Bangladesh University of Engineering & Technology

ME 310: Thermo Fluid System Design

Project Report

Project name: Non-condensing Economizer

Group A12

- Md Jawarul Moresalein (1710002)
- Shouvik Sarker (1710017)
- Sadib Fardin (1710019)
- Md Fuad Amin Jarif (1710020)

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1. Acknowledgement:
I would like to express my deep gratitude to Professor Dr. A K M Monjur Morshed Sir, Assistant Professor Dr. Kazi Arafat Rahman Sir and Lecturer Saif Al-Afsan Shamim Sir for their patient guidance, enthusiastic encouragement, and useful critiques throughout this project.

2. Abstract:
Non-condensing Economizers are products that are specifically designed to improve boiler net thermal efficiency by recovering sensible heat from boiler flue gases. It is a type of heat exchanger that enables some of the sensible heat in boiler flue gases to be recovered. This heat is normally used to preheat the boiler's feedwater. Typically, a non-condensing economizer will increase boiler net thermal efficiency (expressed in percentage terms) by at least 3 percentage points (i.e. a boiler with efficiency of 89.0% is improved to at least 92.0%).

3. Introduction:
The Economizer in Boiler works on the principle of Heat Transfer. Heat transfer usually takes place from high temperature to low temperature. In the case of Boilers, flue gases or exhaust from the boiler outlet are at high temperature and water that needs to be preheated is at low temperature. So, this temperature difference between water and flue gases helps to increase the feed water temperature. Depending on the type of operations, design of Economizers can be smoke tube type [1] or water tube type. In smoke tube type flue gases are inside the tubes and water is on the shell side while in the water tube type, water is in the tube and flue gases are on the shell side. There are two main types of economizers: non-condensing economizer and condensing economizer. Non-condensing economizers are mainly used because this type of economizers increase efficiency by 2% to 4%.

4. Working Principle:
The most widely used one, in a thermal power plant is the **non-condensing economizer**. These are basically heat ex-changer coils, that are finned around in the form of a spiral and are located inside the flue gas duct near the exit region of the boiler. They have the ability to reduces the fuel requirements of a boiler by transferring heat from the exit flue gas to the steam boiler feed water. It is used in the case of coal-fired boilers, where the lowest temperature to which flue gas can be cooled is about 250º F (120ºC).

5. Features of Our Project:

1. Cross flow heat exchanger.
2. Tubes in staggered position
3. Improved efficiency, improved ventilation.
4. Simple structure, easy installation.
5. Improved fin structure to increase efficiency.
6. Non-condensing economizer.

6. Components & Pricing:

The Components that are used in this project and their costing is given below.

COMPONENT	PRICE(TAKA)
SHELL (STAINLESS STEEL)	4,000/-
TUBE (COPPER)	10,500/-
FIN (ALUMINIUM)	2,500/-
INSULATION	2,200/-
ADDITIONAL COST	2,000/-
TOTAL	**21,200/-**

7. Literature Review:

The highest heat losses in boilers is related to dry flue gas that is around 12% of the total heat lost through the exhaust that resulting in efficiency equal to 77.2293% whereas using economizer concludes in a significant reduction of flue gas temperature. And this declining flue gas temperature declines the dry flue gas loss up to around 6 percent and it increases the efficiency of Boiler up to 84.5462%, which is a 7.3169% improvement in efficiency. [2]

The exergy destruction in Low Pressure Economizer is 1% while 5% in High Pressure Economizer for both cases. Installation of Low-Pressure Economizer causes very little increase of the back pressure of the steam turbine, which means that installation of the Low-Pressure

Economizer in the flue gas system has little negative impacts on the operation of the boiler thermal system. [3]

By attaching fins to the tubes of economizers, the feed water temperature along the tube rows increases up to 4.0% in comparison with bare tube economizer. The total heat flux on tube walls and the total heat transfer rate was estimated for all cases and it was observed that the total heat flux and the total heat transfer rate increases up to 38.0% and 40.0% respectively by using circular fins. [4]

