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Thermal Design of Economizer for Waste Heat Recovery Boiler (WHRB)

Mukesh M Chopade#[1]
#Mechanical Engineering student,
Savitribai Phule Pune University,
A.T post Nhavi, Jalgaon, Maharashtra, India, 425524

Abstract:- **Development of any country is largely based on its magnitude of industrial growth. Various processes involved for the use of waste heat which is recovered from the coke oven batteries are:- Production of coke from coal in an oven, Steam Generation in water-tube boiler and Power Generation. Energy saving is one of the key issues, not only from the point of view of fuel consumption but also for the protection of global environment. So, it is very important that a significant effort should be made for conserving energy through waste heat recovery. This paper will address the problem of heat energy which is wasted away from coke oven in the form of flue gases. The main object is to recover waste heat from the system and transfer the lost energy from the source back into the useful work and also to make the energy conversion process as efficient as possible. There are various techniques in use for recovery of waste heat from various systems under different situation. This work is carried out in a battery/coke oven. The heat dissipated during this process is harnessed. A two pass water-tube boiler is used as waste heat recovery boiler (WHRB).In this boiler we install economizer for efficiency improvement. Waste heat recovery economizer uses waste flue gases for steam production which has wide range of variations in parameters. By considering these parameters like gas flow rate, temperature variation, pressure variation, amount of ash content in flue gases we design the economizer & simulate this design with the help of KED software for waste heat recovery boiler. This paper deals with the basic configuration of economizer for waste heat recovery boiler for coke making industries application.**

Key words:- Waste heat recovery application, Economizers, PPSD software, Thermal simulation, Geometry of economizer.

1 INTRODUCTION:-

Economizers are a device fitted to a boiler which saves energy by using the exhaust gases from the boiler to preheat the cold water used to fill it. One of the most cost-effective ways of improving the efficiency of a high pressure steam boiler is to install an economizer on the boiler. The main idea is to extract maximum amount of heat from the flue gases and increase the heat pick up rate of the feed water outlet into the boiler. By assuming the additional bank of tubes, various heat transfer calculations are done and the reduction in the flue gas outlet temperature and increase in the feed water outlet temperature are found out. In the WHRB boiler they intend to install economizer for efficiency improvement. We are designing economizer for waste heat recovery boiler and that waste heat is taken from coke oven batteries. Waste heat recovery boiler uses waste flue gases for steam production, so this economizer is also work on these varying parameters like gas flow rate, temperature variation, pressure variation, amount of ash content in flue gases. By considering these parameters we are going to design the economizer for waste heat recovery boiler. After designing we are going to simulate this design with the help of KED (Kerntechnik Entwickiung Dynamic) software. It is largely used in simulation and performance evaluation of waste heat recovery boiler. Here, it is used to carry out thermal simulation of economizer for waste heat recovery boiler (WHRB). For these purpose KED model is developed and qualified at the steady-state condition .using the plant available data. The control and regulation system are also modelled.This paper includes design of economizer downstream of boiler for further capacity improvement.

3 LITERATURE SURVEY:-

"Waste heat opportunities & recovery, BCS, Incorporated March 2008"

BCS[1] Waste heat losses arise both from equipment in efficiencies and from thermodynamic limitations on equipment and processes. For example, consider reverberatory furnaces frequently used in aluminium smelting operations. Exhaust gases immediately leaving the furnace can have temperatures as high as 1200 - 1300 °C. Consequently, these gases have high heat content, carrying away as much as 60% of furnace energy inputs. Efforts can be made to design more energy efficient reverberatory furnaces with better heat transfer and lower exhaust temperatures. The minimum possible temperature of combustion gases immediately exiting an aluminium reverberatory furnace corresponds to the aluminium pouring point temperature 650 – 750 °C. In this scenario, at least 40% of the energy input to the furnace is still lost as waste heat. This waste heat can be use for various purposes .Combustion air preheat can increase furnace efficiency by as much as 50% Another advantage of waste heat recovery is that it can reduce capacity requirements for facilities thermal conversion devices, leading to reductions in capital costs.

