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UTILIZATION OF WASTE HEAT FROM WASTE HEAT RECOVERY BOILER THROUGH A WATER TUBE HEAT EXCHANGER

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ABSTRACT
Rotary kiln the there is lots of amount of heat is generated during the combustion of coal and that heat to be utilized before throwing it into the environment. Waste heat recovery boiler is quite suitable to utilize that heat from kiln but there is region in boiler where the heat is not utilized efficiently. So, the approach should be made for same purpose. But it is necessary to use waste heat in such a form to make system efficient and productive. Then we have decided to design the heat exchanger for that particular region. But condensate extraction pump (CEP) and deaerator works on low temperature and pressure, so it is necessary to design heat exchanger in same way. Water will be feed through condensate extraction pump (CEP) and condensate water heated in heat exchanger and then goes to deaerator. This water will reduce the fuel consumption and will make system cost effective.

KEYWORDS: Waste heat recovery boiler (WHRB), heat exchanger, Condensate extraction pump (CEP), deaerator.

1. INTRODUCTION

Rotary kiln process
Rotary kiln is nothing but cylindrical long vessel placed horizontally with some inclination to guide the material flow in downward side. In which material feed from its inlet side and transferred to outlet side by rotating it. In material the mixture of iron ore high fixed carbon coal and dolomite is feed. But for reaction it is necessary to inject coal fines from outlet side to gain temperature and reaches to reaction temperature. By this way lots heat is generated during the process and that heat is generated during the process and that can be utilized in waste heat recovery boiler.

Water tube heat exchanger process
Waste heat recovery boiler is a water tube boiler and will be used as heat recovery boiler but with some limitation it cannot be utilized 100%. As per study we found that some of the waste heat can be utilized in ESP inlet and economizer outlet. This waste heat can be utilized by a designing water tube heat exchanger. Water tube heat exchanger will be installed in between electrostatic precipitator (ESP) inlet and economizer outlet and condensate water will feed from Condensate extraction pump (CEP) and water heated from 60 ºC up to 125 ºC. The temperature difference is 65 ºC. Water will go to deaerator. It is basically sensible type of heat exchanger which gains sensible heat. By this is way we have tried to make system efficient and effective.

Waste heat recovery systems
- Recuperator.
- Economizer.
- Regenerator.
- Condenser.
- Heat pipe.
- Waste heat recovery boiler.

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2. DESIGN

1. Calculate number of heat exchanger tubes

Table 1.Given data for water tube heat exchanger

Total mass flow rate of CEP condensate water m_w	175957 kg/hr
Margin mass flow rate of CEP condensate water m_w	12996 kg/hr
Margin mass flow rate of CEP condensate water m_w	3.61 kg/sec
Water temperature at heat exchanger inlet T_{c1}	333 k
Water temperature at heat exchanger inlet T_{c1}	60 ºC
Mass flow rate of flue gas from 500TPD kiln m_{fg}	161640 kg/hr
Mass flow rate of flue gas from 500TPD kiln m_{fg}	44.90 kg/sec
Flue gas temperature at economizer outlet T_{h1}	473 k
Flue gas temperature at economizer outlet T_{h1}	200 ºC
Flue gas temperature at ESP inlet T_{h2}	453 k
Flue gas temperature at ESP inlet T_{h2}	180 ºC

2. Heat transfer rate of flue gas (Q)

$$Q = m_{fg} \times c_{p\,(fg)} \times (T_{h_1} - T_{h_2})$$
$$Q = 44.90 \times 1.097 \times (473-453)$$
$$Q = 985.106 \text{ kj/sec}$$

3. Heat loss by hot flue gases and heat gained by condensate water

$$m_{fg} \times c_{p\,(fg)} \times \Delta T = m_w \times c_{p\,(w)} \times \Delta T$$
$$m_{fg} \times c_{p\,(fg)} \times (T_{h_1} - T_{h_2}) = m_w \times c_{p\,(w)} \times (T_{c_2} - T_{c_1})$$
$$44.90 \times 1.097 \times (473 - 453) = 3.61 \times 4.185 \times (T_{c_2} - 333)$$
$$T_{c_2} = 398 \text{ K } (125\ ^\circ\text{C})$$