8. Mathematical Model:

8.1. Problem Statement:

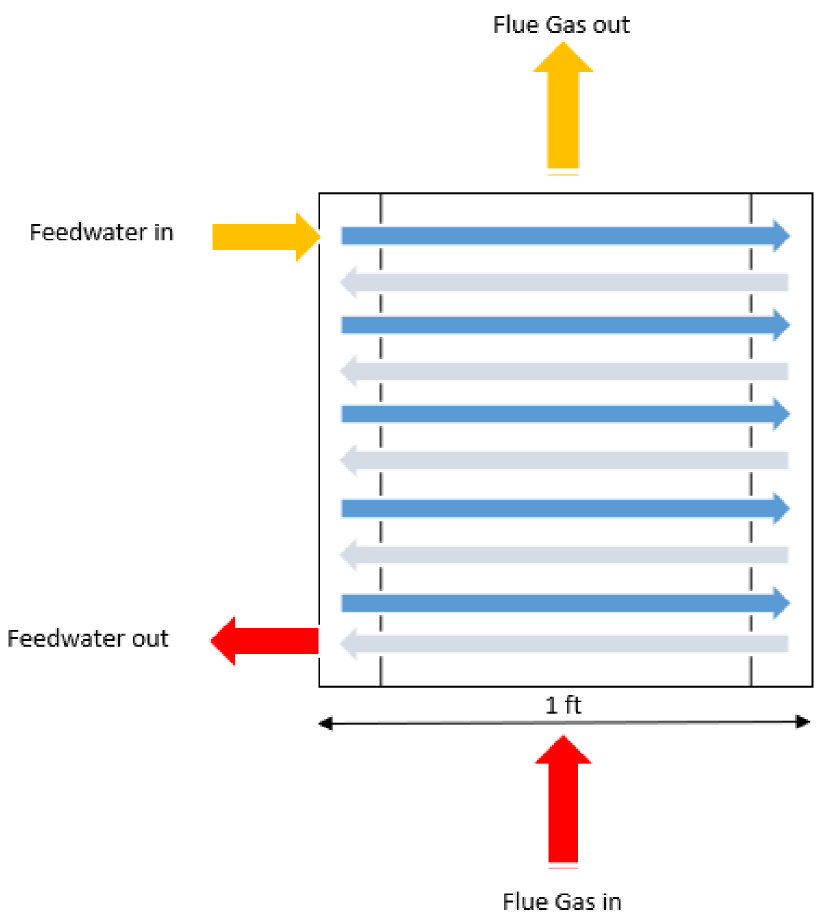

Figure 01: Fluid pass ways

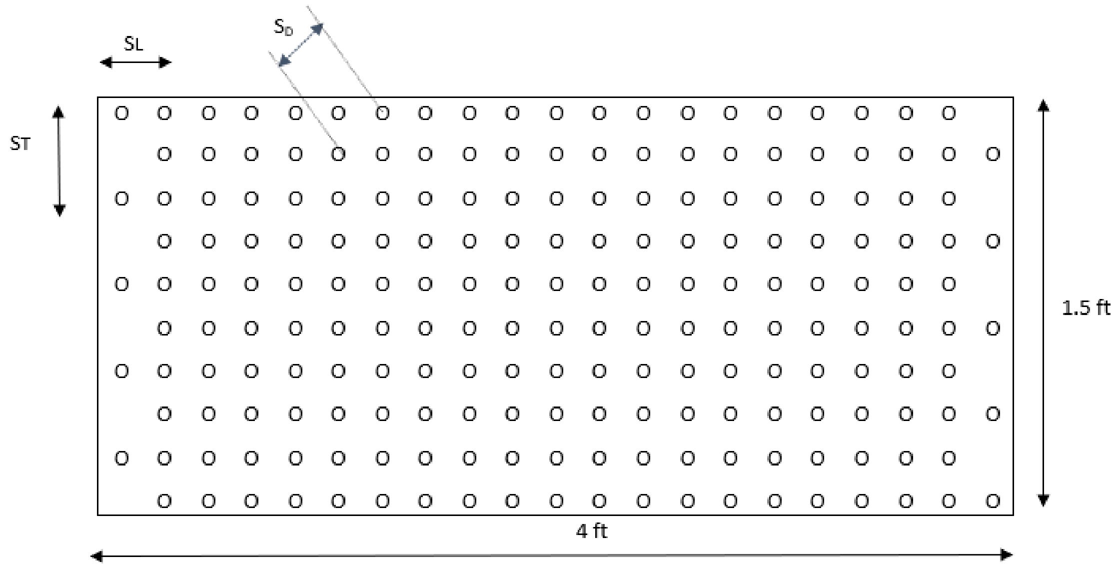

Figure 02 : Schematic of tube layout

Hot fluid : Flue Gas

Position : Shell

Inlet temperature, $\mathbf{T_{in} = 180^\circ\ C}$

Outlet temperature, $\mathbf{T_{out}=120^\circ\ C}$

Mass flow rate, $\dot{m}_h = 60$ kg/hr

Uniform velocity, $U_\infty = 3$ m/s

Cold fluid : Feedwater

Position : Tubes

Inlet temperature, $\mathbf{T_{in} = 50^\circ\ C}$

Outlet temperature, $\mathbf{T_{out}=80^\circ\ C}$ **(Assumed value)**

Mass flow rate, $\dot{m}_c = 6$ kg/hr

8.2. Physical Dimensions:

Length, L = 4 ft

Width, W = 1 ft

Height, H = 1.5 ft

Tangential pitch, S_T = 5 cm

Longitudinal pitch, S_L = 2.5 cm

Tube outer diameter, D = 2.5 cm

Tube inner diameter, d = 2.4 cm

Number of tubes in longitudinal distance, N_L = 20

Number of tubes in transverse distance, N_T = 10

Tube outer surface temperature, T_S = 160˚ C (let)

8.3. Heat Transfer Co-efficient Calculation:

$T_{avg} = \frac{180+120}{2}\,^\circ C = 150^\circ C$

Flue gas properties @T_{avg}= $\mathbf{150^\circ C}$

$\rho = 0.8068\ kg/m$^3

Cp = 1043 J/kg K

K = 0.03416 W/m K

μ = 2.3 x 10^-5 kg/m s

ν = 2.851 x 10^-5 m^2/s

Pr = 0.7025

$s_D = \sqrt{S_L^2 + \left(\frac{s_T}{2}\right)^2} = 3 \cdot 54$ mm

$$U_{max} = \max\left(U_\infty\left[\frac{S_T}{S_T - D}\right], U_\infty\left[\frac{S_T}{2(S_D - D)}\right]\right)$$

$$= \max\left(3\left[\frac{5}{5-2.5}\right], 3\left[\frac{5}{2(3.54-2.5)}\right]\right)$$

$$= \max(6,7.2)$$

$= 7.2\ ms^{-1}$

$$R_e = \frac{U_{max} \times D}{\nu}$$

$$= \frac{7.2 \times 2.5}{2.85 \times 10^{-5}}$$

$= 6313.57$

Zukauskas co-relation for cross flow heat exchanger:

$N_{u_m} = \frac{h_m D}{K} = C_1 \times R_{e_{D,max}}^{m} \times P_r^{0.36}$ [5]

$\frac{h_m \times 2.5 \times 10^{-2}}{0.03416} = 0.40 \times (6313.57)^{0.60} \times (0.7020)^{0.36}$ [C_1=0.40 & m=0.60]

h_m= 91.75 W/m^2-K

Exit temperature, $T_{e,w} = 160 - (160-50)\exp\left(-\frac{15.71 \times 91.75}{1.21 \times 4180}\right)$

$= 77.2\ ^\circ C$

$\therefore$ error $= \frac{80-77.28}{80} = 3.40\%$

So our assumption is accurate enough.