"Waste heat recovery from furnace flue gases using waste heat recovery boiler"

NFC Institute of Engineering[2] This research paper will address the problem of heat energy which is wasted away from furnace in the form of flue gases. There are various techniques in use, for recovery of waste heat from various systems under different situation. This work is carried out on prototype Cupola furnace which is the most widely used industrial melting furnace. While a two pass fire tube Boiler is used as waste heat recovery boiler (WHRB). This paper involves the (a) calculation of energy which is wasted due to the different heat losses in furnace, (b) Recovery of the waste heat of flue gases, (c) Generation of process steam in WHRB.

Reay found by experiments that not only is heat recovery economical, but that it also reduces pollution. He used heat exchangers for recovering the heat. Jekerle Jiri Orman and Heinrich Rothenpieler invented a waste heat boiler in 2006 which included an axial bypass pipe and multiple heat transfer pipes disposed within a cylindrical jacket. Cosme Matias Meneze (CMM) group in 2005 conducted a research on heat recovery boiler and they concluded that the steam generated can be used as main stream steam. Schalles found that much of the heat produced in melting operation is lost to atmosphere. When this waste energy is reused, it may save up to approximately 20% of a facility's energy cost and, in some cases, reduce emissions. Tang Jinquan developed many waste heat recovery power plants (WHRPP) while serving as Chief Technical Director of Dalian East New Energy Development Co., Ltd. Zainal Zakaria and nor Ismail Hashim found that the cost of system increases due to the erosion and corrosion in boiler.

“Improvement in Boiler Efficiency through Incorporation of Additional Bank of Tubes in the Economizer”.

P.Ravindra Kumar[3] One of the most cost effective ways of improving the efficiency of a high pressure steam boiler is to install an economizer on the boiler. Typically, on a high pressure water tube boiler, the efficiency improvement with an economizer is 2 to 4%, depending on firing rate. On a high pressure fire tube boiler, the improvement is 2 to 3.5%, depending on boiler size and firing rate. As the temperature difference between two working media is small, economizer needs a very large heat exchange surface. The regenerative feed water preheating, this heats the feed water up to the temperature of 200 to300 ˚C before it enters the economizer and which lets the flue gas cools down to the temperatures of , at most above the level determines the fireside outlet temperature of depending on the Terminal Temperature Difference (TTD) of the economizer. The Present work is to carry out by providing an additional bank of tubes in the economizer for checking its performance levels and pollution control.

4 COKE OVEN BATTERIES:-

Coke oven plant consists of Coke oven batteries containing number of oven (around 65 ovens in each battery). The coal is charged to the coke oven through charging holes. The coal is then carbonized for 17-18 hours, during which volatile matter of coal distills out as coke oven gas and is sent to the recovery section for recovery of valuable chemicals. The ovens are maintained under positive pressure by maintaining high hydraulic main pressure of 7 mm water column in batteries. The coking is complete when the central temperature in the oven is around 950-1000^{0}C. At this point the oven is isolated from hydraulic mains and after proper venting of residual gases, the doors are opened for coke pushing. At the end of coking period the coke mass has a high volume shrinkage which leads to detachment of mass from the walls ensuring easy pushing. The coke is then quenched and transferred to coke sorting plant. The control of oven pressure is quite important because lower pressure leads to air entry while higher pressure leads to excessive gassing, leakage of doors, stand pipe etc. Proper leveling of coal is important and care is taken so that free board space above (300 mm) is maintained to avoid choking. Coke oven plants are integral part of a steel plant to produce coke, which is used as fuel in the blast furnace. Coke oven plant produces important by product coal chemical tar, ammonia, crude benzoyl which is fractionated to produce aromatics-benzene toluene, xylene. Coke oven are used to convert coal into coke by carbonizing coal in absence of air and there by distilling the volatile matter out of coal. Coke is taken as product which is use as fuel and as a reducing agent in smelting iron ore in a blast furnace and coke oven gas as byproduct is treated for recovery of coal chemicals. The coke oven temperature is keep as high as 2000^{0}c.We are using the waste flue gases which are liberating at such a high temperature as a waste heat from the coke oven in the economizer. Crushing and screening of coke is done to obtain suitable size for use in blast furnace.