4. Log mean temperature difference (ΔT)

$$\Delta T = \frac{(T_{h_1} - T_{c_2}) - (T_{h_2} - T_{c_1})}{\ln\left[\frac{T_{h_1} - T_{c_2}}{T_{h_2} - T_{c_1}}\right]}$$
$$\Delta T = \frac{(473 - 398) - (453 - 333)}{\ln\left[\frac{473-398}{453-333}\right]}$$
$$\Delta T = 368.74 \text{ K } (95.74\ ^\circ\text{C})$$
$$\Delta T_{lm} = F \times \Delta T_{lm\,(\text{counter flow})}$$
$$\Delta T_{lm} = 0.99 \times 95.74$$
$$\Delta T_{lm} = 367.78 \text{ k } (94.78\ ^\circ\text{C})$$

Table 2.Find out data for water tube heat exchanger

Heat transfer coefficient of water $h_{i\,(w)}$	5250.74 w/m²k
Heat transfer coefficient of flue gas $h_{total\,(fg)}$	140.31 w/m²k
Overall heat transfer coefficient U_o	133.84 w/m²k
Capacity ratio (C)	0.3
NTU	0.74
Surface area of tube (A)	77.65 m²

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5. Number of tube(N)

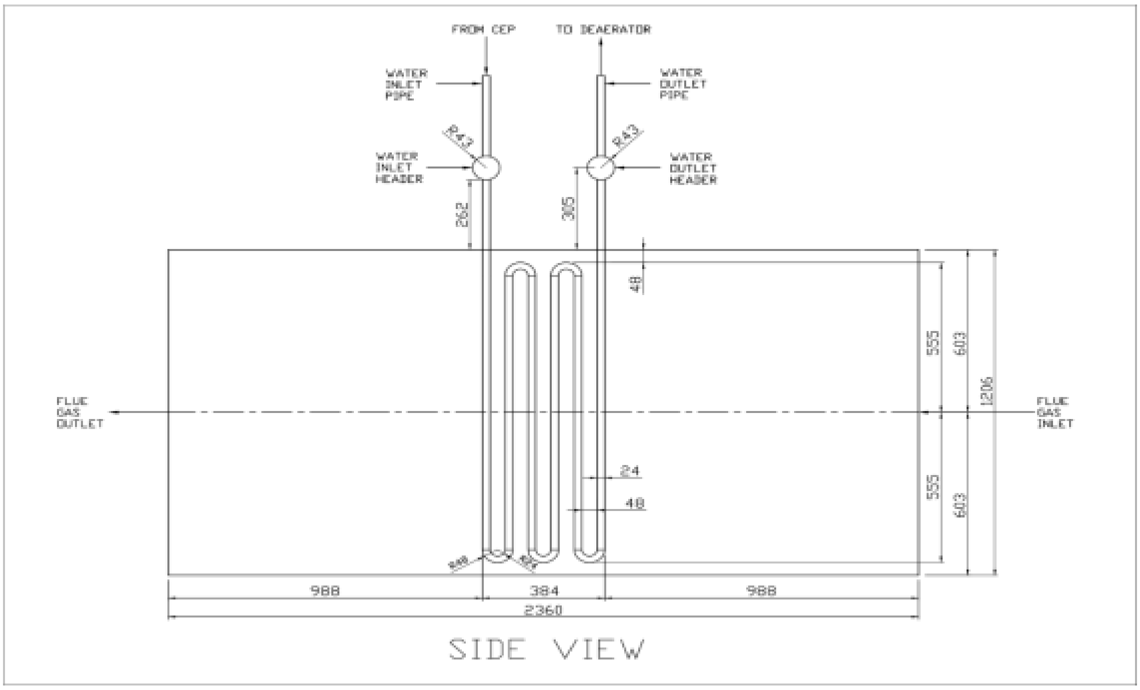
$$A = \pi \times d_o \times L \times N \times P$$
$$77.65 = 3.14 \times 0.024 \times 1.110 \times N \times 6$$
$$N = 156$$

6. Effectiveness of counter flow heat exchanger (ϵ)

$$\epsilon = \frac{1 - e^{[-NTU(1-c)]}}{1 - ce^{[-NTU(1-c)]}}$$
$$\epsilon = \frac{1 - e^{[-0.74(1-0.3)]}}{1 - 0.3 \times e^{[-0.74(1-0.3)]}}$$
$$\epsilon = 0.5$$

