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Utilization of waste heat from condensate water by heat exchanger

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Abstract-In present scenario, the energy crisis is the major problem faced by all the industries. The Cogeneration plant has two multi fuel boiler produces 170 Tonnes per hour of steam at a pressure of 86 kg/sq.cm at a temperature of 510˚C. The steam is used to produce electric power and the exhaust steam is being supplied to sugar plant to boil the sugarcane milk. The return condensate from sugar plant has temperature of 85˚C. It is being cooled by spray pond. In this project, the forced draught air is preheated by flue gas in air preheater. The preheated air is sent to boiler. In this project an attempt has been made to utilize the waste heat by a cross flow heat exchanger. By considering these design parameters namely outlet temperature of condensate, Inlet temperature of air, Mass flow rate of water & air. Finally, the potential savings are presented by implement the newly designed cross flow heat exchanger. In cross flow heat exchanger, the hot water flows inside the tube and the air flows over the tube. In turns there is a scope for reduction in fuel consumption.

Keywords: Cogeneration, spray pond, heat exchanger, potential savings, fuel consumption

I. INTRODUCTION

The co-generation boiler of 170 Tonnes per hour of steam, at the pressure of 87 kg/sq.cm at the temperature of 510±5°C. The fuel is coal cum bagasse.

In the existing circuit, forced draught (FD) air is sent through a rectangular duct to air-preheater (APH) unit where FD air is preheated using a fuel gas exhausted. The typical layout of the cogeneration power plant duct system between the air preheater (APH) and forced draught fan. The configuration shows that the inlet and exit of the duct is connected with an elbow. The FD fan inlet duct having rectangular cross section and is made up of galvanized steel. This is connected between the air-preheater and forced draught fan. The power consumption of the fan is 90KW and the mass flow rate through the fan is 41.47 kg/s.

1.1. COGENERATION PLANT

Cogeneration is simultaneous generation of electric and thermal energy from a single fuel source. Such a plant utilizes the waste heat from the prime mover in HRSG (heat recovery steam generator) sometimes called heat recovery boiler.

- Reduced energy bills
- Additional profit from selling surplus electricity
- Additional profit from selling GHG certified emission reduced (CER)
- Additional profit from selling by products (such as ash etc.)
- Increasing security of energy supply

II. LITERATURE REVIEW

2.1. COGENERATION POWER STATION

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which either drives an electrical generator or does some other work, like ship propulsion. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated. The greatest variation in the design of thermal power stations is due to the different fuel sources. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency. Power plants burning coal, oil, or natural gas are often referred to collectively as fossil-fuel power plants.

In some industrial, large institutional facilities, or other populated areas, there are combined heat and power (CHP) plants, often called cogeneration plants, which produce both power and heat for facility or district heating or industrial applications. AC electrical power can be stepped up to very high voltages for long distance transmission with minimal loss of power. Steam and hot water lose energy when piped over substantial distance, so carrying heat energy by steam or hot water is often only worthwhile within a local area or facility, such as steam distribution for a ship or industrial facility or hot water distribution in a local municipality.

2.2. CLASSIFICATION OF HEAT EXCHANGER

The Classifications of Heat Exchangers are

- Parallel-flow exchanger
- Counter-flow exchanger
- Cross-flow exchanger

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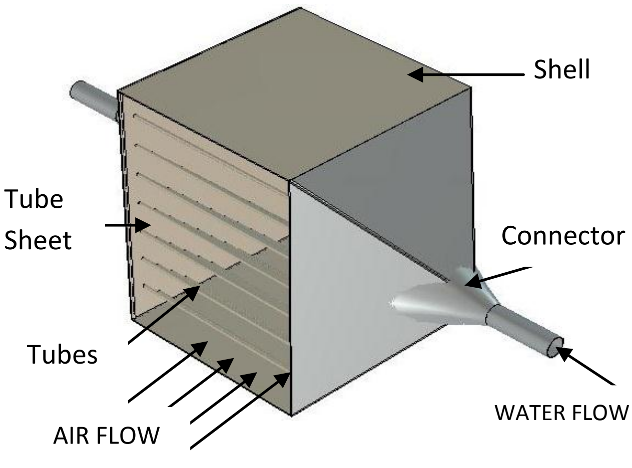
CROSS-FLOW EXCHANGER

