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Analysis of Heat Recovery from Top Coat Oven Exhaust in Paint Shop

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***Abstract* — Presently in paint shop there are three types of ovens i.e. Electro deposition (ED) oven, Top coat oven and Primer oven. Our focus is on (top coat) TC oven. Currently, the exhaust which is at high temperature from the oven is directly exhausted to environment. The exhausted flue gases temperature is around 280^{0}C -340^{0}C. The proposed system is to reuse that hot exhaust gases for hot water generation. The hot water generated will be at approximately 110^{0}C. Total heat energy required for hot water generation is 1253 KW. Hence the potential of energy recovery & reuse can be realized. About 843 KW of energy can be recovered from TC oven exhaust. The proposed system consists of shell & tube heat exchanger with counter flow arrangement. Tube shape has a significant impact on the heat recovery. In this study Computational Fluid Dynamics (CFD) is used to investigate the effect of different tube cross sections with the same surface area on heat transfer resistance, gas flow resistance & heat recovery. Four types of different shapes i.e. circular, square, hexagon & flattened round are used and the shape which required minimum time to heat the water is selected with the use of CFD technique. Objective of this proposal is to reuse the heat generated by TC oven for generation of hot water. The exhaust energy from top coat oven is around 843 kW. According to proposed system our target is to get 90% efficiency in heat recovery i.e. 760 kW of energy. The flow rate of exhaust air is maintained at 12000nm3/hr. The unused heat from oven is use to generate hot water (110^{0}C) which will be supplied to pretreatment and oil conservation processes. This reuse of heat will save the energy along with the CNG consumption required for boiler to heat the water.**

Keywords—Computational fluid dynamics; Energy conservation; Heat recovery; Paint curing oven; Shell and tube heat exchanger

I. INTRODUCTION

Industrial ovens are heated chambers used for a variety of industrial applications, including drying, curing, or baking components, parts or final products. Industrial ovens can be used for large or small volume applications, in batches or continuously with a conveyor line, and a variety of temperature ranges, sizes and configurations. Such ovens are used in many different applications, including chemical processing, food production, and even in the electronics industry, where circuit boards are run through a conveyor oven to attach surface mount components [2-3]. The oven tunnel is part of the unit visible from outside. The drying process takes place inside it. The tunnel has an internal paneling, the circulation ducts, a thick insulation of rock wool and an external plate panel [8]. To prevent escape of gases and vapors, the internal paneling and the circulation ducts of the oven are welded to make them gas-tight. The installed insulation layer is for energy saving. The factor of the heavy temperature fluctuations necessarily needs requirements in the oven construction. So for that the oven tunnel is movable means as steel expands on heating, the tunnel provide expansion at compensation points. On an average, each meter of the oven expands by 1 mm on heating by 100°C. As inflow as well as outflow of the oven is fixed, the expansion must be internally compensated. A special problem is the internal expansions in the oven. The insulation causes the external skin to expand less than the interior. This change of state is countered by appropriate movement. On longer ovens, side doors are provided for the service access. The most important point is that the doors are absolutely tight and no heat and vapors from the interior doesn't reach to outside. To avoid twisting during expansion, the doors are installed at the fix points of the oven. At these points the thermal expansion is not so drastic. The same goes for the contact points of the channels. To save energy and not to heat up the workshop unnecessarily, all the free channels and the oven tunnel are insulated with rock wool. The insulations are fire-proof and water-repellent [8]. At the start-up of the oven ambient air is admitted inside the oven through air breather & then to the filters. The heat energy at high temperature from the incinerator exchanges the heat exchanger with ambient air which is taken inside the oven. So there is no direct contact between the heat energy from incinerator & the air inside the oven. Only exchanging of heat takes place.

II. LITRATURE REVIW

F. Pask, J. Sadhukhan b, P. Lake, S. McKenna, E.B. Perez, A. Yang, [1] Systematic approach to optimize the oven by using DMAIC technique is the powerful tool to save the energy up to large extent. DMAIC method has been used to cure adhesive on masking tape web. LEL level of the oven had been maintained within a range which shut the system if it goes below 35%. By performing experiments they concluded that if adjusting the damper positions lots of energy can be save. Annual gas saving is 16, 58,000 kWh. By increasing the heat transfer coefficient faster drying rates can be achieved.