Table 2.Specification of water tube heat exchanger

Number of tubes (N)	156
Passes Or Pitch (S_L)	Longitudinal (6)
Passes Or Pitch (S_T)	Transverse (26)
Length of tube	1.110 m
Tube OD	24 mm
Tube ID	16 mm
Tube thickness	8 mm
Arrangement	Inline
Flow	Cross
Weight of heat exchanger with water	457 kg
Water holding capacity	58.12 litre



Water tube heat exchanger (Side view)

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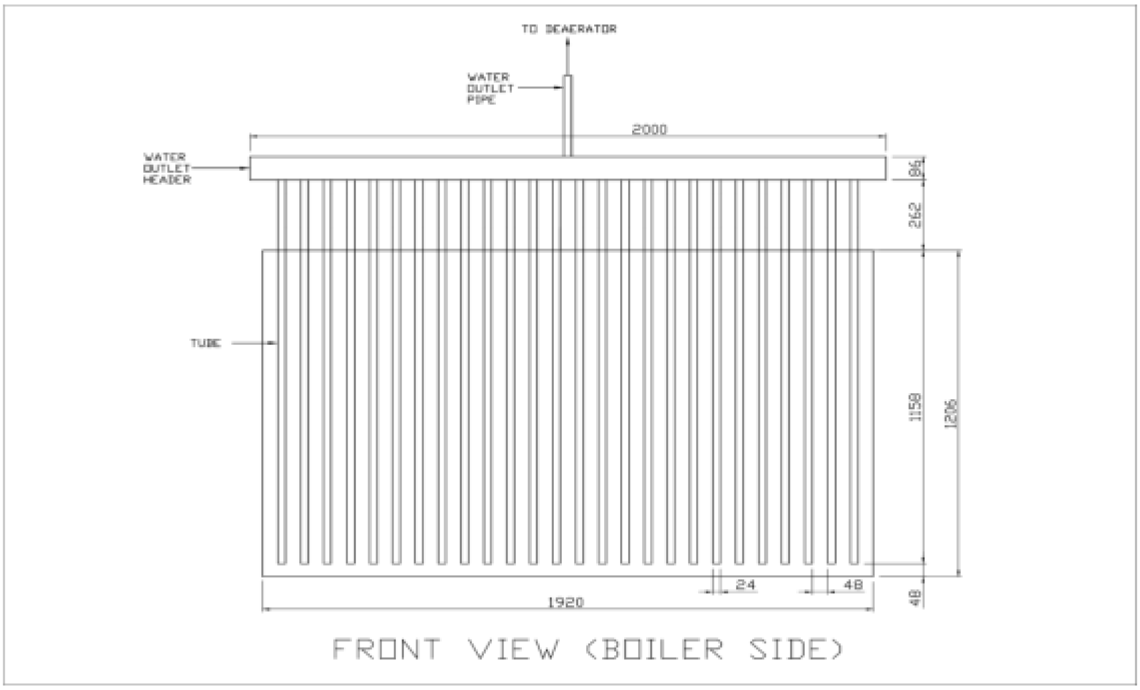

Water tube heat exchanger (Front view)

7. Calculate pressure drop (Δp)

7.1. *Calculate pressure drop between CEP to HE (Δp₁)*

$$\frac{p_1}{\rho \times g} + \frac{v_1^2}{2 \times g} + z_1 = \frac{p_2}{\rho \times g} + \frac{v_2^2}{2 \times g} + z_2 + h_{L3\,(total)}$$
$$\frac{700000}{983 \times 9.81} + \frac{0.75^2}{2 \times 9.81} + 0 = \frac{p_2}{983 \times 9.81} + \frac{0.75^2}{2 \times 9.81} + 14 + (3.3808)$$
$$p_2 = 5.3239 \text{ bar}$$
$$\Delta p_1 = p_2 - p_1$$
$$\Delta p_1 = 7 - 5.3239$$
$$\Delta p_1 = 1.6761 \text{ bar}$$