8.4. Pressure Drop Calculation:

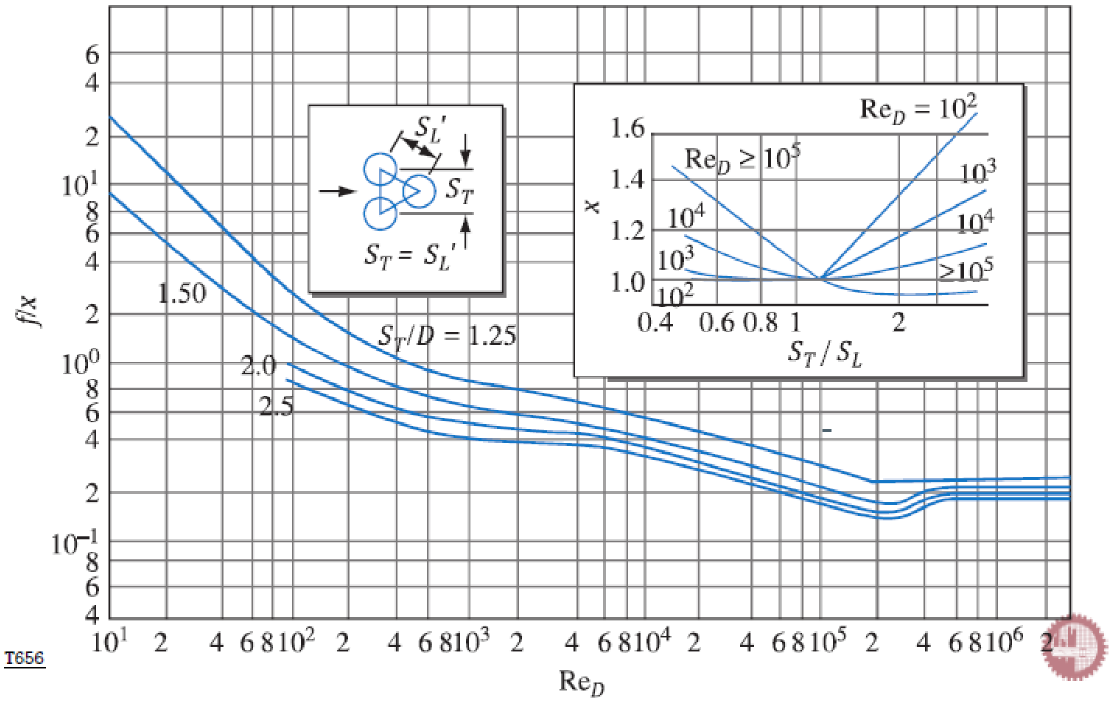

Figure 03 : Chart for f/x calculation [5]

We know, $\Delta P = f\left(\frac{1}{2} \times \rho \times v^2\right) N_L$

Now, $\frac{S_T}{S_L} = 2$; $\frac{S_T}{D} = 2$

$R_e = 6313.57$

$\therefore x = 1$

$\therefore \frac{f}{x} = \ 2 \cdot 1 \times 10^{-1}$

$\therefore x = 1.9 \times 10^{-1}$

$\therefore$ Pressure drop of feedwater, $\Delta P = x = 1.9 \times 10^{-1} \times \left(\frac{1}{2} \times 997 \times 1^2\right) \times 20$ Pa

(Water velocity, v= 1ms^{-1} is assumed)

$\therefore \Delta P = 1356\ Pa$

8.5. Fin Analysis:

Number of fins per tube, $N_{fin} = 35$

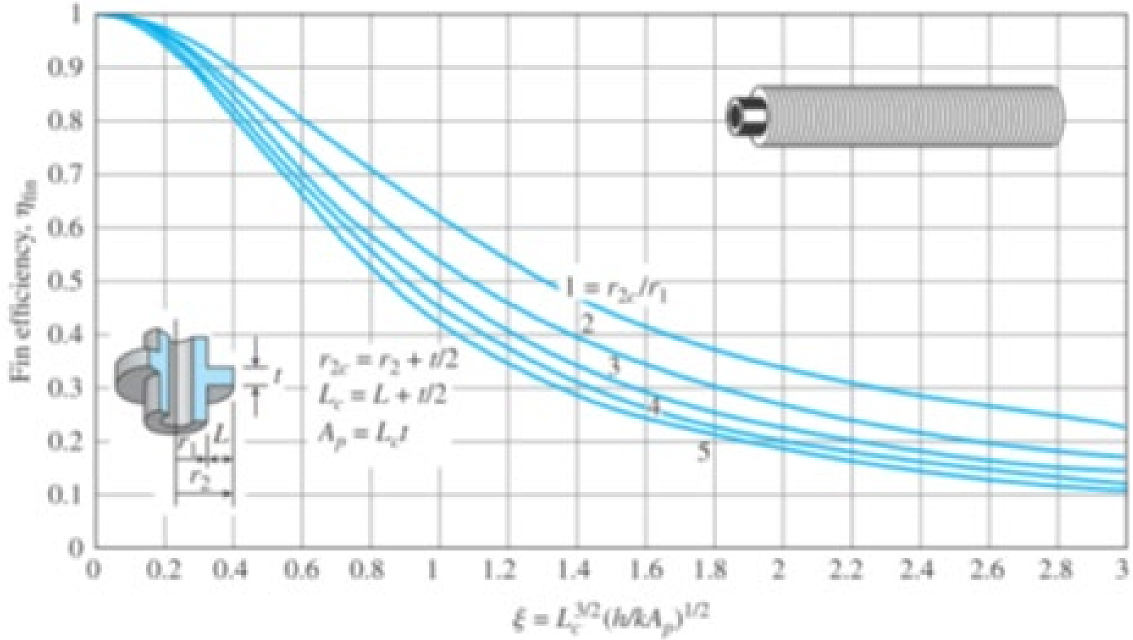

Figure 04 : Chart for fin efficiency [6]