Temperature (˚C)	Water	Flue Gases
At Inlet	$T_{Ci} = 126$	$T_{hi} = 383$
At Outlet	$T_{Co} = 294$	$T_{ho} = 170$

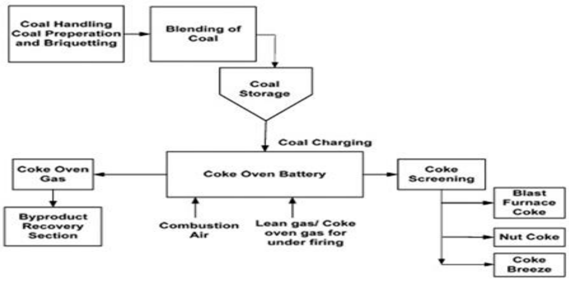


Figure No.1:- Flow Diagram of Coke Oven Plant.

5 ECONOMIZERS:-

Number	Tube Size ($r_O * t$)	Tube Length
1	25.4*3.66	3000
2	31.75*3.66	3000
3	38.1*4.06	3000
4	44.4*4.06	3000
5	50.8*4.06	3000

Economizer surfaces transfer heat from flue gases to pressurized and sub-cooled FW on its way to the drum. Heat transfer in an ECON is nearly entirely by convection, and hence the gas velocities are maximized consistent with pressure drop and tube spacing limitations. Coal ash in flue gas at temperatures <600°C is no longer sticky and hence fouling of tubes is not as much an issue as in SH. The ash is loose and does not form strongly adhering deposits and hence is easily removed by soot blowing. However, if there is a mixed firing of oil and coal, the ash can stick over the oil deposits that form on the tubes. The major concern is to reduce the surface and volume to optimize the space and cost. Usually smaller tubes with 38.1, 44.5, and 50.8 mm (1½, 1¾, and 2 in.) ODs are chosen to increase the heat-transfer rate. 31.8 mm (1¼ in.) tubes are used in SC boilers and vertical HRSGs. Large-diameter tubes like 63.5 and

76.2 mm are adopted in vertical ECONs based on strength considerations. Close bending of tubes with radius of 1D or lower is also used most frequently. Care is taken to avoid a back pitch (along the gas flow) of 1.07–1.25 times the OD, via development of boundary layer, to avoid excessive draft loss and reduced heat transfer. Heat transfer can reduce by as much as 30% with this spacing. Optimum mass velocity for bare tube ECON lies between 5.4 and 6.8 kg/m2 s (4000–5000 lb/ft2 h).

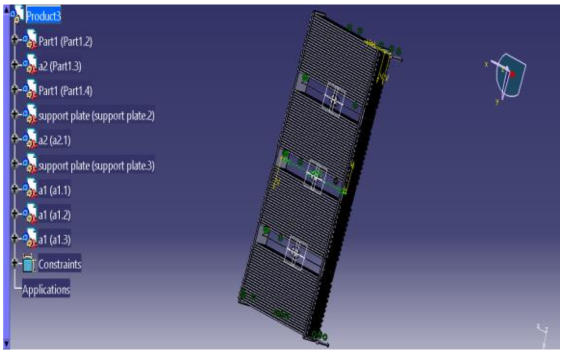


Figure No.2:- Catia 3D Model.