7.2. *Calculate pressure drop at HE (Δp₂)*

$$\frac{p_2}{\rho \times g} + \frac{v_2^2}{2 \times g} + z_2 = \frac{p_3}{\rho \times g} + \frac{v_3^2}{2 \times g} + z_3 + h_{L\,(total)}$$
$$\frac{532390}{983 \times 9.81} + \frac{0.75^2}{2 \times 9.81} + 0 = \frac{p_3}{983 \times 9.81} + \frac{0.75^2}{2 \times 9.81} + 0 + (9.1546)$$
$$p_3 = 4.4411\text{bar}$$
$$\Delta p_2 = p_2 - p_3$$
$$\Delta p_2 = 5.3239 - 4.4411$$
$$\Delta p_2 = 0.8828 \text{ bar}$$

7.3. *Calculate pressure drop between HE to deaerator (Δp₃)*

$$\frac{p_3}{\rho \times g} + \frac{v_3^2}{2 \times g} + z_1 = \frac{p_4}{\rho \times g} + \frac{v_4^2}{2 \times g} + z_2 + h_{L\,(total)}$$
$$\frac{444110}{983 \times 9.81} + \frac{0.75^2}{2 \times 9.81} + 0 = \frac{p_4}{983 \times 9.81} + \frac{0.75^2}{2 \times 9.81} + 6 + (5.4508)$$
$$p_4 = 3.3368 \text{ bar}$$
$$\Delta p_3 = p_3 - p_4$$

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$$\Delta p_3 = 4.4315 - 3.3368$$
$$\Delta p_3 = 1.0947 \text{ bar}$$

7.4. ***Calculate total pressure drop (Δp)***

$$\Delta p = p_1 - p_4$$
$$\Delta p = 7 - 3.3368$$
$$\Delta p = 3.6632 \text{ bar}$$

8. Calculate Total pressure drop across tube and across duct (Δp)

8.1. ***Total pressure drop across tube (Δpd_o)***

$$\Delta p = N_L \times f \times x \times \left(\frac{\rho \times v_{max}^2}{2}\right)$$
$$\Delta p = 4 \times 0.5 \times 1 \times \left(\frac{0.748 \times 16^2}{2}\right)$$
$$\Delta p = 287.23 \text{ n/m}^2$$
$$\Delta p = 29.2893 \text{ mmwc}$$

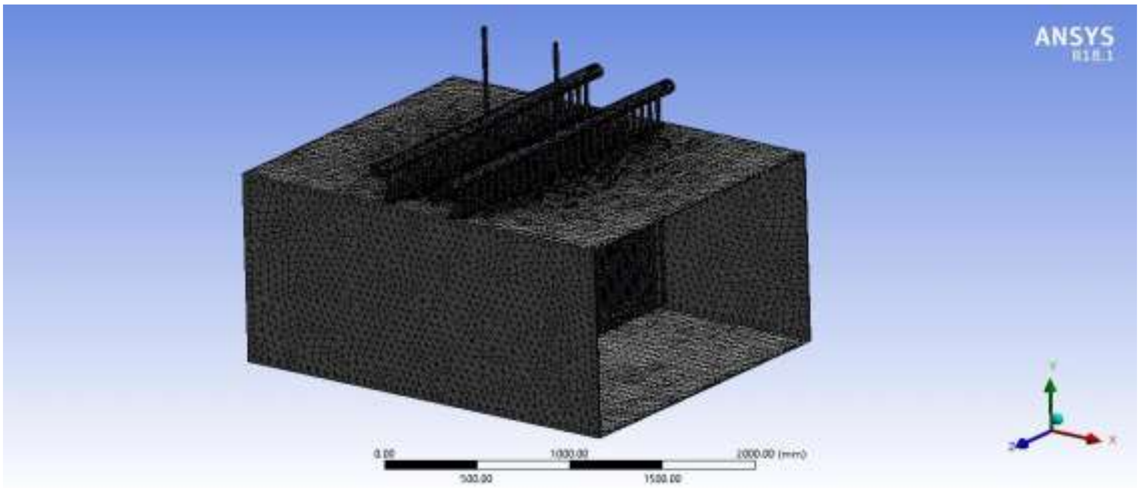
8.2 ***Pressure drop across duct (Δp_{Duct})***

$$\Delta p = \frac{f \times L}{m}\left[\frac{V}{4.04}\right]^2$$
$$\Delta p = \frac{0.005 \times 2.36}{0.3516}\left[\frac{8}{4.04}\right]^2$$
$$\Delta p = 0.1315 \text{ mmwc}$$