$r_1 = 2.5\ cm = 2.5 \times 10^{-2}\ m$

$r_2 = 3\ cm = 3 \times 10^{-2}\ m$

$t = 0.1\ cm = 1 \times 10^{-3}\ m$

$L = 0.5\ cm = 0.5 \times 10^{-2}\ m$

$$\therefore\ r_{2C} = r_2 + \frac{t}{2} = \left(3 + \frac{0.1}{2}\right) = 3.05\ cm = 3.05 \times 10^{-2}\ m$$

$$L_C = L + \frac{t}{2} = \left(0.5 + \frac{0.1}{2}\right) = 0.55\ cm$$

$$A_P = L_C t = 0.55 \times 0.1 = 0.055\ cm$$

$$A_{fin} = 2\pi\ (r_{2C}^2 - r_1^2) = 2\pi\ (3.05^2 - 2.5^2) = 19.17\ cm^2 = 19.17 \times 10^{-4}\ m^2$$

$$\xi = (L_C)^{\frac{3}{2}}\left(\frac{h}{kA_P}\right)^{\frac{1}{2}}$$

$$\xi = (0.55 \times 10^{-2})^{\frac{3}{2}} \left(\frac{91.75}{239.1 \times 0.055 \times 10^{-4}}\right)^{\frac{1}{2}} = 0.10$$

$$\frac{r_{2C}}{r_1} = 1.22$$

From *figure x*,

$$\eta_{fin} = 0.98$$

$$\therefore A_t = NA_{fin} + \pi D(L - Nt)$$

$$A_t = 35 \times 19.17 \times 10^{-4} + \pi \times 2.5 \times 10^{-2}(0.35 - 35 \times 0.1 \times 10^{-2})$$

$$A_t = 0.09\ m^2$$

$$\therefore \dot{Q} = hA_t\left[1 - \frac{NA_{fin}}{A_t}(1 - n_f)\right](T_S - T_\infty)$$

$$\therefore \dot{Q} = 91.75 \times 0.09\left[1 - \frac{35 \times 19.17 \times 10^{-4}}{0.09}(1 - 0.98)\right](160 - 150)W$$

$$\therefore \dot{Q} = 81.34\ W$$

$$\therefore \dot{Q}_{no\ fin} = h\ A_b(T_S - T_\infty)$$

$$\therefore \dot{Q}_{no\ fin} = 91.75 \times \pi \times 2.5 \times 10^{-2}\ \times 0.35(160 - 150) = 25.22\ W$$

$$\therefore Effectiveness\ of\ fin, \epsilon = \frac{\dot{Q}}{\dot{Q}_{no\ fin}} = \frac{81.34}{25.22} = 3.23$$

So, 35 fins per tube will be beneficial as it will increase heat transfer rate by almost 3.23 times.

9. CAD Model:

The CAD model is based on an actual economizer. The finned tube placed in staggered position on base plate. There are 20 tubes in transverse direction and 10 tubes in longitudinal direction. The fins are located on tube in helical shape. There are almost 35 turns of fin on a single tube so the surface area can be increased to enhance heat transfer. The tube fittings are positioned on outside of base plate to change the direction of feed water. Flue gas enters from downside and exits from outlet later through the chimney. The economizer has overall dimension is in length, in width and in height.

