Expenses:* As long as any impurities picked up during condensate transport are removed, condensate can be reused as boiler feed water, reducing water supply and treatment costs, as well as costs associated with cold water used to lower condensate temperatures before sewering, where applicable.
3) *Positive Impact on Safety and the Environment:* Reducing boiler fuel needs through condensate recovery leads to less air pollution by lowering CO_2, NOx, and SOx emissions. Additionally, condensate recovery lines can also limit vapor clouds to reduce noise generated from atmospheric condensate discharge and help prevent the build-up of water on the ground, considerably improving a plant's work environment. Depending on the amount of condensate being recovered and reused, other benefits may include a reduced need for boiler blowdown through better feedwater quality, and less corrosion in the system as water quality becomes more consistent throughout the grid.

F. Fire Tube Boiler Specification

The fire tube boiler which was the subject of our interest and research had the following specifications:

SR. NO.	PARAMETERS	VALUE
1	Manufacturer	Energy pack
2	Year of Installation	2010
3	Capacity	1000 kg/hr
4	Design pressure	10.54 kg/cm2
5	Operating pressure	6-6.5 kg/cm2
6	Fuel used	Natural gas
7	Fuel consumption/day	Average 300-350 sm3/day
8	Stack temperature	120-150 Deg C
9	Boiler feed water temp.	55-60 Deg C
10	Boiler operating hours	24 hours
11	Burner firing hours/day	12-13 hours
12	Peak steam load	Depend on production demand
13	Price of fuel	35 per sm
14	Working days in a month	25-30 days

Table 2.6.

G.   Log Book Readings Taken

The readings that were taken by our team members   during our period in the Surya Life Science Ltd. are:

SR. NO.	PARAMETERS	DAY 1	DAY 2	DAY 3
1.	Fuel gas at boiler inlet [kg/cm^2]	0.16	0.16	0.16
2.	Fuel gas temp at economizer [Celsius]	189	187	186
3.	Feedwater pump 1 Outlet pressure [kg/cm^2]	5	5.5	5
4.	Steam pressure [kg/cm^2]	6.5	6.5	5.5
5.	Steam flow in	-	-	-
6.	Water tank level	-	-	-
7.	Blowdown min	-	-	-
8.	Soft water ppm	<5	<5	<5
9.	Chemical charging	-	-	-
10.	Water meter reading [KL]	4465.20	4465.20	4466.24

Table 2.7.

III.   RESULT ANALYSIS

We were told to calculate the total cost of running the boiler. The different types of energy are given as input and come out as output.

1)   Input Energy
a)   Electricity reading (GEB)
b)   Gas reading (LPG)
c)   Water meter reading / Water cost

2)   Energy Transferred
a)   Sensible heating
b)   Latent heat transfer

3)   Things That Can Be Done To Improvise The Efficiency Of Boiler
a)   Proper insulation
b)   Air preheater / Gas preheater
c)   Superheating
d)   Proper care to be taken regarding blowdown
e)   Corrosion
f)   Vibration control

A.   Methods To Calculate The Efficiency Of The Boiler

There are two types of efficiencies:

1)   Combustion Efficiency: Combustion efficiency is the effectiveness of the boiler to burn the fuel.
2)   Thermal Efficiency: Thermal efficiency is the effectiveness of the heat exchanger to transfer the heat from the fireside to the waterside of the boiler.
3)   Indirect Efficiency: Indirect efficiency is the efficiency which is obtained by subtracting a different kind of losses such as friction losses, blowdown losses from the total efficiency (100%).
4)   Direct Efficiency: Direct efficiency is obtained by using this formula given below

$$E = \left[\frac{Q(H-h)}{q*GCV} \right] * 100$$

Where,

Q=quantity of steam generated [kg/hr] H=enthalpy of steam [Kcal/kg]

h=enthalpy of water [Kcal/kg]