8.3 ***Total pressure drop across tube and across duct (Δp)***

$$\Delta p = \text{pressure drop across tube outside} + \text{pressure drop in rectangle duct}$$
$$\Delta p = 29.2893 + 0.1315$$
$$\Delta p = 29.4208 \text{ mmwc}$$

9. Thermal Analysis



Model (C4) Mesh 1 of 2

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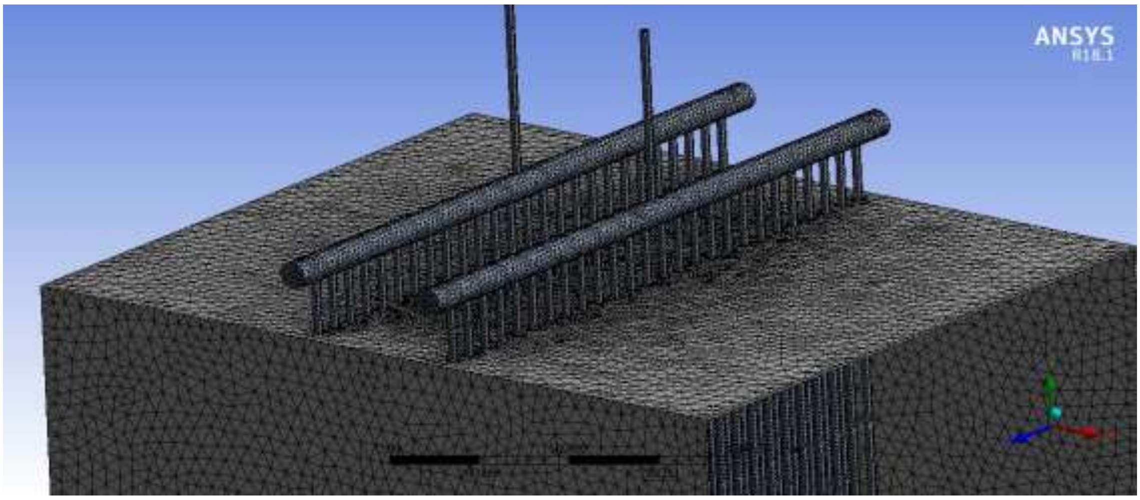
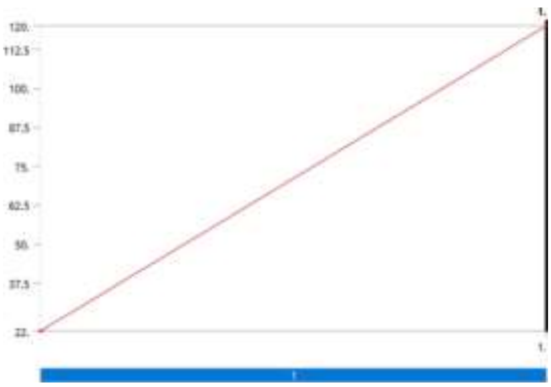


