IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY

VOLUME : 4 ISSUE : 07 Print / Issue Publication Date: 07-Jan-2020

ISSN : 2455-2143

DOI : 10.33564/IJEAST.2019.v04i07.039

Indexed In

International Journal of Engineering Applied Sciences and Technology, 2019
Vol. 4, Issue 7, ISSN No. 2455-2143, Pages 233-235
Published Online November 2019 in IJEAST (http://www.ijeast.com)

HEAT RECOVERY FROM THE EXHAUST FLUE GASES OF NON-OX FURNACE

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Abstract- This is the industrial project based on the recovery of heat from exhaust flue gases. Exhaust flue gases from non-ox furnace at Continuous Galvalume line in JSW Steel Coated Products Ltd as observed leaves the furnace at 200°C and is effluated to atmosphere through chimney.

The advantage of recovering heat from flue gases of a propane fired non-ox furnace aiming to trap heat from enthalpy of flue gases released to the chimney at 200 degrees centigrade and proposes to accommodate the trapped heat to heat the air used in hot air dryer from ambient to 80 degrees centigrade, existing heat exchanger uses steam to elevate the temperature of air by regulating the mass flow rate of the flue gases. In this improvement technique the task is to heat ambient air using heat of flue gases averagely leaving the furnace at 200 degrees centigrade. The exhaust blower blows flue gases to heat exchanger at 55000m3/hr replacing steam in the existing heat exchanger using flue gases to use its enthalpy to better use. Existing system uses steam to increase the temperature of air, by cutting the supply of steam with exhaust flue gases we are able to use non-ox furnace to its fullest capacity. The proposed improvement eliminates the plants dependence on Coal and indirectly diminishes daily water consumption.

Key words: Galvalume, Heat Recovery, Heat Exchanger, Hot Air Drye

I. INTRODUCTION

Galvalume process is carried out to protect the steel and iron product from the atmospheric conditions. During this process hot air is required which is prepared by making use of steam. We intend to use heat available from chimney to preheat the air used in the Hot Air dryer in the GAL plant.

1.1 Problem Statement

As observed the exhaust flue gas from Non-Ox furnace has the significant enthalpy that released to atmosphere through chimney. It was identified that a source of heat is being wasted.

1.2 Problem Objective

Following are the objectives of the project:

- Existing system uses steam to increase the temperature of air, by cutting the supply of steam with exhaust flue gases we are able to use non-ox furnace to its fullest capacity.
- The proposed improvement eliminates the plants dependence on Coal and indirectly diminishes daily water consumption.
- Reduced cost of acquiring Coal.

1.3 Research Objective

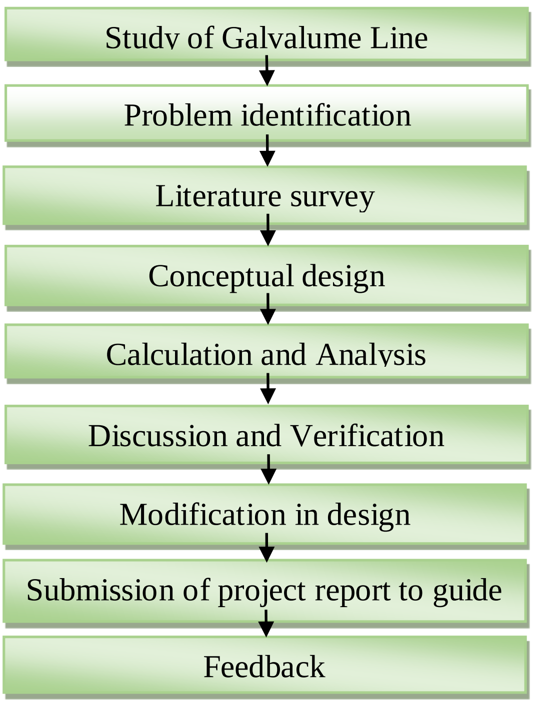
This thesis proposes whole idea regarding the project HEAT RECOVERY FROM EXHAUST FLUE GASES OF NON-OX FURNACE. Our aim is to put necessary details about the project in front of the readers. It gives the information about necessary component, their contribution in the project etc. Also the thesis provides work we have done for making this project a unique one.