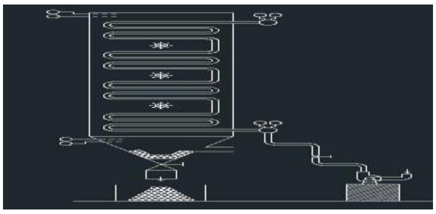


Figure No.3:- Autocad 2D Model.

6 DESIGN ANALYSIS:-

6.1 Assumption:-The properties are remain constant under steady state conditions & neglect surrounding losses. Changes in KE & PE are neglected.

Table No.1:- Temperature Reading's.

$Q = U.A.LMTD$

Economizer Specification:-

Table No.2:- Tube Sizes And Length.

LMTD $= (\Delta T_b - \Delta T_a) / [\ln (\Delta T_b - \Delta T_a)]$

$= 63.87\ ^\circ C.$

Overall Heat Transfer Coefficient :-

$[1/U] = \{[1/hi] + ff_i + ff_o + [1/ho]$

6.2 Water side H.T coefficient (hi) estimation:-

Consider 3rd observation from the table;

Nu=0.023 Re^0.8pr^0.4

$Nu = (h_i .d_i) /12K$

$Re = (15.2\ Wd_i) / \mu$

Re = {(15.2*2.9166*0.02998)/0.000016}

Re = 83067.68

Pr = (μ .Cp)/K

Pr = 1.24* 10^-6

Nu = 0.023 Re^0.8pr^0.4

Nu = 0.023*83067.68^0.8*(1.24*10^-6)^0.4

Nu = 8.6028

$Nu = \{(h_i .d_i)/12K\}$

8.6028 = {(hi*0.02998)/(12*54)}

hi = 185944 W/m²K

6.3 Gas side H.T coefficient estimation $(ho+h_c)$:-

h_o= negligible,

Nu= 0.33 Re^0.6*Pr^0.33

Re= (Gd)/ 12μ

pr= (μ .Cp)/ K

$Nu=(h_c . d_o)/12K$

From the above four equation's;

h_c =0.9 G^(0.6) [k^0.63 [Cp^0.33 / μ^0.27] / d^0.4]

h_c=0.9*7.22^0.6[54^0.67[1443.56^0.33*2.629*10^-5] /0.038^0.4]

h_c= 48.43 W/m²K.

6.4 Overall heat transfer coefficient:-

$\{[1/U] = \{[1/ h_i] + ff_i + ff_o + [1/ h_o]\}$

= {[1/185944]+0.004+0.004+[1/48.43]

= 34.89 W/m²K.

Heat absorbed by water (Q),

$Q = U.A.LMTD$

= 34.89 * A* 63.83

Heat given by flue gases to water

$Q_1 = m\,.\,Cp\,.\,\Delta T$

Q_1 = [10500* 1.443* (383-170)] / [3600]

= 2219.13 kW

$Q_{act} = 0.98* Q_1$

= 2174.75 kW

6.5 Calculation for heat transfer surface area:-

$$Q_{act} = U.A.LMTD$$

$$2174.75*1000 = 34.899*A*63.87$$

$$A = 975.66\ m^2.$$

By considering the usable factor 0.84 take the required area as 1160 m^2.

6.6 Estimation of configuration of tubes in economizer for area (A = 1160 m^2)

By considering the soot blower arrangement here we have made 4 modules of 24 rows each. Each module having 32 W × 24 D, as;

6.6.1 Tube sizes -

Consider, 38.1 * 4.04 (outer diameter * thickness)

Total no. of tubes = 32 *24*4

=3072 tubes .

1 module = 32 * 24 = 768 tubes

Area of 1 module = (No. of tubes in one set)*(Surface area of tube)

$$= 768\ .\pi.D.L$$

$$= 768\ .\pi *0.0381 *3$$

$$= 275.77\ m^{2.}$$

No. of Module = (1160)/(275.77)

$\approx$ 4 modules.

Transverse pitch = 75 mm.

Longitudinal pitch = 100 mm.