Model (C4) Mesh 2 of 2

Model (C4) steady state thermal (C5) temperature 1 of 2



Model (C4) steady state thermal (C5) temperature 2 of 2

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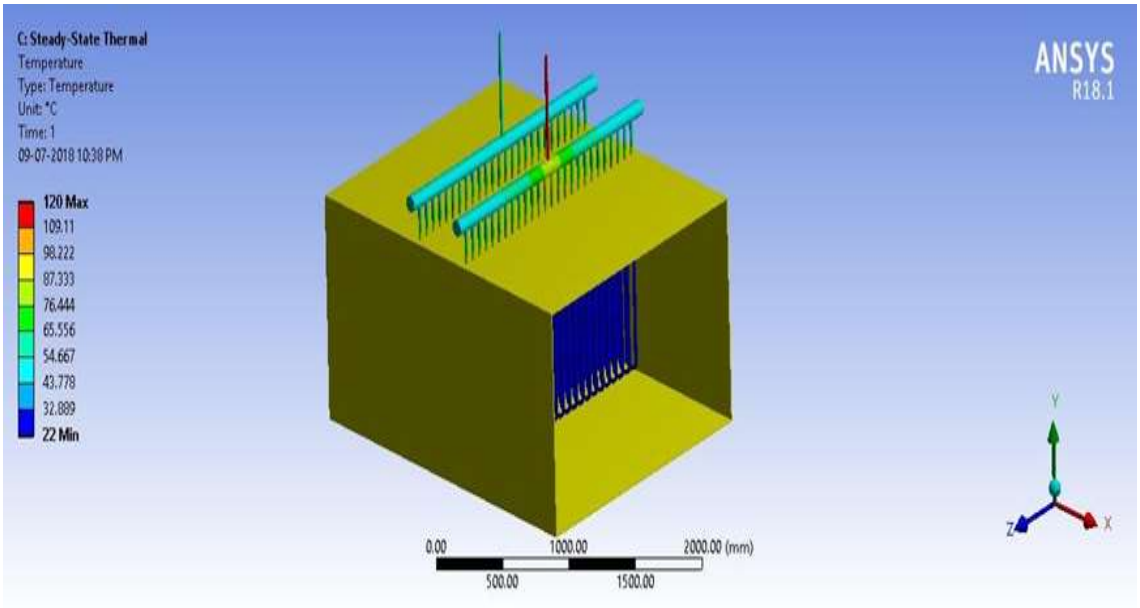
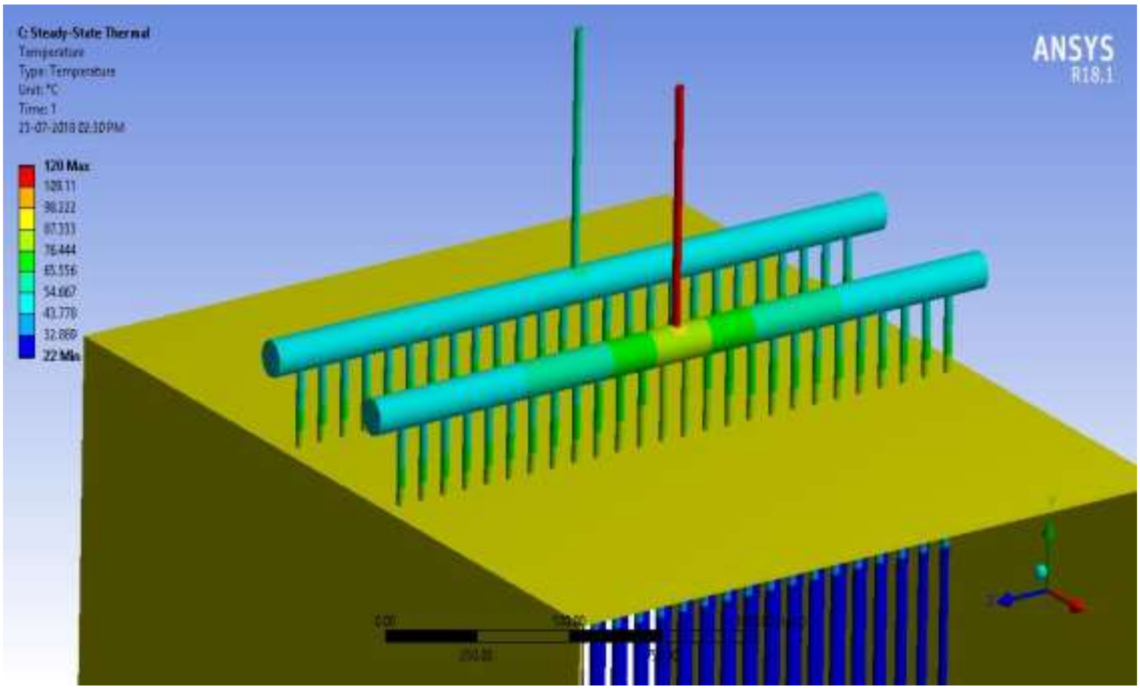
10. CFD Analysis