GCV=Gross Calorific Value

q=fuel firing rate

Another method of calculating the efficiency of the boiler is as follows:

a) *Input Data*

- Boiler pressure
- Temp of feed water
- Feed water rate
- Calorific value of fuel (low vale)
- Fuel consumption
- Maximum rated feed water flow rate

$$\eta = \frac{(m_{fw} - m_b)(h_w + 0.98 \, \triangle H - h_{fw})}{m_{fl} * H_f}$$

Where,

m_b = Boiler blow down rate (Kg/hr)

m_{fw} = Feed water rate (Kg/hr)

H_f = C.V. of fuel (KJ/kg)

m_{fl} = Fuel consumption (Kg/hr)

$m_{fw\,max}$ =Maximum rated feed water rate(Kg/hr)

η = Boiler efficiency LF = Load factor

ΔH = Latent heat of steam (KJ/kg)

h_w =Specific enthalpy of saturated water (KJ/kg) h_{fw} = Specific enthalpy of feed water (KJ/kg)

B. *Calculation*

1) *Given Data*

Ambient temperature = 36⁰C

Steam temperature = 174 ⁰C

Quantity of steam = 1 TPH = 1*103 kg/hr

Enthalpy of steam = 2773.6 kJ/kg

Enthalpy of feed water = 2565.3 kJ/kg

Stack temperature = 174 – 36 = 138⁰C

GCV = 35-40 MJ/m^3

= 35000 kJ/m^3 – 40000 kJ/m^3 = 37000 kJ/m^3

= 8809.523 kCal/m^3 = 11452.3799 kCal/kg

Fuel Firing Rate: Reading at 11:15 am

= 477231.2 m^3

Reading at 11:45 am = 477239.7 m^3

Density = 1.3 kg/m^3

Fuel firing rate=477239.7–477231.2 = 8.5 m^3 (in half hour)

= 17 m^3 (in 1 hour)

We know,

Density = Mass/Volume

1.3 = Mass/17 m^3

Mass = 17*1.3 = 22.1 kg per hr = 0.0221 TPH

$$\eta = \frac{Steam\ flow\ rate(Steam\ Enthalpy - Feed\ water\ enthalpy)}{Fuel\ firing\ rate * GCV}$$

$$= \frac{1TPH * \frac{1000kg}{T}(2773.6 - 2563.3)}{0.0221TPH * 1000\frac{kg}{T} * \frac{11452.32kCal}{kg}} \times 100 = 210.3 * 100/253.09$$

Efficiency = 83.09 %

C. Observation

The steam from the boiler was carried to the reactor at high pressure and high temperature. After the utilization of this heat, the outlets from the reactors carried the condensate to the heat sink where the condensate was left to the atmosphere.

The readings of these outlets were taken so we can get an idea about how much heat we can utilize in a given time.

The distance from the boiler to the reactors is **116m**. The distance from the reactors to the outlet pipe end is **30m**. The readings are as follows:

	D1	D2 (10,11,13)	D3(5,6)
Time	17 min 30 sec	4 min 12 sec	4 min 30 sec
Outlet temperature	94ºC	93ºC	97ºC
Inlet temperature	37.5ºC	37.5ºC	37.5ºC
Mass flow rate	17.15 kg/hr	71.6 kg/hr	60 kg/hr

Table 3.3.

The condensate came from the reactors (which are heat consuming devices). These reactors are numbered according to the algorithm of the company as R1, R5, R6, R10, R11, R13.

According to the steam table,

h_f = 697 kJ/kg

h_{fg} = 2064 kJ/kg

Dryness fraction = (h_{total} -h_f)/h_{fg}

h_{total} = total enthalphy content in steam

Pressure = 7 kg/cm^2

Temp = 165ºC

h_{total} = 2761 kJ/kg

The Dryness fraction of the steam is 0.6225

m = V/v = 250/0.88 = 284.09 kg/min

= 4.755 kg/s

Q = m (h1-h2) = 4.75 x (70.6 – 38)

= 160.98 kJ/s

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D. Calculation After Installation

As per the previous calculations, the efficiency calculation of the ideal system without any adjustments was 83.09%. Now, we will calculate the efficiency of the system after the installation of the condensate recovery system.