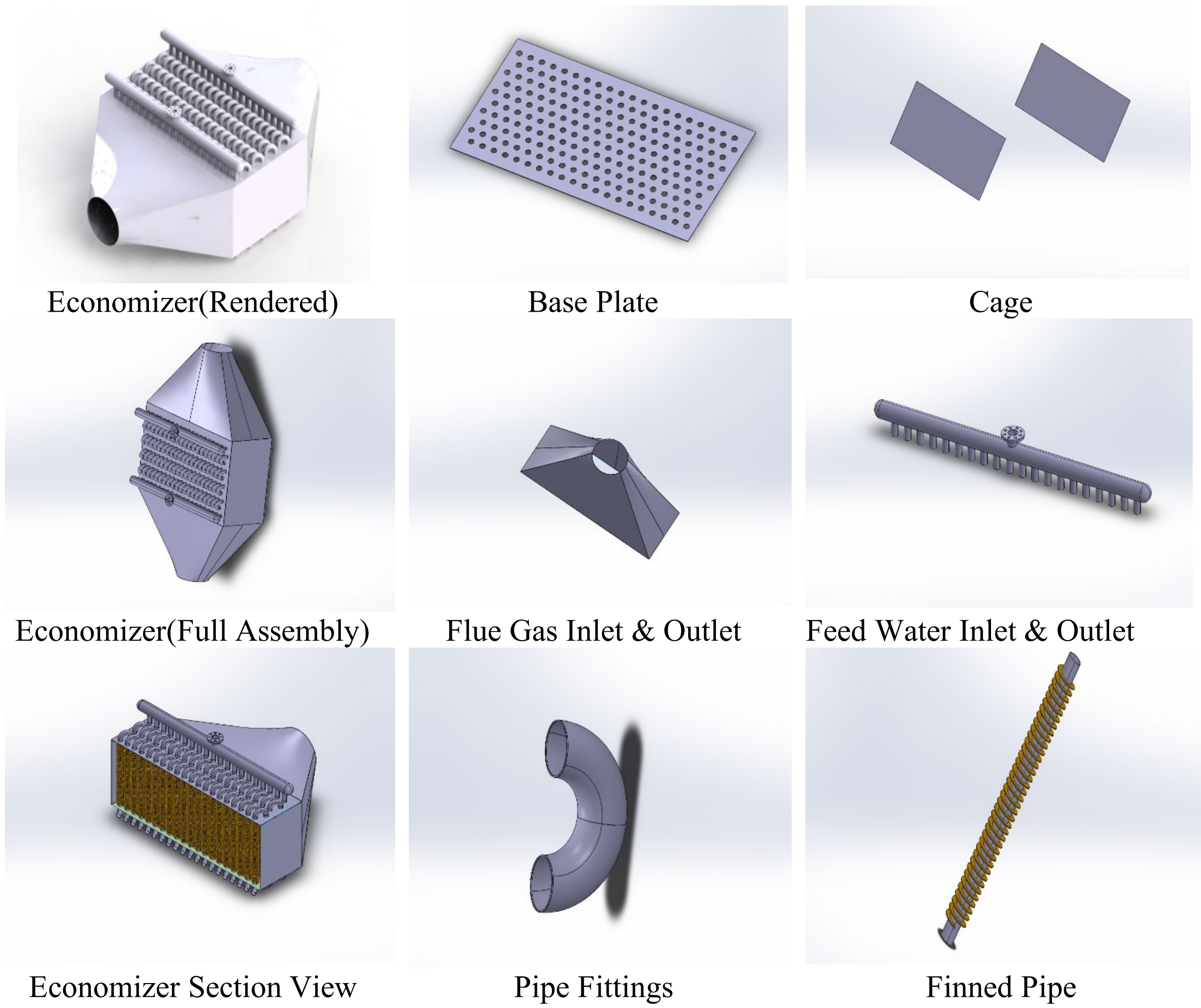

Figure 5: Different Parts of Economizer

9. Ansys Estimation:

To save computational time, only one tube with same amount of fin is modelled in Ansys. A domain around the finned tube is selected for flue gas. The mass flow rate of flue gas is 60 kg/hr and feed water enter the tube with mass flow rate 6 kg/hr. The inlet temperature for water is 300K and the outlet temperature for flue gas is 781K. For up and down surface, adiabatic wall condition is applied. The present model is shown in figure 6.

The main purpose of an economizer in boiler is to increase the temperature of feed water and overall efficiency. From the analysis in Ansys Fluent [figure 9], the outlet temperature of water was found to be raised by 0.57°C. This is a significance increase because the temperature would further raise if all the pipes could be simulated. As the surface area increase with tube number, it will enhance the heat transfer.

From figure 8 it is evident that a temperature gradient is present on fin surface which is an indication of heat transfer. The plain green in figure 7, indicates the inlet velocity of flue gas but it is obstructed by the pipe in the middle thus reducing the velocity.