Model (C4) steady state thermal (C5) solution (C6) temperature profile 1 of 2



Model (C4) steady state thermal (C5) solution (C6) temperature profile 2 of 2

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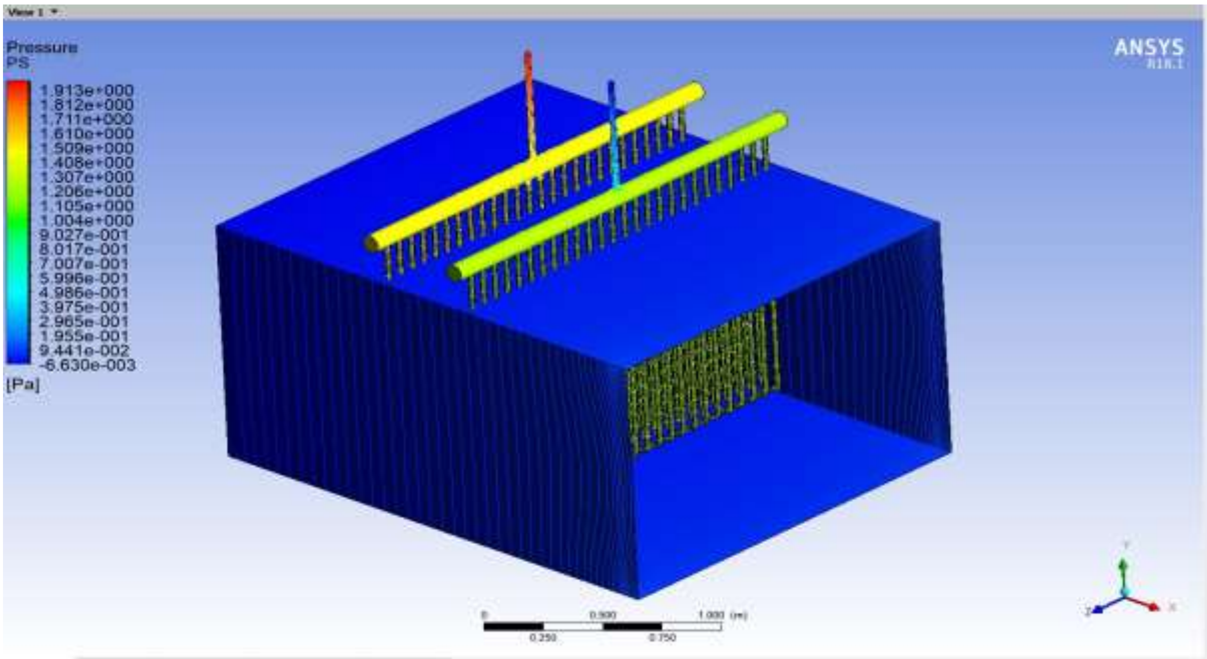
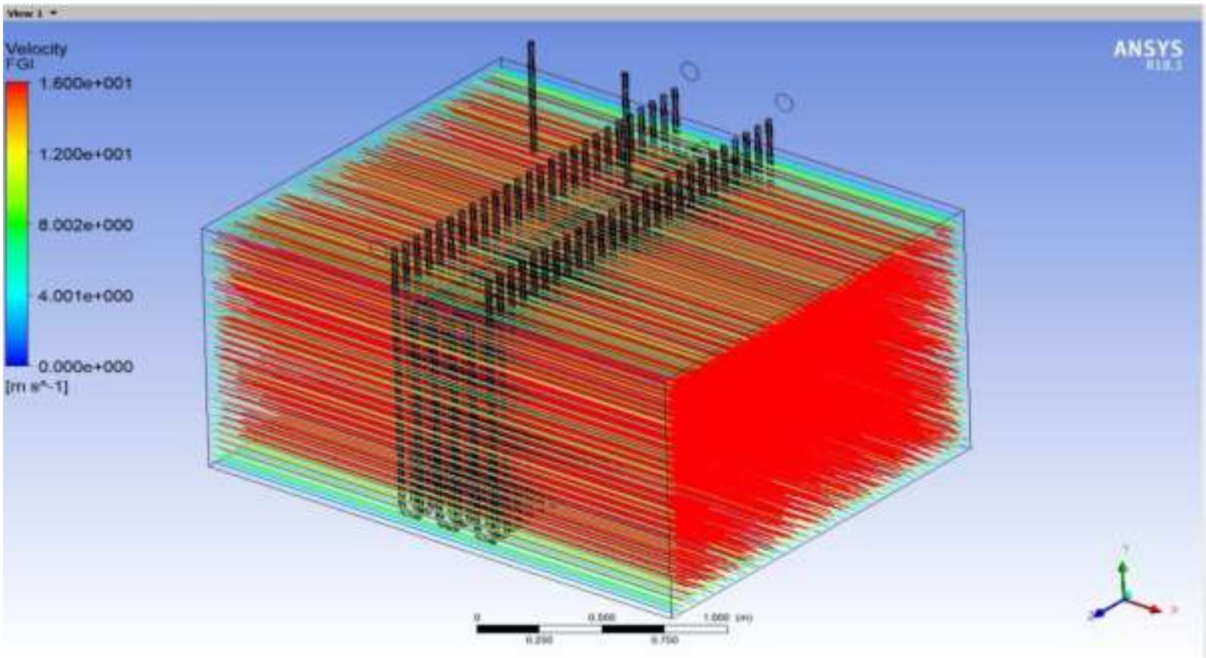