II. WORKDONE

2.1 Overview

Aim of the project is to replace maximum amount of steam going to heat Exchanger of Hot Air Dryer for heating of atmospheric air by the Exhaust flue gases coming from the furnace. In designing and validation of this change we have gone through a process which will be explained in this chapter. This chapter comprises of the discussions about the designing, calculation and discussion of various facts and figure. It will also include the drafting of CAD models and the mathematical calculations done in designing the system for recovery of heat from exhaust gas. Designing process and methods used will also be discussed along with the specifications of components used.

2.2 Plan of Work



III. DESIGN CALCULATION

Phase 1

Project has two main task in which 1st task is to supply exhaust gas from Exhaust blower of non-ox furnace to the heat exchanger of hot air dryer while 2nd task is to check for the suitability of exhaust gas in heat exchanger by checking its effectiveness. Total distance between the Exhaust blower and Heat exchanger is about 30m. So it was a big task to design a system for minimum heat loss so that more amount of temperature can be available at the inlet of heat exchanger.

Design Parameter

- **Exhaust Blower**
  Capacity: $55000m^3/hr$
  Power: 52.11kw
  Pressure: 1.01325bar
  Fan speed: 1104rpm
  Fan efficiency: 84.5%
  Duct size: 762mm*609mm
- **Exhaust Gas**
  Content: CO_2 (maximum percentage), Air, N_2, CO
  Temperature: Max 300ºC to Min 150ºC
  Calculation Temperature: 250ºC
  Density of CO_2: $1.05kg/m^3$
  Mass flow rate: 16kg/s

Calculations for Pipe

Considerations: 1) Taking 15inch of pipe for supplying exhaust gas
2) Material of pipe taken as Mild Steel
3) Conductivity of MS found as 53w/mk
4) Convective heat transfer taken as $8w/m^2k$
5) Available temperature 250ºC

∴ Total Heat loss in pipe without Insulation is as follow,

Q_{loss} = Heat loss by radiation + Heat loss by convection

$$= \{\sigma*\varepsilon*A*(T_{max}^4-T_s^4)\}+\{h*A*(t_{max}-t_s)\}$$
$$= \{5.67*10^{-8}*0.25*(\pi*0.393*30)*(523^4-303^4)\} + \{8*(\pi*0.393*30*(250-36)\}$$
$$= 99000W$$

- **With insulation Heat loss**

We have made iteration for deciding thickness of insulation over pipe associated heat loss

Assumptions:

1) Taking glass wool as Insulating material

2) Conductivity 0.0372w/mk

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Table 1 Iteration for the thickness of insulation

Heat loss (Kw)	Thickness of insulation (mm)
50	2.4
20	4
5	4.27
2	7
1	12
0.5	22.5

- **Temperature available at inlet of heat exchanger**

Heat available at exhaust blower
Q = Mh*Cph*(Th1-Th2)
= 16*995*(250-100)
= 2289000W

Taking 7mm of insulation by glass wool on the pipe
Hence total heat loss for 30m pipe comes to 60KW
After subtracting this heat loss from available heat total 2229000W of heat remains
∴ 2229000=16*995*(Th1-100)
Th1=240^{o}C
Hence after applying insulation of glass wool we getting 240^{o}C of temperature at the inlet of heat exchanger.
If insulation thickness raise it can also lead to decrease in heat loss at certain value.
∴ Hence finalizing the parameters of delivery pipe
Inlet diameter: 381mm
Outlet diameter: 393mm
Insulation thickness: 7mm (can be alter if required)
Material of pipe: Mild Steel
Thermal Conductivity of pipe: 51w/mk

- **Costing of insulation**

$\therefore V_1-V_2= (\pi*r_o^2*h)-(\pi*r_i^2*h)$
$= (\pi*0.203^2*30)-(\pi*0.1965^2*30)$
$= 0.24473m^3$
Density of MS: 16Kg/m^3
∴ Total weight of pipe= 0.24473*16
=3.91kg
∴ Total price= 3.91*33= Rs129