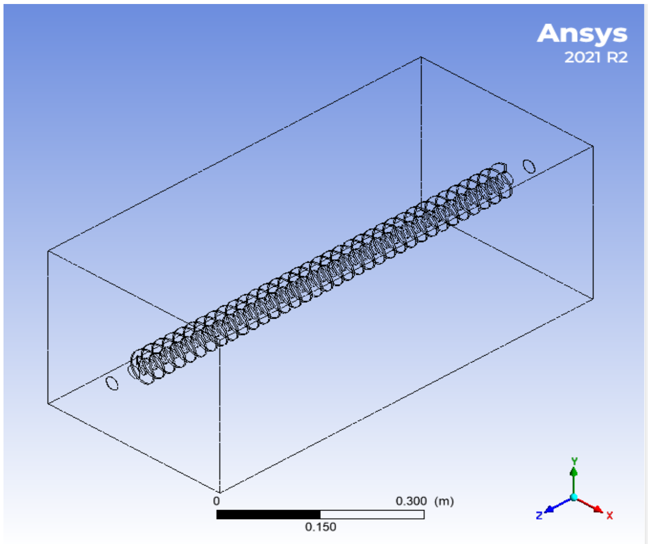

Figure 6: Finned Pipe with Flue Gas Domain

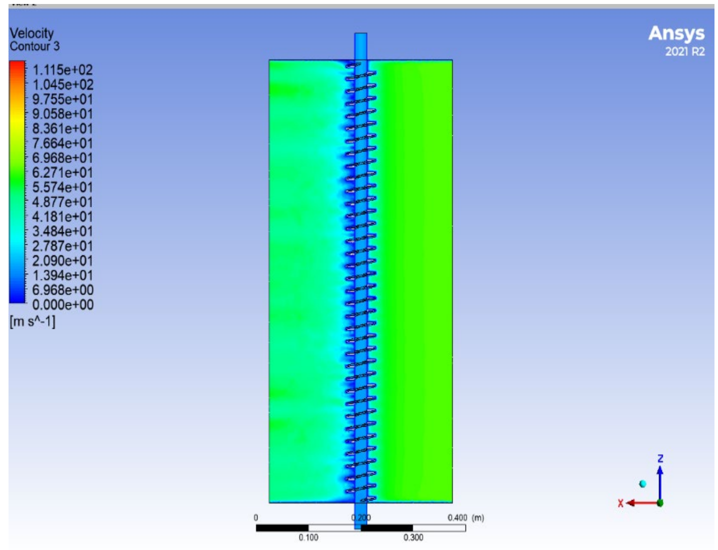

Figure 7: Velocity Variation of Flue Gas

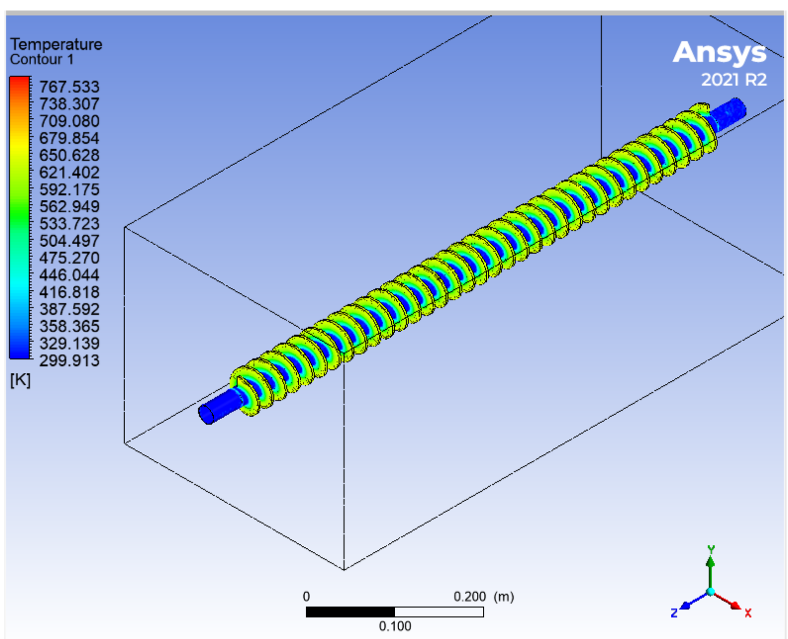

Figure 8 : Temperature Variation Along the Finned Pipe

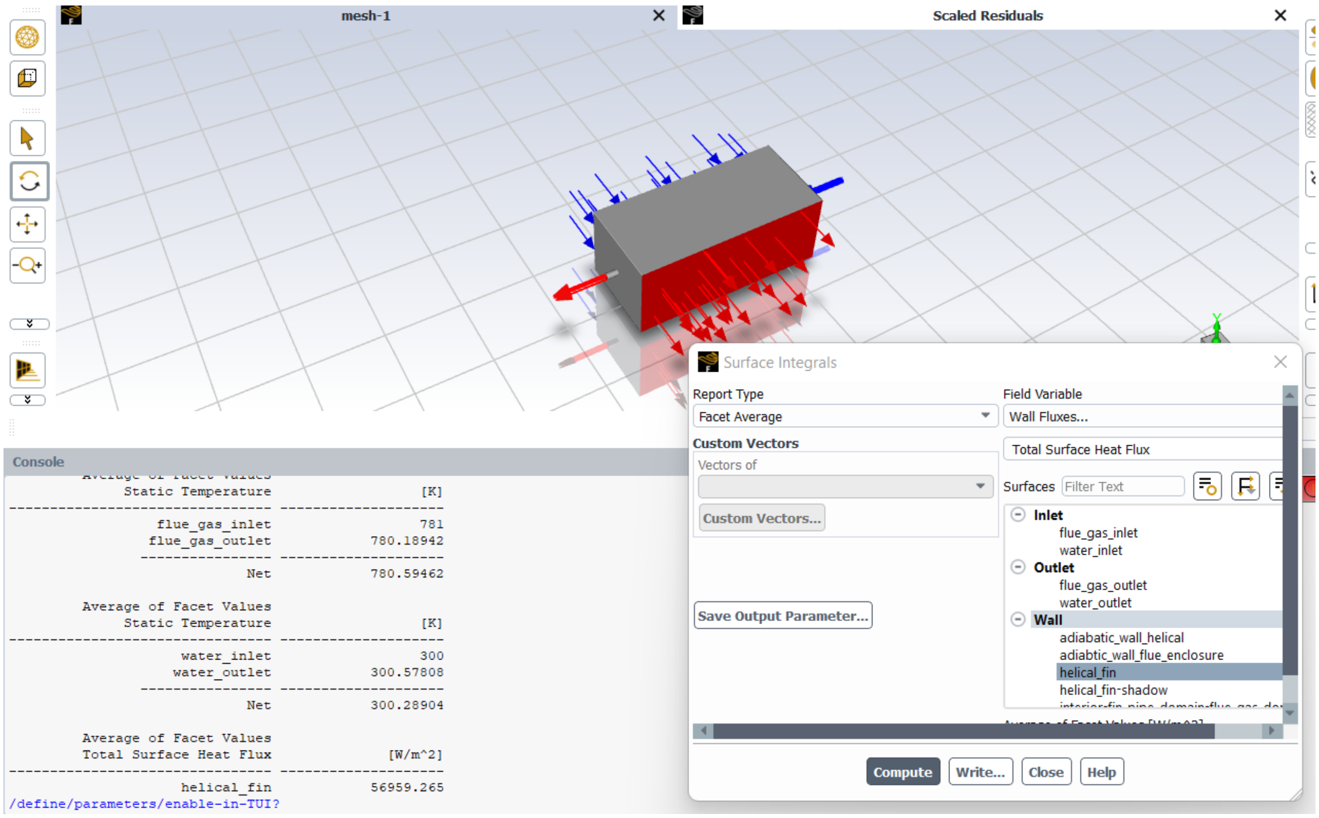

Figure 9: Inlet and Outlet Temperature of Both Water and Flue Gas

10. HTRI Validation:

The mathematical model, calculated using theoretical formula, co-relation & graphs, is later validated using HTRI Exchanger Suite. The overall heat transfer co-efficient got from HTRI report was 98.836 W/m^2-K, which was very close to our theoretical result theoretical result (91.75 W/m^2-K). In figure 15 & 16, the overall heat transfer co-efficient generated from HTRI simulation is shown. Here the value of overall heat transfer co-efficient is varying from 95 to 100 W/m^2-K . In figure 13 & 14, the temperature distribution of the hot fluid & cold fluid is shown. Here we can see that the temperature rise in the feedwater & the temperature drop in the flue gas is identical with our mathematical model. Later we generated a graph of pressure drop inside the tube of feedwater, where we got the pressure drop in the range of 1000-1050 Pa (figure 17) & we got our theoretical result of tube side pressure drop as 1356 Pa which is very