7 Economizer Simulation using PPSD:-

Numerical simulation is very useful tool and it is extensively used now-a-days to assess the thermal-hydraulic behavior of boiler. The economizer simulation is a rigorous and high–fidelity mathematical process model that provide a realistic steady state static and dynamic response for economizer. This help is avoided expensive tests in experimental set-up. Here, it is used to carry out thermal-hydraulic simulation of high pressure natural circular water tube economizer. For these purpose KED model is developed and qualified at the steady-state condition using the plant available data. The control and regulation system are also modeled. To reduce product development cost and time, traditional prototyping and testing has been replace in the by a simulation-driven design process. Thermal analysis generally used to find temperature distribution, temperature gradient, and heat flowing in the model, as well as the heat exchange between the model and its environment. Thermal simulation is the dynamic analysis of the energy performance of products using computer modeling and simulation techniques.

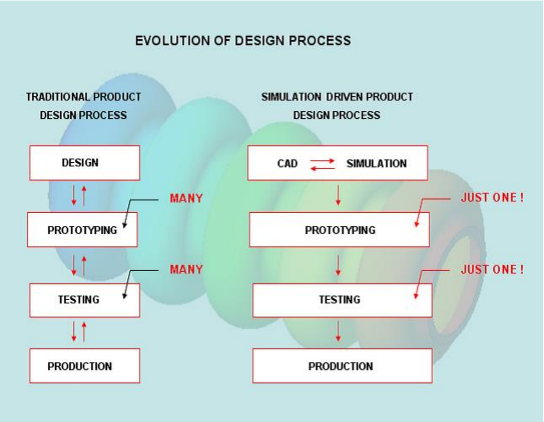


Figure No.4:- Analytical Design Vs Simulation.

7.1 Power Plant Simulator and Designer :-

The program “power plant simulator and designer” is design for construction of thermal and hydraulic model of economizer. The model is can be used for following static and dynamic calculations. The program is represented in two variants, viz. static and dynamic. The first variant includes constructing economizer models and then following static heat and hydraulic calculation of the boiler. In addition to “ normal “ economizer calculation, the programme can used for :

a. Hydraulic calculation of regeneration schemes of the power plant.
b. Calculations of the circulation of the systems of drum type boilers.

The second variant has the same information as that of first one and it also includes additional calculations for the transmission processes at the variable work regimes (starting up, stop, changes of loading, variation of rate of fuel, feeding and injected water, air and etc.).The programme is built on the object oriented principle. All economizer model are constructed from standard parts: furnace, heating surface of different types, spray coolers and surface steam coolers, mixture and division of gas and water streams, different types of fuel (coal, fuel oil, gas)etc. Some elements have a hierarchic structure that is they contains nested groups where other elements can be dispose. The quantity of levels is not limited. Such a hierarchic structure provides the opportunity to construct any complex schemes of gas and water / gas and steam circuits of economizer.

7.2 Diagnostic :-

When to the software model is given real time data from running plant, the model can be used as a diagnostic tool for specific economizer conditions. These can further increase the optimisation of the unit be determining and minimising the following -

- Determining metal temperatures in heated zones, which influence thermal creep fatigue.
- Control of excess air,which improve combustion efficiency and reduce flue gas losses.

7.3 Gas Side Heat Transfer Using KED:-

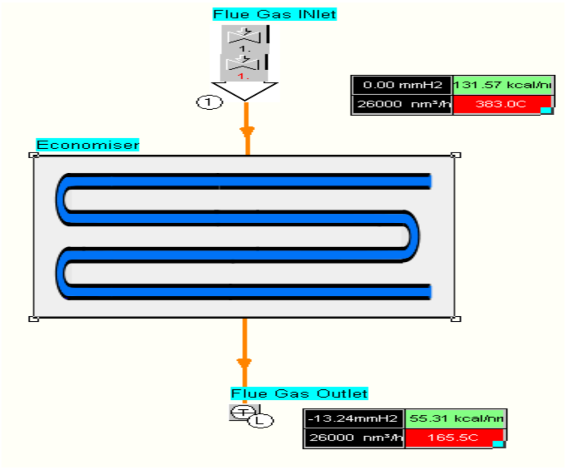


Figure No.5:-Gas side heat transfer.