- **Cost of Pipe**

$\therefore V_1-V_2= (\pi*r_o^2*h)-(\pi*r_i^2*h)$
$= (\pi*0.1965^2*30)-(\pi*0.1905^2*30)$
$= 0.218843m^3$
Density of MS: 8055Kg/m^3
∴ Total weight of pipe= 8055*0.21884
=1762kg
∴ Total price= 1762*83= Rs146308

From above costing it is found that as per the thickness of material and price available for the material in the current market it get vary.

Phase 2

In this phase work is done to check for the effectiveness of heat ex-changer by using NTU method and the same value is compared with another formula to calculate the outlet temperature of exhaust gas from heat ex-changer. For obtaining the values various assumption have made.

Design Parameter

- **Hot air dryer Blower**

Capacity: 42000m^3/hr
Power: 36kw
Pressure: 1.01325bar
Fan speed: 1500rpm
Fan efficiency: 84.5%
Duct size: 609mm*457mm
Mass flow rate of air: 13.42kg/s

- **Heat Exchanger**

Type: Cross flow single pass vertical type finned heat exchanger
Tube ID: 25.4mm
Tube OD: 30.7mm
Thickness: 2.65mm
Tube Material: SA-179 Gr Seamless
Length: 1170mm
Number of tubes: 20
Length: 1m
Distance between two tubes: 55mm
Thermal conductivity of tube: 51.9 w/m^2k

Calculation for Heat Ex-changer

- **Heat required to raise temperature of atmospheric air from 30^{o}C to 80^{o}C**

$$\therefore Q= \dot{m}*C_p*\Delta T$$

Let, air is present at 30^{o}C and C_P of air is 1005 J/kg.k

Q=13.42*1005*(80-30)

∴ Q=674.355KW

Total 674.355kw heat will be required to raise the temperature of air from 30^{o}C to 80^{o}C

- **Calculating overall heat transfer coefficient (U)**

Calculating for Overall heat transfer coefficient (U) for Heat Exchanger When saturated Steam is used as a hot fluid

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Steam at a pressure of $2.5kg/cm^2$ and 126^oC temperature enters into heat exchanger and leave at 118^oC

By using formula,

$\therefore$ Q= U*A_s*LMTD

Where,

LMTD: 61.66^oC

A_S: $1.5959m^3$

Q: 674.355kw

$\therefore$ 674355=U*1.5959*61.66

$\therefore$ U=6859.40w/m^2k

From here it is clear that Overall heat transfer for this heat exchanger is 6859.40w/m^2k.

- **Checking Heat Exchanger Effectiveness by Number of Transfer unit (NTU) Method using Exhaust Gas as a Hot fluid**

$$\therefore \; NTU = U * \frac{As}{Cmin}$$

Here, C_{min} is a minimum fluid capacity rate amongst the Hot fluid and cold fluid
$\dot{m}_h*C_{ph}$=16*1005= 16080w/k
$\dot{m}_c*C_{pc}$=13.42*1005=13487.1w/k
From above it is clear that fluid capacity rate for cold fluid is less than the hot fluid

$\dot{m}_c*C_{pc}< \dot{m}_h*C_{ph}$
$\therefore$ C_{min}=13487.1w/k

$$\therefore NTU = 6859 * \frac{1.5959}{13487.1}$$

$\therefore$NTU = 0.81161
As cross flow heat exchanger is used,
$\varepsilon =1-e^{-NTU(1-C)}/1-C*e^{-NTU(1-C)}$

where, $C = \frac{Cmin}{Cmax}$

$\therefore C = \frac{13487.1}{16080}$

$\therefore$ C=0.8387
$\varepsilon =1-e^{-0.81161*(1-0.8387)}/1-0.8387*e^{-0.81161*(1-0.8387)}$