The two fluids flow at right angles to each other. Two different arrangements of this exchanger are commonly used. In one case, each of the fluids is unmixed as it flows through the exchanger. As a result, the temperatures of the fluids leaving the exchanger are not uniform. An automobile radiator is an example of this type of exchanger. In other case, one fluid is perfectly mixed while the other is unmixed as it flows through the exchanger.



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III.DESIGN OF HEAT EXCHANGER

INLET PARAMETERS OF HEAT EXCHANGER

The specifications of the condensed water are

PARAMETERS AND SPECIFICATION

Mass flow rate =22.22kg/s

Pressure=0.5kg/m^2

Temperature=85^{o}C

Diameter of pipe=150mm

The specifications of the forced draught air are

PARAMETERS AND SPECIFICATION

Mass flow rate=41.47 kg/s

Pressure=170mmwc at outlet

Operating temperature=45^{o}C

Design temperature=60^{o}C

Speed=980rpm

Velocity of air =20-22m/s

PROPERTIES OF CONDENSATE WATER

Inlet temperatureT_1= 85ºC

Density ρ = 970.75 kg/m^3

Kinematics viscosity ϑ = 0.3463 * 10^{-6} m^2/s

Thermal diffusivity α = 0.1647 *10^{-6} m^2/s

Prandtl number Pr = 2.1

Specific heat capacity C = 4200 J/kg K

Thermal conductivity k = 0.6716W/mK

PROPERTIES OF FORCED DRAUGHT AIR

Inlet Temperaturet= 32ºC

Density ρ = 1.156 kg/m^3

Absolute viscosity μ = 18.75 * 10^{-6} Ns/m^2

Kinematic viscosity ϑ = 16.24*$10^{-6}$$m^2$/s

Thermal diffusivity α = 23.22 *10^{-6} m^2/s

Prandtl number Pr = 0.693

Specific heat capacity C = 1005 J/kg K

Thermal conductivity k = 0.0269 W/mK

VELOCITY CALCULATION

FOR AIR

Mass flow rate = 41.47 kg/s

Density = 1.156 kg/m^3

Mass flow rate = Flow Rate * Density

Flow rate = Mass Flow Rate / Density

= 41.47 / 1.156

Flow rate = 35.59 m^3/s

Flow rate = Velocity * Area

Cross Sectional Area of duct = 1900*1600
= 3.04 m^2

Velocity of air = Flow Rate / Area

= 35.59 / 3.04

Velocity of air = 11.7 m/s

FOR WATER

Mass flow rate = 80 Tonnes / hr=22.22 kg/s

Density = 964.25 kg/m^3

Mass flow rate = Flow Rate * Density

Flow rate = Mass Flow Rate / Density

= 22.22 / 964.25

Flow rate = 0.0230 m^3/s

Flow rate = Velocity * Area

Diameter of pipe= 150 mm

Cross sectional Area of duct = (π / 4) * 0.150^2

= 0.0176 m^2

Velocity of water = Flow Rate /Area

= 0.0230 / 0.0176

Velocity of water = 1.3 m/s

SELECION OF MATERIAL

TUBE MATERIAL

Aluminum alloy (Duralumin) is selected for Tube material

The composition of Aluminum alloy

- Aluminum (over 90%)
- Copper (about 4%)
- Magnesium (0.5%–1%)
- Manganese (less than 1%)

The Physical Properties of Duralumin are

- High thermal conductivity
- High corrosive resistance

PROPERTIES OF DURALUMIN

Density ρ = 2707 kg / m^3

Specific heat capacity C = 0.883 KJ/kg ºC

Thermal conductivity k = 164 W/m ºC

Thermal diffusivity α = 6.676 * 10^5 m^2/s

SPECIFICATION OF PIPE

According to Indian standards, the sizes of the pipes available in the markets are at ¼, ½, ¾, 1 inch.