7.4 Water Side Heat Transfer Using KED:-

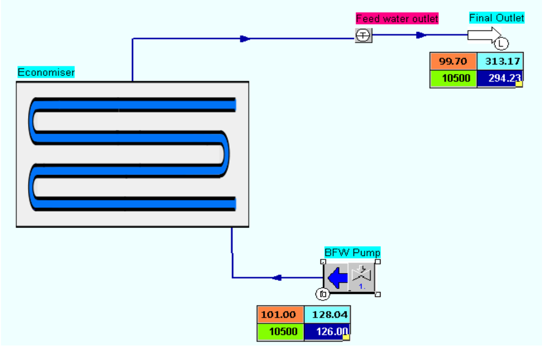
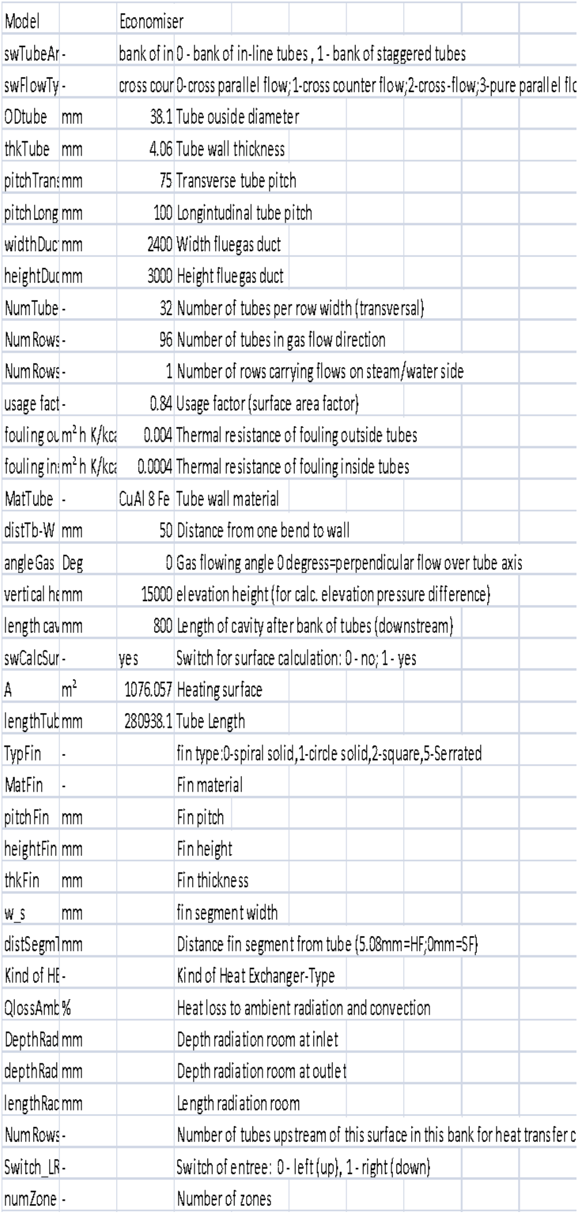