Ambient temperature = 36⁰C

Steam temperature = 174⁰C

Quantity of steam = 1 TPH = 1000 kg/hr

Feed water temperature = 47⁰C (increased)

Enthalpy of feed water at 36⁰C = 150.9 kJ/kg = 36.065 kCal/kg

Enthalpy of feed water at 47⁰C = 196.8 kJ/kg = 47.035 kCal/kg

Enthalpy of steam = 2773.6 kJ/kg = 662 kCal/kg

GCV of CNG = 52300 kJ/kg = 12500 kCal/kg

New efficiency,

$$\eta = \frac{Steam\ flow\ rate(Steam\ Enthalpy - Feed\ water\ enthalpy)}{Fuel\ firing\ rate*GCV}$$

$$= \frac{1000*(662.34-47.035)*100}{54*12500}$$

$$= 91.156\ \%$$

It should be noted that there will be convective and radiative losses in the pipes. These losses can be calculated with the help of the formula:

1) Heat Loss Due To Radiation & Convection

$$H_L = 0.548 * \left(\left[\frac{T_s}{55.55}\right]^4 - \left[\frac{T_g}{55.55}\right]^4\right) + 1.957 * (T_s - T_g)^{1.25} * \sqrt{\frac{68.9+196.85Vm}{68.9}}$$

where , T_s = pipe surface temp (⁰C)

V_m = velocity of wind (m/s)

$$H_L = 0.548 * \left(\left[\frac{47}{55.55}\right]^4 - \left[\frac{35}{55.55}\right]^4\right) + 1.957 * (47-35)^{1.25} * \sqrt{\frac{68.9+196.85*4.2}{68.9}}$$

$$= 0.19446 + 157.59$$

$$= 157.786\ kCal/kg$$

But we know that 12.500 = 100% heat input and 157.786 heat loss will be,

$$= \frac{157.786*100}{12500} = 1.26\ \%\ heat\ loss$$

Therefore, actual efficiency will be,

Actual efficiency = 91.156% - heat loss

$$= 91.156 - 1.26$$

$$= 89.8\ \%$$

Efficiency = 89.8 %

Increased efficiency after installation of system = New efficiency – Old efficiency

= 89.896% – 83.5%

= 6.396%

IV. MODEL

To implement the idea of our Industrial defined problem, our team members along with some help from the engineering staff of the company, have designed the condensate recovery system which is one step forward towards putting the idea into implementation.

As per the previous, the three different outlets when combined give out 148.75kg/hr. The inlet of the boiler is 1TPH, i.e. 1000kh/hr. So, we aim to connect the outlet to the inlet of the boiler so that the heat required to obtain a certain temperature is reduced and the water cost of 148.75kg per hour is reduced too. As a result, the cost required to treat the raw water in the water treatment plant is reduced as well. The condensate storing tank is a rectangular tank with a capacity of 2.162944 cubic meter which roughly translates to 2163 liters.

This storage capacity is enough to store the desired quantity of fluid. The components of the system include 1. Rectangular tank 2. Manhole 3. Strainers 4. Steam Globe valve 5. Control panel 6. Flow switch 7. Vertical high-pressure pump 8. Lifting hook 9. Standby vertical high-pressure pump 10. Flow switch 11. Level switch 12. Nozzles 13. Inlet ports 14. Outlet ports 15. Flanges 16. Pipes 17. Flange coupling.