A.Lozano, F Barreras, N. Fueyo, S Santodomingo, [3] This paper numerically investigated the thermal hydraulic performances for various OSF fins with well validated 3D models. The roposed ones provide well-adapted predictions for OSF fins with different fin thickness covering a broad range of blockage ratio, while previous ones only adapt to the thinner fins & apparently deviate from higher blockage ratios.

Jongyeok Lee, Kwan-Soo Lee, [4] has analysed that the friction factor f & Colburn factor j were found as functions of the various geometrical parameters, Researcher carried out an unsteady numerical analysis using a large eddy simulation to investigate the fluid flow in chevron-type plate heat exchangers. The flow consisted of a stream wise component and a component in the furrow direction. The friction factor f and Colburn factor j were found as functions of the various geometrical parameters, i.e., 30o < β < 60o and 2.0 < p/h < 4.4, and the performance of the heat exchanger was characterized using the JF factor. Both f and j increased as b increased and as p/h decreased.

Yujie Yang, Yanzhong Li, [5] this paper numerically investigates the thermal hydraulic performances for various OSF fins with well validated 3D models. The proposed ones provide well-adapted predictions for OSF fins with different fin thickness covering a broad range of blockage ratio. The proposed ones provide well-adapted predictions for OSF fins with different fin thickness covering a broad range of blockage ratio, while previous ones only adapt to the thinner fins & apparently deviate from practice at higher blockage ratio.

T. G. Walmsley, M.R.W. Walmsley, M. J. Atkins, J. Hoffman-Vocke, J. R. Neale, [6] has concluded that tube shape has a significant impact on the j/f and jf/f ratios. Assuming these ratios account for heat transfer, gas flow resistance and foul ability, the recommended tube for exhaust gas heat recovery is elliptical tube. The ellipse shape tube produced a j/f ratio 100 % and 120 % higher than that of round tube for the two arrangements considered. The flattened round tube is also effective, given enough spacing between the tubes, and may be a good solution.

Guo-yan Zhou, Ling-Yun Zhu, Hui Zhu, Shan-tung Tu, Jun-jie Lei, [10] this research presented the simplified and accurate model for temperature distribution in the shell and tube heat exchanger. Two examples of BEU and AES heat exchangers with single-phase fluid are analyzed to demonstrate the application and accuracy of the proposed model in temperature distribution, compared with the Cell model and HTRI. The research shows that the proposed model reproduces the temperature distribution given by the HTRI solution on the tube side flow with 0.19% accuracy for the BEU heat exchanger and 0.35% for the AES heat exchanger. Two engineering cases have been introduced and the results show that the calculated temperature is more accurate than that by Cell model and agrees well with that by HTRI program. It should be noted that the proposed model can be successfully used for all shell-and-tube heat exchangers with straight tube or U-tube types.

Wang Yongqing, Gu Xin, Wang Ke, Dong Qiwu, [11] Researcher addresses that analysis of fluid flow and heat transfer characteristics were carried out with different shaped baffle namely segmental, rod and H-shaped support structures in shell-sides of shell-and-tube heat exchangers, by using numerical models. At the same flow flux, both the heat transfer coefficient and flow pressure drop in shell-side of H-shape baffle heat exchanger lie between that of segmental heat exchanger and ROD baffle heat exchanger. In shell and tube heat exchange at shell-side of heat exchanger, at some range of flow flux, H-shape baffle is an ideal tube support structure, which induces fluid flows in a mixing pattern and enhances greatly heat transfer. The characteristics of shell-side of H-shape heat exchanger combine that of cross flow and longitudinal flow. The H-shape heat exchanger merits both heat exchangers with cross flow in shell-side and with longitudinal flow in shell-side.