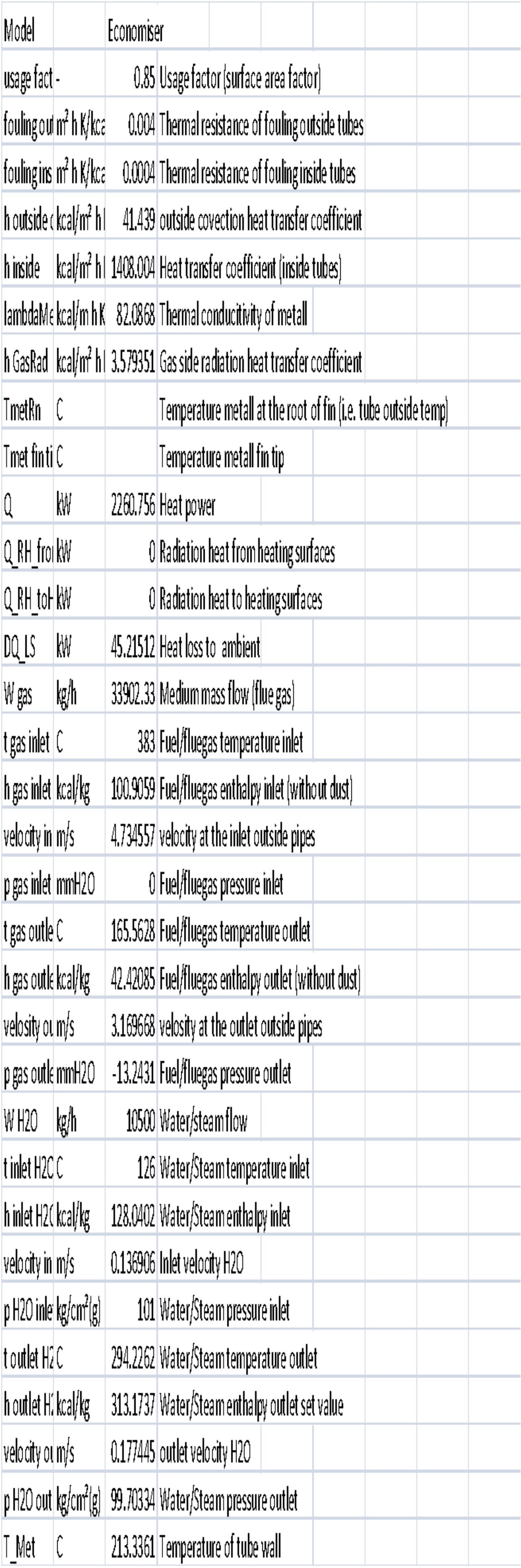
Figure No.6:-Water side heat transfer.

7.5 Software Data:-



Model		Economiser	
swTubeAr	-	bank of in	0 - bank of in-line tubes , 1 - bank of staggered tubes
swFlowTy	-	cross cour	0-cross parallel flow;1-cross counter flow;2-cross-flow;3-pure parallel flc
ODtube	mm	38.1	Tube ouside diameter
thkTube	mm	4.06	Tube wall thickness
pitchTrans	mm	75	Transverse tube pitch
pitchLong	mm	100	Longintudinal tube pitch
widthDuc	mm	2400	Width fluegas duct
heightDuc	mm	3000	Height fluegas duct
NumTube	-	32	Number of tubes per row width (transversal)
NumRows	-	96	Number of tubes in gas flow direction
NumRows	-	1	Number of rows carrying flows on steam/water side
usage fact	-	0.84	Usage factor (surface area factor)
fouling ou	m² h K/kca	0.004	Thermal resistance of fouling outside tubes
fouling ins	m² h K/kca	0.0004	Thermal resistance of fouling inside tubes
MatTube	-	CuAl 8 Fe	Tube wall material
distTb-W	mm	50	Distance from one bend to wall
angleGas	Deg	0	Gas flowing angle 0 degress=perpendicular flow over tube axis
vertical he	mm	15000	elevation height (for calc. elevation pressure difference)
length cav	mm	800	Length of cavity after bank of tubes (downstream)
swCalcSur	-	yes	Switch for surface calculation: 0 - no; 1 - yes
A	m²	1076.057	Heating surface
lengthTub	mm	280938.1	Tube Length
TypFin	-		fin type:0-spiral solid,1-circle solid,2-square,5-Serrated
MatFin	-		Fin material
pitchFin	mm		Fin pitch
heightFin	mm		Fin height
thkFin	mm		Fin thickness
w_s	mm		fin segment width
distSegmT	mm		Distance fin segment from tube (5.08mm=HF;0mm=SF)
Kind of HE	-		Kind of Heat Exchanger-Type
QlossAmb	%		Heat loss to ambient radiation and convection
DepthRad	mm		Depth radiation room at inlet
depthRad	mm		Depth radiation room at outlet
lengthRad	mm		Length radiation room
NumRows	-		Number of tubes upstream of this surface in this bank for heat transfer c
Switch_LR	-		Switch of entree: 0 - left (up), 1 - right (down)
numZone	-		Number of zones