close. Also we generated an isometric model from HTRI that is shown n figure 10, & it was very much identical with our solidworks model. Also, the front view & the schematic of pipe layout is shown figure x & y. So we can say that, our mathematical model was correct.

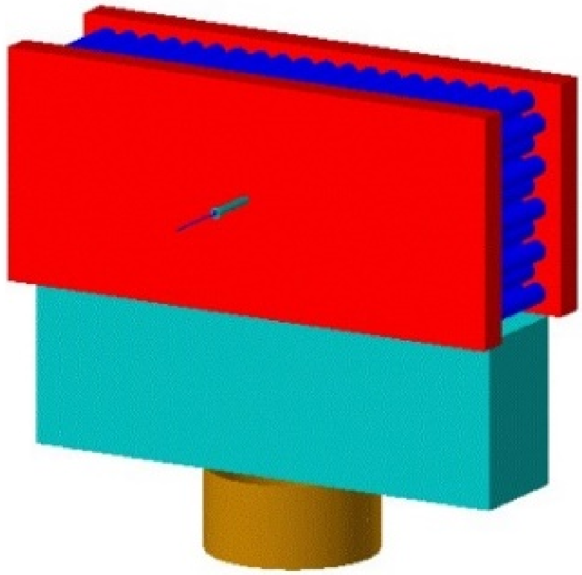

Figure 10 : 3D model from HTRI

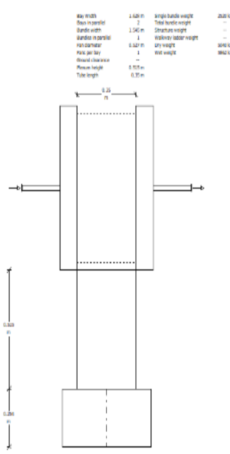

Figure 11 : 2D Front view from HTRI

ID	Name	Type	Outer Diameter (mm)	Wall Thickness (mm)	Transverse Pitch (mm)	Longitudinal Pitch (mm)	Fin Height (mm)
T1	TubeType1	Plain	63.5000	1.0000	75.0001	64.9501	n/a

Row From Top	Number of Tubes	Tube Type Name	Wall Clearance (mm)	Row From Top	Number of Tubes	Tube Type Name	Wall Clearance (mm)
1	20	TubeType1	9.5250	6	20	TubeType1	47.0251
2	20	TubeType1	47.0251	7	20	TubeType1	9.5250
3	20	TubeType1	9.5250	8	20	TubeType1	47.0251
4	20	TubeType1	47.0251	9	20	TubeType1	9.5250
5	20	TubeType1	9.5250	10	20	TubeType1	47.0251

Bundle Information
Bundle width 1.545 m
Number of tube rows 10
Number of tubes 200
Minimum wall clearance
Left 9.5250 mm
Right 9.5250 mm
Number of tubes per pass
O Tubepass # 1: 200

Figure 12 : Tube layout from HTRI

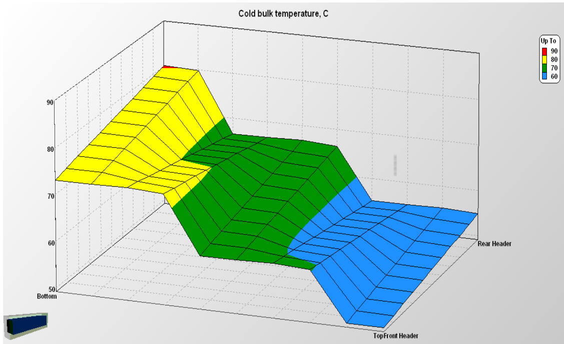

Figure 13 : Temperature distribution (cold13fluid)

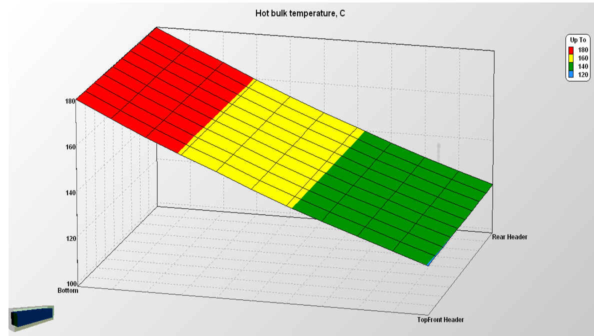

Figure 14 : Temperature distribution (Hot fluid)