K. Srinivasana, S. Muthu, S. R. Devadasan, C. Sugumaran, [12] This research addresses the pilot implementation of Six Sigma DMAIC (Define-Measure-Analyze-Improve-Control) phases to improve the effectiveness of shell and tube heat exchanger in a small sized furnace manufacturing company. Shell and tube heat exchanger is one of the critical components of the furnace. The imperative objective is to improve the quality of the furnace through DMAIC phases. Six Sigma DMAIC methodologies were implemented in the furnace manufacturing company to reduce the thermal energy in exhaust flue gas which extremely impacts the efficiency of the furnace. Thus, DMAIC phases revealed that, the best solution to the shell and tube heat exchanger by increasing heat transfer rate and reducing thermal energy in the waste flue gas through implementation of circular fins over bare tubes.

III. CONCEPT & MECHANISM

A. Concept:

Conservation of energy is the basic need for any industry because cost of energy is increasing day by day. The concept behind the heat recovery is to reuse the heat which has been exhausted to atmosphere without using it. With the use of exhaust which has high heat energy around 932kW we can recover around 885kW of energy considering 90% efficiency. This recovered heat energy can be utilized to heat the water which is used for various industrial processes. Currently, temperature of exhaust gases from oven is ranging from 280ºC -340ºC. Shell & tube heat exchanger will be use to exchange the heat from high temperature exhaust gases to heat the water which is heated by boiler. So the energy required to heat the water by boiler will be save. CNG gas is used to heat the water which will be considerably saved.

B. Mechanism:

Current System design does not allow recovery or reuse of the high temperature gas as shown in the fig.1

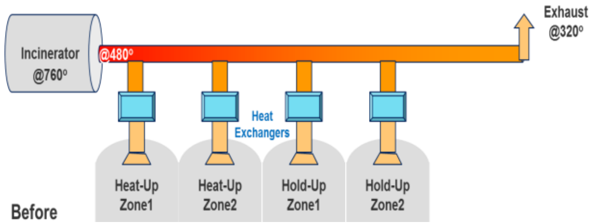


Fig.1 Current Oven exhaust system

By installing heat recovery system ~885KW Heat energy equivalent can be recovered. This will be used to heat the water as shown in fig 2.