ε = 0.4644
Now, as we know that

$$\varepsilon = \frac{\text{Actual heat transfer}}{\text{Maximum possible heat transfer}}$$

$\therefore$ $Q_{actual}= \dot{m}_h*C_{ph}*(t_{h1}-t_{h2})= \dot{m}_c*C_{pc}*(t_{c2}-t_{c1})$
$\therefore$ $Q_{actual} =\dot{m}_c*C_{pc}*(t_{c2}-t_{c1})$
=13.42*1005*(80-30)
=674355W
$\therefore Q_{max} =C_{min}*(t_{h1}- t_{c1})$
=13487.1*(250-30)
=2967162W

$\therefore \varepsilon = \frac{Qactual}{Qmax}$

$\therefore 0.4644 = \frac{\dot{m}h*Cph*(th1-th2)}{2967162}$

$\therefore 0.4644 = \frac{16*995*(250-th2)}{2967162}$

$\therefore$ $t_{h2}=163.44^oC$.

$\therefore 0.4644 = \frac{\dot{m}c*Cpc*(tc2-tc1)}{2967162}$

$\therefore 0.4644 = \frac{13.42*1005*(tc2-30)}{2967162}$

$\therefore t_{c2}=132.16^oC$

From above calculation it is cleared that outlet temperature of the exhaust gas is 163.

Observation table

Table no.3.2: Variation in outlet temperature according to changing Inlet temperature of exhaust gas

Sr. No.	Mass flow rate ($\dot{m}_h$)	Inlet temperature (t_{h1})	Effectiveness (ε)	Max heat transfer (Qmax)	Actual heat transfer (Qactual)	Outlet temperature of hot fluid (t_{h2})	Outlet temperature of Cold fluid (t_{c2})
1.	16	250	0.4644	2967162	1377950	163.44	132.16
2.	16	225	0.4644	2629984.5	1221364	148.28	120.55
3.	16	200	0.4644	2292807	1064779	133.11	108.94
4.	16	175	0.4644	1955629.5	908194	117.95	97.33
5.	16	150	0.4644	1618452	751609	102	85.72
6.	16	125	0.4644	1281274.	595023	87.62	74.11

In above table we have calculated the Outlet temperature of both Exhaust fluid and Atmospheric air when 16kg/s of mass flow rate given at various Inlet temperature. Manipulating mass flow rate of Exhaust gas to get outlet temperature of Atmospheric air as 80ºC$\dot{m}_h * C_{ph} * (t_{h1}-t_{h2}) = \dot{m}_c * C_{pc} * (t_{c2}-t_{c1})$

When,
$t_{h1}=250^oC$ $t_{h2}= 163.44^oC$ $t_{c2}=80^OC$
$t_{c1}=30^oC$
$\dot{m}_c=13.42$kg/s
∴ $\dot{m}_h*995*(250-163.44)=13.42*1005*(80-30)$
∴ $\dot{m}_h=7.82$Kg/g

Table no.3.3: Iteration for mass flow rate of Exhaust gas

Sr. no.	Inlet temperature (t_{h1})	Outlet temperature (t_{h2})	Mass flow rate of exhaust gas ($\dot{m}_h$)
1.	250	163.44	7.82
2.	225	148.28	8.83
3.	200	133.11	10.13
4.	175	117.95	11.87
5.	150	102	14.11
6.	125	87.62	18.13

As we got the various mass flow rate of exhaust gas depending on their available Inlet temperature so we can use a flow control valve before the inlet of the heat exchanger so that we can control the flow.

Cost associated with the steam being used as a hot fluid source in heat exchanger

- **Heat required for producing 1kg steam**

Assumption:
1) For making 1kg of steam taking 1kg of water
2) Let water be at room temperature
3) Taking no loss of heat in heating the water from 20ºC to its boiling point and then converting water from 100ºC to steam at 100ºC.