Table No.3:- Input.



Model		Economiser	
usage fact	-	0.85	Usage factor (surface area factor)
fouling out	m^2 h K/kca	0.004	Thermal resistance of fouling outside tubes
fouling ins	m^2 h K/kca	0.0004	Thermal resistance of fouling inside tubes
h outside c	kcal/m^2 h l	41.439	outside covection heat transfer coefficient
h inside	kcal/m^2 h l	1408.004	Heat transfer coefficient (inside tubes)
lambdaMe	kcal/m h K	82.0868	Thermal conducitivity of metall
h GasRad	kcal/m^2 h l	3.579351	Gas side radiation heat transfer coefficient
TmetRn	C		Temperature metall at the root of fin (i.e. tube outside temp)
Tmet fin ti	C		Temperature metall fin tip
Q	kW	2260.756	Heat power
Q_RH_fro	kW	0	Radiation heat from heating surfaces
Q_RH_toH	kW	0	Radiation heat to heating surfaces
DQ_LS	kW	45.21512	Heat loss to ambient
W gas	kg/h	33902.33	Medium mass flow (flue gas)
t gas inlet	C	383	Fuel/fluegas temperature inlet
h gas inlet	kcal/kg	100.9059	Fuel/fluegas enthalpy inlet (without dust)
velocity in	m/s	4.734557	velocity at the inlet outside pipes
p gas inlet	mmH2O	0	Fuel/fluegas pressure inlet
t gas outle	C	165.5628	Fuel/fluegas temperature outlet
h gas outle	kcal/kg	42.42085	Fuel/fluegas enthalpy outlet (without dust)
velosity ou	m/s	3.169668	velosity at the outlet outside pipes
p gas outle	mmH2O	-13.2431	Fuel/fluegas pressure outlet
W H2O	kg/h	10500	Water/steam flow
t inlet H2O	C	126	Water/Steam temperature inlet
h inlet H2(	kcal/kg	128.0402	Water/Steam enthalpy inlet
velocity in	m/s	0.136906	Inlet velocity H2O
p H2O inle	kg/cm^2(g)	101	Water/Steam pressure inlet
t outlet H2	C	294.2262	Water/Steam temperature outlet
h outlet H:	kcal/kg	313.1737	Water/Steam enthalpy outlet set value
velocity ou	m/s	0.177445	outlet velocity H2O
p H2O out	kg/cm^2(g)	99.70334	Water/Steam pressure outlet
T_Met	C	213.3361	Temperature of tube wall

Table No.3:- Output.

8 CONCLUSION:-

A heat recovery unit needs to be installed to recover the heat potential from this stream so that, power can be produced. Design of such equipment to recover this heat and power savings through that is must be carried out to improve the efficiency of plant.

1. Waste heat recovery is an environmental friendly technology for saving fuels.
2. The power produced depends on heat consumption, gas temperature and flow rate of preheater and cooler.
3. It is seen that the total waste heat content can approximately satisfy the requirement of heat duties of evaporator, super-heater and economizer..
4. The Waste Heat Recovery Technology, as any other technology, is in an incessant phase, and many more innovations, in terms of equipment and applications may be expected in future.

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