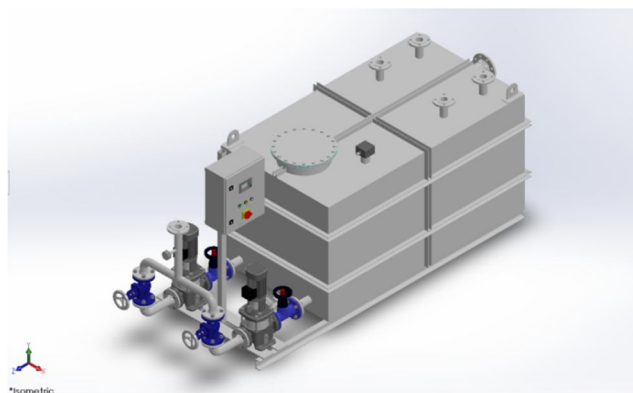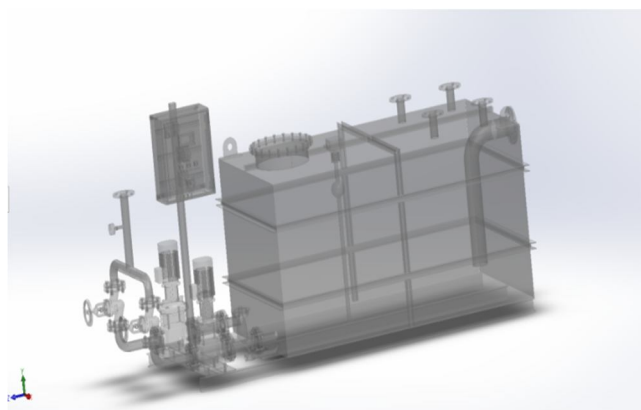The following model has been prepared in Solidworks 2018 by Dassault Systems.

Fig 4.1 Isometric view

Fig 4.2 Transparent view.
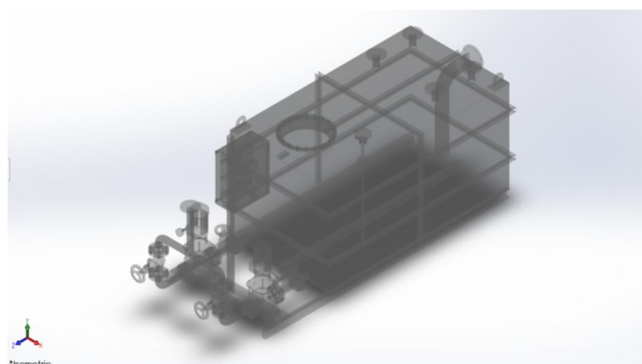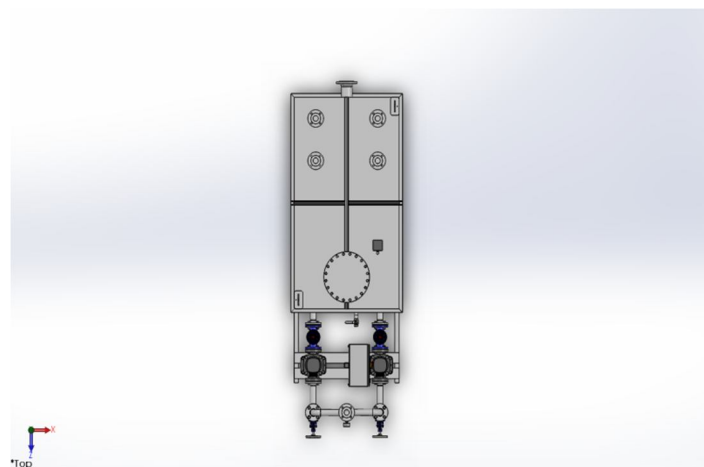