The ½ inch tube is selected for heat exchanger. The diameter for ½ inch tube is

Outer diameter of the tube D_o= 21.336 mm

Inner diameter of the tube D_i =15.7988 mm

TUBE ARRANGEMENT

No. of tubes n = 90

No. of tubes in the first column = 7

No. of tubes in the first column = 8

S_p-D_o = 1900/8 = 237.5 m

S_p = 190 + D_o

S_p = 258.836 mm

For Square Arrangement Sn = Sp/2

S_n = 211.336/2

S_n = 129.48 mm

S_d = $\{S_n^2 + (S_p/2)^2\}^{0.5}$

= $\{129.48^2 + (258.836/2)^2\}^{0.5}$

S_d = 183 mm

NTU METHOD

Convective Heat Transfer Coefficient for Air

V_{max} = [Sp/ (S_p – D)]

= [258.836/258.836 - 21.336)

V_{max} = 12.75 m/s

Reynolds no. Re = (U_{max}*Do*ρ)/μ

= (12.75 * 21.336 * 1.156)/18.75 * 10^{-6}

Re = 16.24 * 10^3

For Staggered Arrangement

S_p/D = 9, C= 0.421& n = 0.574

Nusselt No. Nu=1.33*C*Re^n*$Pr^{0.33}$

= 1.33*0.421*(16.24*10^3)$^{0.574}$*$0.693^{0.33}$

Nu = 133.4449

Nusselt No. Nu= h*D_o/k

h = Nu * k/ D_o

h = 168.24 W/m^2 K

For 9 rows, Correction Factor is 0.99

Convention Heat Transfer Coefficient

h = 168.24*0.99

h = 166.56 W/m^2 K

Convective Heat Transfer Coefficient for Water

Reynolds no. Re = (U*D_i)/ϑ

= (1.3 * 0.0157988)/(0.3463 * 10^{-6})

Re = 5.93 * 10^4

For L/Di = 101.27 & Re = 5.93 * 10^4

The Colburn Factor J_H = 10

Colburn Factor J_H = ((h*D_i/k)*(C_p*μ)/k)$^{-1/3}$*(μ/μ_w)$^{-0.44}$

h = ((J_H*k/D_i)*(C_p*μ)/k)$^{1/3}$*(μ/μ_w)$^{-0.44}$

the value of (μ/μ_w)$^{-0.44}$ = 1

h= ((100*0.6716/0.0157988)*(4200*970.75)/0.6716)$^{1/3}$

Convective Heat Transfer Coefficient

h = 5445.688 W/m^2 K

Overall Heat Transfer Coefficient

(1/U_o) = (r_i/r_o)*(1/h_o)+(r_i/r_o) *R_{fo}+(r_i/k)ln(r_o/r_i)+R_{fi}+)(1/h_i)

Fouling factors

R_{fo} = 0.0003525 m^2 K/W for air

R_{fi} = 0.0001751 m^2 K/W for water

(1/U_o) = (r_i/r_o)*(1/h_o)+(r_i/r_o)*R_{fo}+(r_i/k)ln(r_o/r_i)+R_{fi}+(1/h_i)

(1/U_o) = ((7.8994 * 10^{-3})/ (10.668 * 10^{-3}))*(1/166.56) + (7.8994 * 10^{-3})/ (10.668 * 10^{-3}) * 0.0003525 + (7.8994 * 10^{-3}/164) ln (7.8994 * 10^{-3})/ (10.668 * 10^{-3}) + 0.0001751 + (1/5445.68)

(1/U_o) = 0.0050

Overall Heat Transfer Coefficient

U_o = 196.85 W/m^2 K

Hot fluid (condensate water)