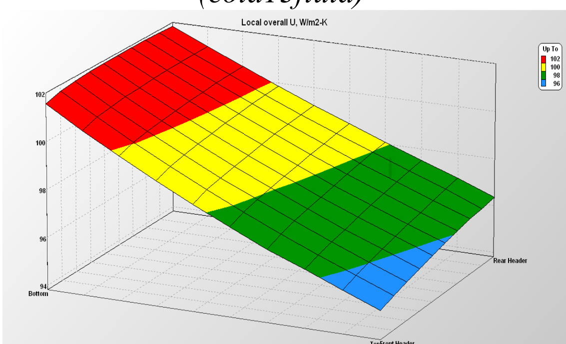

Figure 15 : Local Overall U (3D)

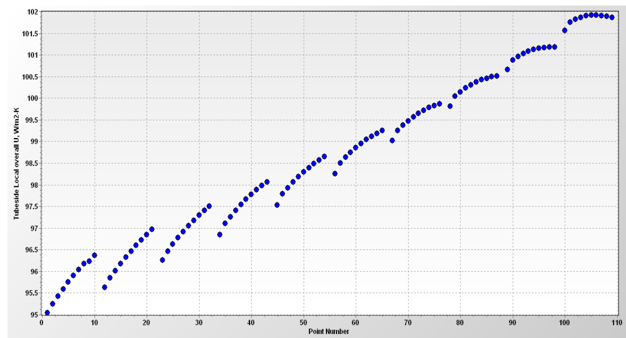

Figure 16 : Local Overall U (2D)

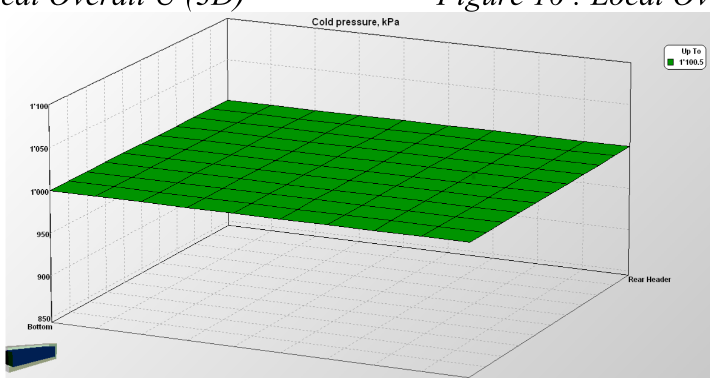

Figure 17 : Pressure drop of feedwater inside the tubes

11. Economic Calculation:

During our project of non-condensing economizer, the economic calculation to find the insulation layer thickness and payback period, was done using the 3E plus software. For the calculation the base material used is Stainless Steel. Insulation material is 1000MF Board Type III(Wool). And the economic thickness we got from the detailed economic analysis is single layer 25mm thickness. The payback period is 3.51 years, and the estimated surface temperature is 45C. The final output of detailed economic calculation which was done using the 3E Plus Software is attached below -

NAIMA 3E Plus 4.1

Group A12
BUET
Dhaka
Phone Number

Item ID = 1
Item Description = Non Condensing Economizer

Fuel Type = Flue Gas
Heat Content =
Fuel Cost =
Efficiency = 75 %
Annual Fuel Escalation Rate = 0 %/yr
Process Temp = 180°C
Ambient Temp = 30.0 °C
Wind speed = 0.0 m/s
Hours Per Year = 8320
Installation Complexity = Average
Discount Rate = 5 %
Effective Income Tax Rate = 0 %
Physical Plant Depreciation Period = 10 years
Expected Service Life of Insulation = 10 years
Incremental Cost of Plant Capacity = 0 \$/MMBtu/hr
Percent of New Insulation Cost for Annual Insulation Maintenance = 0 %
Percent of Annual Fuel Bill for Physical Plant Maintenance = 0 %
Reference Thickness for Payback Calculations = 0 mm
Material Price, \$/ft for 2x2 pipe insulation, including jacket = 2.00\$/m
Material Price, \$/sqft for 2 inch thick board or block, including jacket = 2.00\$/sqm
Labor Rate, \$/hr including overhead = 5 \$/hr

Labor Rate, $/hr including overhead = 5 $/hr

Labor Productivity Factor = 100

Emittance of outer jacketing = 0.9 All Service Jacket

Complexity factor = 1.3

Horizontal Cylinder

Size = 15 mm

Base Material = Stainless Steel

Emittance of existing surface = 0.3

Insulation material = 1000F MF BOARD, Type III, C612-11

Insulation costs estimated by FEA method.

Insulation Thickness	Insulation Cost	Annualized Cost	Payback Period	Heat Loss	Surface Temp
mm	$/m	$/m	Years	J/hr/m	°C
25	3.28	0.82	3.51	135289	45
38	4.08	0.85	4.12	109549	40
51	4.95	0.92	4.93	96888	37
64	5.46	0.95	5.32	84499	35
76	6.10	1.02	5.96	79379	34
102	8.93	1.38	9.24	72106	33
Double Layer					
76	8.02	1.28	8.28	79379	34
102	10.77	1.61	11.81	72106	33
127	13.59	1.97	16.14	66826	33
152	16.41	2.30	21.65	62784	32

The Economic Thickness is single layer 25 mm.

12. Conclusion:

When economizer is used in a boiler the efficiency is increased significantly. Without boiler the combustion efficiency is around 80% whereas with the economizer it shoots up to 86% [7]. Low pressure economizer needs very low exergy in compared to boilers which has no economizer. [7] Our non-condensing economizer uses the waste flue gas to heat the feedwater from 50° C to 80° C which increases the efficiency of the boiler and reduces the thermal stresses. And as the payback period is also not very high it is very much useful from the economic perspective too. There are also some future plans regarding the project which includes market study, completion of the whole project, market launching, expansion of the project, further research and overall efficiency improvement.

13. Index

To view our presentation file & ANSYS simulation video, click here.

14. References:

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