Fig 4.3 Transparent view.
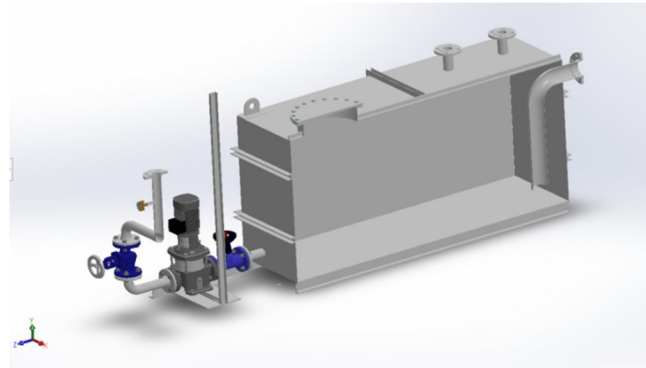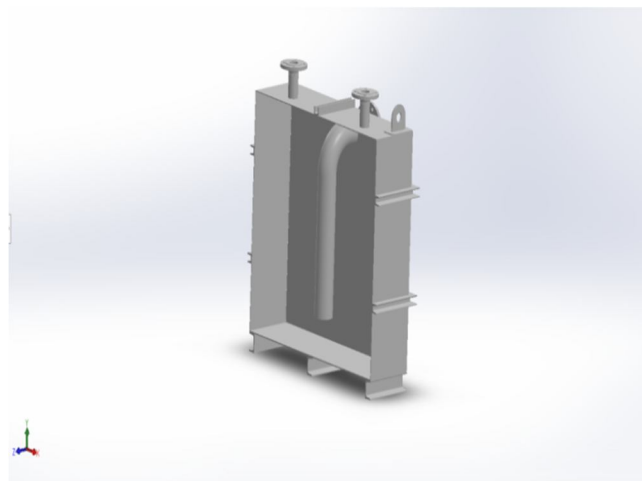
Fig 4.4 Sectional view.

Fig 4.5 Sectional view.
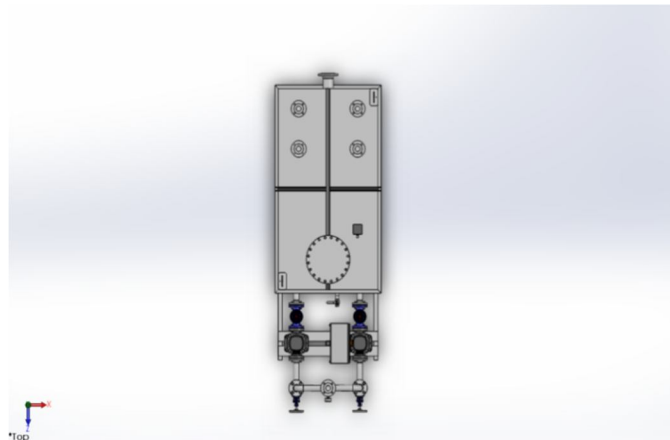

Fig 4.5 Sectional view.
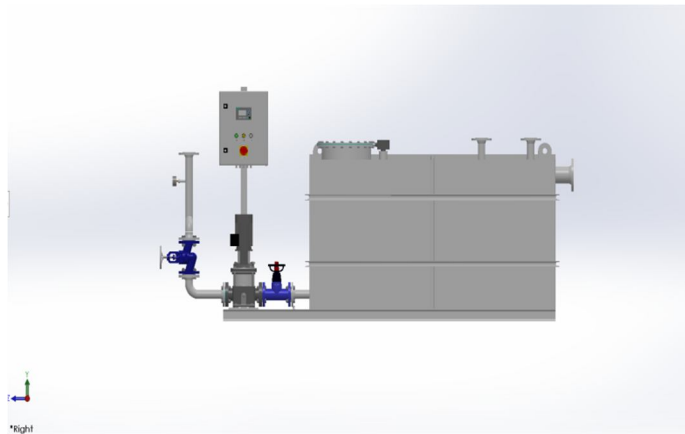
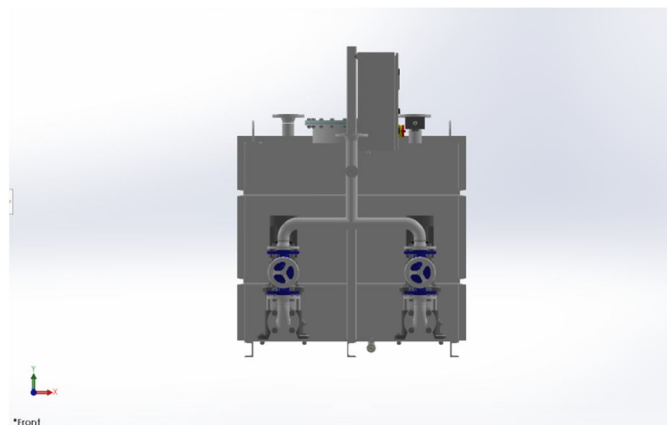Fig 4.6 Top view.