Specific heat capacity C_h= 4200 J/kg K

Mass flow rate m_h= 22.22 kg/s

Capacity rate of hot fluid

$C_h\ m_h$ = 93324 W/K (C_{max})

Cold fluid (forced draught air)

Specific heat capacity C_c = 1005 J/kg K

Mass flow rate m_c = 41.47 kg/s

Capacity rate of cold fluid

$C_c\ m_c$ = 41677.4 (C_{min})

No. of transfer units = NTU = UA/C_{min}

Where, U_o = 196.85 W/m2 K

A = π*D_i*L*n

= π * 21.336 * 10^{-3} * 1600 * 91

A = 10.08 m^2

NTU = UA/C_{min}

= 10.08 * 196.85/41677.4

NTU = 0.047

C = C_{min}/C_{max}

= 41677.4/93324

C = 0.45

For NTU = 0.5 & C = 0.45, Effectiveness **ε = 0.2**

Heat Transfer Q = ε* C_{min}*(T_1-t_1)

= 0.2* 41677.4 *(85 – 32)

Q = 441780.4 W

Outlet Temperature

Outlet temperature of water

T_2 = T_1-(Q/C_h m_h)

= 85 – (441780.4/93324)

T_2 = 80.2°C

Outlet temperature of air t_2= (Q/C_c m_c)+t_1

= (441780.4/41677.4) + 32

Outlet temperature of air t_2= 40.6°C

Energy saved

Energy Saved = Heat Transfer (Q)* Operating Hour

Where, Heat Transfer (Q) = 441780.4 W

Operating Hour = (Hours/Day) * (Days/Year)

= 24 * 365

Operating Hour = 8760 hr/yr

Energy Saved = Heat Transfer (Q)* Operating Hour

= 441780.4 * 8760

Energy Saved = 3869.996*10^3KW hr/yr

FUEL SAVED (IN TERMS OF ENERGY)

Fuel saved (In Terms Of Weight) = Fuel Saved (In Terms Of Energy) / colorific value of coal

Fuel saved (In Terms Of Energy) = Energy Saved/ boiler efficiency

Where, The boiler efficiency = 85%

Energy Saved= 3869.996*10^3KW hr/ yr

Fuel Saved (In Terms Of Energy) = Energy Saved/ Boiler Efficiency

= 3869.996 * 10^3 / 0.85

Fuel saved (In Terms Of Energy) = 4552.93724 * 10^3 KW hr/yr

FUEL SAVED (IN TERMS OF WEIGHT)

Where, Colorific value of coal = 6500 Kcal/kg = 7.5596 KW hr/kg

(Coal used is A grade coal)

Fuel saved (In Terms Of Energy) = 4552.93724 * 10^3 KW hr/yr

Fuel saved (In Terms Of Weight) = 4552.93724 * 10^3 / 7.5596

Fuel saved (In Terms Of Weight) = 602272.24 kg/yr = 602.2Tonnes/yr

Money Saved

Money Saved = Fuel saved * Prize of the Fuel

Fuel saved (In Terms Of Weight) = 602.27 Tonnes/yr

Prize of the fuel = Rs. 4500 / Ton.

Money Saved= Fuel saved * Prize of the Fuel

= 602.27 * 4500

Money Saved=Rs. 2710215/ yr

Money Spent For Fuel

Capacity of fuel for boilers = 130 Tonnes/day

Capacity of fuel for boilers = (Tonnes/day) * (days/year)

= 130 * 365

Capacity of fuel for boilers = 47450 Tonnes/yr

Cost of fuel = (Capacity of fuel for boilers/yr) * (prize of the fuel)

= 47450 * 4500

Cost of fuel = Rs.213525000/yr

Reduced fuel = (Capacity of fuel for boilers) – (fuel saved)

= 47450 – 602.27

Reduced fuel = 46847.73 Tonnes/yr

Money reduced = (Cost of fuel/yr) – (Money Saved)

= 213525000 – 2710215

Money reduced = Rs.210814785/yr

IV. WORKING PRINCIPLE

In this heat exchanger, the hot water is flow inside the tube and the air is flow outside the banks of the tube.