∴ Heat required to heat 1gm of water by 1ºC is 1 calorie
∴ Heat required to heat 1000gm of water,
$Q_1=1000*1*(100-20)$
$Q_1=80000$ Calorie
Now, each gram of water at 100ºC requires 540 Calorie of heat to convert to steam at 100ºC
∴ Heat required to change 1000gm of water at 100ºC to steam at 100ºC
$Q_2= 1000*540$
$Q_2= 540000$ Calorie
∴ Net Heat required to produce 1kg of water to 1kg of steam,
∴$Q = 80000+540000$
∴$Q = 620000$ Calorie

- **Capacity of boiler section**

Capacity: 10000kg/hr
Per day coal consumption: 30000kg
Coal used: Bituminous Grade 7
Calorific value: 4500 to 5000 Kcal/kg

Operating cycle: 24hrs

Cost of coal: Average Rs7/kg
∴ In 1kg of coal 8kg of steam can be produced.
As about 22.6kg/s of steam were in use so we can see that per day 81360kg/hr of steam is used by hot air dryer
Hence associated cost for producing 542kg of steam 10170kg of coal required
∴ Total Rs 469 required per day

IV. CAD MODELLING

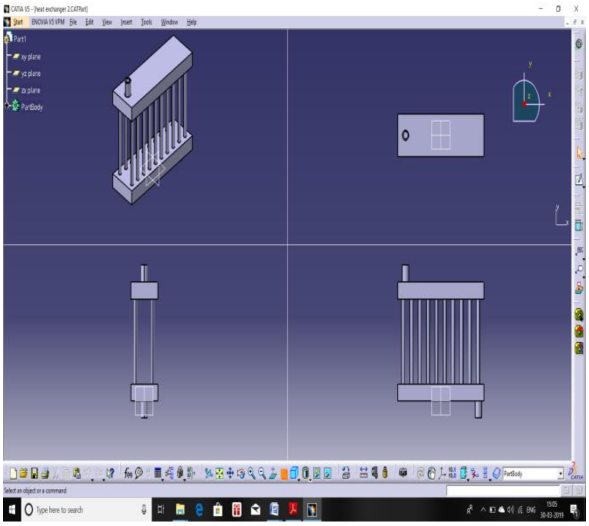

Fig3.1 CAD model of Heat exchanger

The 3D model depicts actual view of heat exchanger, the actual heat transfer area needs to be calculated accurately for which the cross flow heat exchanger has to be designed. Also number of tubes has to be decided on what amount of the heat is to be convected through convective heat transfer mod.

V. RESULT

After calculating for various factors we found that,

- Finalized diameter of pipe as 381mm made up of Mild Steel with a thermal conductivity of 50w/mk
- Heat loss through pipe can be vary according to thickness of insulation. (Refer Table 3.1)
- Using glass wool with thermal conductivity of 0.0372w/mk
- Total 674355W of heat required by the air to raise its temperature to 80ºC
- Overall heat transfer for this heat exchanger is 6859.40w/m^{2}k.
- Effectiveness for the heat exchanger came as 0.4644 which became the base for further calculations.
- When 16kg/s of exhaust flue gases supplied at 250ºC the outlet temperature of Air reaches to 132ºC
- Table no.3.1 give the iterative value for the various available inlet temperature
- Table no3.2 gives the variation in mass flow rate of exhaust gas that to be made for getting 80ºC of air in outlet.

VI. CONCLUSION

From the result and discussion above we draw following conclusion on the Heat recovery from the exhaust flue gases.

- By this project work we have made efficient use of recovering heat before exhausting to atmosphere
- Replacement of steam will lead to saving of cost associated with steam generation
- It will reduce the effect of harmful gases on the atmosphere due to burning of coal
- This will save more water and cost associated with storage and maintenance form water requirement.
- It will reduce the handling cost of steam and labour requirement.

VII. FUTURE SCOPE

- Material for exhaust gas delivery pipe can also be taken as Stainless Steel as its thermal conductivity is very low but cost is high.
- Better insulating method for pipe can be used.
- New heat exchanger suitable for exhaust gas can be used.
  - Exhaust gas leaving the heat exchanger can be used for other works such as heating in rinsing tank.
  - Hot air dryer can be made to work on electric heater.

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