Fig 4.7 Right-hand side view

Fig 4.8 Front view.

V. ECONOMIC ANALYSIS

Economic analysis is the study of economic systems. It may also be a study of a production process or an industry. The analysis aims to determine how effectively the economy or something within it is operating. For example, an economic analysis of a company focuses mainly on how much profit it is making. In our industrial defined problem, we are concerned about recovery costs. Cost recovery, defined as the method of recovering an expenditure which a business takes on, is both a specific and general term. Generally, cost recovery is simply recovering the costs of any given expense. This can be the initial startup costs of the business by meeting and exceeding the break-even point, the cost of investment through evaluating the return on investment, or even the cost of capital taken to finance the firm. Specifically, the cost recovery method of accounting gains back the cost of investment by relying on the certified depreciation schedule of the item. Cost recovery explained simply as regaining the value of an expense, is an important concept for accountants and company founders alike. Each of these parties is interested in cost recovery solutions.

A. Calculation Of Economic Analysis

1) The Heat Required To Increase The Temperature Of 1 Kg Of Feed Water

$Q = mC_PT$

$= 1 \times 4.19 \times (96 - 37)$

$= 247.21$ kJ/kg

where 4.19 is C_P of water

T= wastewater temperature - feedwater temperature

Now, our boiler work approximately 20 hours per day and 300 hours per year.

Therefore, 20 x 300 = 6000 hr/year

2) Saved Water Calculation

Water is sold in volume. We know that the density of water equals to 1000 kg/m^3

The total amount of water required per year in our industry is

= 6000 x1000 / 1000

= 6000-meter cube per year

= 6000 kilolitres per year

But after installation of the system, we can save approximately 148.75 kg/hr water

Therefore, we save 148.75 x 6000 = 892500 kg of water per year

= 892.5 kilo liter per year

Cost of water per kilolitres in industry is ₹37

Therefore our total saving on water = 892.5 x 37

                         = ₹33022

3) Fuel Calculation

Our industry uses 60 scm fuel per hour

Therefore per year use 60 x 6000 = 36000scm/year

And price of fuel is 60 scm = ₹33

Therefore, 33 x 36000 = ₹198000/year

But after installation of system,

New fuel consumption is 55scm/hr (Approx)

Therefore per year use = 55 x 6000 = 330000 scm/year

Price of fuel = 33 X 6000 x 55 = ₹181500 /year

Total amount saving on fuel

= Old price -New price = 198000 - 181500

= ₹16500 / year

4) Overall Savings Per Year

Overall savings per year= Fuel saving + Water cost saving

= 16500 + 33022 = ₹49522 /year

Which means ₹4127 /year

Our total system installation price is approximately

= ₹9000 + ₹25000 + ₹1000 x 2 + ₹40000 – ₹60000

= ₹136000

Our Payback

= 136000/4127

= 32.954

= 33 months (approx.)

VI. CONCLUSION

During our period in the industry for Industrial Development Problem (IDP), our approach became more and more specific day by day. We finally decided to work on the condensate recovery system.

We measured almost all the parameters affecting the heat utilization and also measured and analyzed parameters which led to heat loss. The current system installed in our industry is an open system so the condensate gets contaminated by external factors.

Therefore, our team members along with some help from the engineering staff of the company, have managed to design the condensate recovery system. The model has been designed and needs further consideration to implement the non-conventional renewable sources of energy for heat generation. Our model will not only maximize profits of the industry but will also reduce water and thermal pollution which is the current call of an hour!

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