The water at 85˚C from the sugar plant is flow inside the tubes. The water from the 150 mm diameter pipe is taken into 90 tubes of Outer diameter Do= 21.336 mm &Inner diameter D_i = 15.7988 mm. These tubes are 1600mm long. While flowing through the tubes, a convective heat transfer takes place between the tubes surface and the hot water. The value of convective heat transfer coefficient of water is h = 5445.688 W/m^2 K.

The tube material conducts the heat energy from inside of the tube to the outside surface. The material of the tube is Duralumin. The thermal conductivity of the tube material is k = 164 W/mK.

The air at 32˚C from the forced draught fan is flow over banks of tubes. The velocity of the air is v = 11.7 m/s. The air flows inside the 1900* 1600 mm^2 duct. The duct material is Galvanized iron. The convective heat transfer takes place between the air and the surface of the tubes. The value of the convective heat transfer coefficient of air is h = 166.56 W/m^2 K.

After the heat transfer, the water flows to the spray pond for the further cooling and the air flows to boiler for the burning of the fuel.

V. ADVANTAGES AND LIMITATIONS

5.1. ADVANTAGES

1. Energy waste is recovered. Thus the heat lost to the atmosphere is reduced.
2. Inlet temperature of preheated air is increased which increases the efficiency of boiling process
3. The fuel consumption is reduced.
4. Reduced fuel consumption gives the economical benefit to the company.
5. Reduction of the fuel reduces the transportation of coal, preparation of coal and reduces man power.

5.2. LIMITATIONS

1. Staggered arrangement of tubes is difficult to clean.
2. Additional pump required to pump the outlet water to spray pond.

VI. RESULTS AND DISCUSSION

Thus, the heat exchanger is designed to utilize the waste heat from the condensate water to preheat the forced draught air. The heat exchanger recovered some amount of heat energy from the condensate water without wasting it to atmosphere.

Thus, the energy saved from condensate water is used for preheat the forced draught air. The inlet air temperature gets increased and the water temperature is reduced.

The increased air temperature increases the effectiveness of the burning and reduces the fuel consumption. The reduced fuel consumption reduced the money spend for the fuel. Thus, it's an economical benefit of the company.

The amount of fuel used presently in the company is 47450 Tonnes/yr (A grade coal) and the cost of the fuel is Rs.213525000/yr.

The energy saved from the heat exchanger is 441780.4 W. This energy saved reduces the fuel consumption up to 602.27Tonnes/yr and reduces Rs. 2710215/ yr.

Thus the fuel consumption is reduced from 47450 Tonnes/yr to 46847.73 Tonnes/yr and the money spend is reduced from Rs.213525000/yr toRs.210814785/yr.

VII. CONCLUSION AND SCOPE FOR FUTURE WORK

7.1. CONCLUSION

The Cross flow heat exchanger is designed to utilize the waste from the condensate water. The waste heat is used to preheat the air before the air entered into preheater. The water from the sugar plant at 85˚C is taken as the inlet to the heat exchanger. The Duralumin is used as the tube material to transfer heat from water to air, because of its high thermal conductivity and high corrosive resistance.

The air flows over the staggered arrangement tubes and gets the heat energy from the tubes surface. Thus the temperature of the forced draught air is increased and also the effectiveness of the burning is improved. It reduces the fuel consumption up to 602.27Tonnes/Year and also reduces the money spend for the coal up to Rs. 2710215 / year.

7.2. SCOPE FOR FUTURE WORK

The amount of heat transfer is based on the surface area in which the heat transfer occurs. So, in future the use of the fins on the external surface of the tube will increase the heat transfer area which increases the heat transfer rate.

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