Model (C4) steady state thermal (C5) solution (C6) pressure profile



Model (C4) steady state thermal (C5) solution (C6) velocity profile

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3. RESULTS

a. Heat gain across heat exchanger

$$1\frac{\text{kj}}{\text{sec}} = 860.421\frac{\text{Kcal}}{\text{hr}}$$
$$Q = 985.106\frac{\text{kj}}{\text{sec}}$$
$$Q = 847605.8896\frac{\text{Kcal}}{\text{hr}}$$

b. Total saving in rupees per year (I-coal)

$$\text{Total saving of coal} = \frac{\text{Heat gain across heat exchanger}}{\text{GCV of coal}}$$
$$\text{Total saving of coal} = \frac{847605.8896}{3400}$$
$$\text{Total saving of coal} = 249.2958 \text{ kg/hr}$$
$$\text{Total saving of coal} = 0.2492958 \text{ ton/hr}$$
$$\text{Total saving of rupees per hour} = \text{Coal Rupees per ton } \times \text{Total saving of coal ton per hour}$$
$$= 3500 \times 0.2492958$$
$$\text{Rs per hr} = 872$$
$$\text{Total saving of rupees per day} = \text{Tatal saving of rupees per hour} \times 24$$
$$= 872 \times 24$$
$$\text{Rs per day} = 20928$$
$$\text{Total saving of rupees per Month} = \text{Tatal saving of rupees per day} \times 30$$
$$= 20928 \times 30$$
$$\text{Rs per month} = 627840$$
$$\text{Total saving of rupees per year} = \text{Tatal saving of rupees per month} \times 12$$
$$= 627840 \times 12$$
$$\text{Rs per year} = 7534080$$

4. CONCLUSION

a. Heat transfer rate of flue gas of installed new heat exchanger (Q_2)

$$Q = m_{fg} \times c_{p\,(fg)} \times (T_{h_1} - T_{h_2})$$
$$Q = 44.90 \times 1.097 \times (473 - 453)$$
$$Q = 985.106 \text{ kj/sec}$$

b. Total heat transfer rate of flue gas of WHRB (Q_1)

$$Q = m_{fg} \times c_{p\,(fg)} \times (T_{h_1} - T_{h_2})$$
$$Q = 44.90 \times 1.332 \times (1223 - 373)$$
$$Q = 50454.13 \text{ kj/sec}$$
$$\text{Heat transfer rate of flue gas (Q)} = \frac{Q_1 - Q_2}{Q_1} \times 100$$
$$\text{Heat transfer rate of flue gas s (Q)} = \frac{50454.13 - 985.10}{50454.13} \times 100$$
$$\text{Heat transfer rate of flue gas (Q)} = 98\ \%$$
$$\text{Utilised of heat transfer rate of flue gas} = 100 - \text{Heat transfer rate of flue gas (Q)}$$
$$\text{Utilised of heat transfer rate of flue gas} = 100 - 98$$
$$\text{Utilised heat transfer rate of flue gas} = 2\%$$

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c. Payback period on the basis of I coal

$$\text{Payback period} = \frac{\text{Total project cost}}{\text{Actual profit per day}}$$
$$\text{Payback period} = \frac{185000}{20928}$$
$$\text{Payback period} = \frac{185000}{20928}$$
$$\text{Payback period} = 8.83 \text{ Days}$$
$$\text{Payback period} = 9 \text{ Days}$$

d. Water tube heat exchanger successfully designed for WHRB

- Waste heat is used from WHRB.
- As suggested by energy auditor that, 5% total heat is remains unutilized between ESP and economizer, it can be utilize by placing heat exchanger in between.
- We analyzed that 5% of flue gases is wasted from the WHRB. So, we suggested for installation of a water tube heat exchanger to recover a waste heat up to 2%.
- Water tube heat exchanger (Inline arrangement and cross flow type).
- It is a vertical and bends in U shape.

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