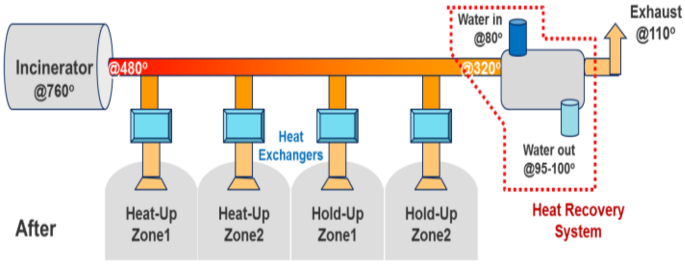


Fig.2 Proposed Heat recovery system from the oven exhaust

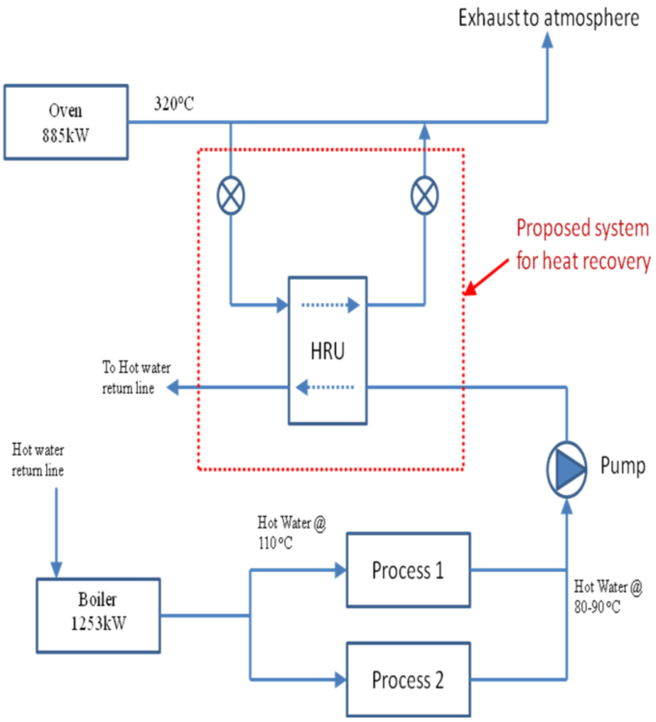


Fig. 3 Schematic of heat recovery system

Fig. 3 shows the schematic of heat recovery system in which shell and tube heat exchanger will be used to recover the heat from the high temperature oven exhaust which is at 280ºC to 340ºC. Pump is used draw a water from return line of hot water which will be fed into the heat exchanger at around 80 ºC to 90ºC and then it will be heated around 110 ºC and that hot water will be again connected to the main water line so that water will be preheated and less CNG will required for boiler to heat the water so that energy conservation takes place along with cost for CNG will be save.

The main heart of the proposed heat recovery system is the heat exchanger which is shell & tube heat exchanger with counter flow arrangement. The purpose of selecting this type of heat exchanger is that we will get a highest efficiency and to transfer equal amount of heat parallel flow heat exchanger is larger in size as compared with counter flow heat exchanger. Hence counter flow heat exchangers are generally preferred. Tube shape has a significant impact on the heat recovery. Different shapes of tube as shown in fig.3

Tube geometry:

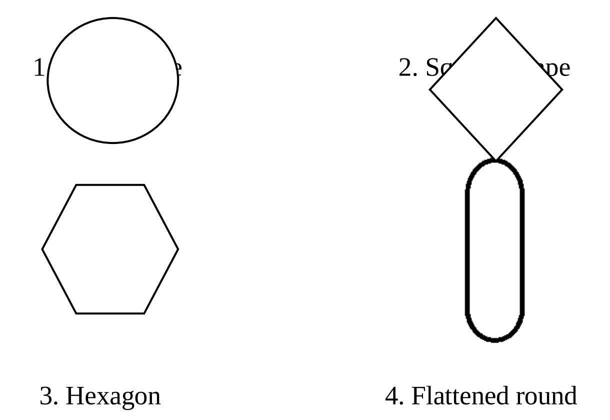


Fig.4 Different tube geometry

Heat recovery calculations:

Exhaust Energy (Q) = ρ x V x Cp x ΔT ……………. (2)

Exhaust flow rate of flue gas (V) = 12000 Nm^3/hr

Density of air (ρ) = 1.2 kg/Nm^3

Exhaust temp. Inlet (T2) = 320ºC

Exhaust temp. Outlet (T1) = 110ºC

Specific heat of air (Cp) = 0.24 Kcal/KgºK

= 12000 x 1.2 x 0.24 x (320-110)

Q = 725760 Kcal/hr

As, 1 kW= 860Kcal

Therefore, Exhaust Energy = 725760/860

= 843.2 kW/hr

Considering 90% efficiency = 843.2 x 0.9

= 760 kW/hr

Total available energy in top coat oven/year = total production hours x 760 kW/hr

Total available energy in top coat oven/year = 41,69,744 kW/year

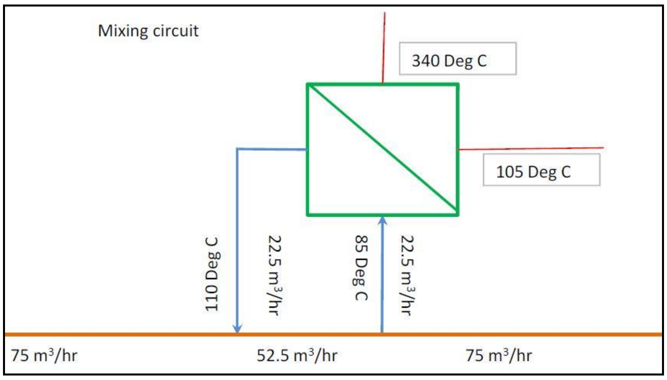


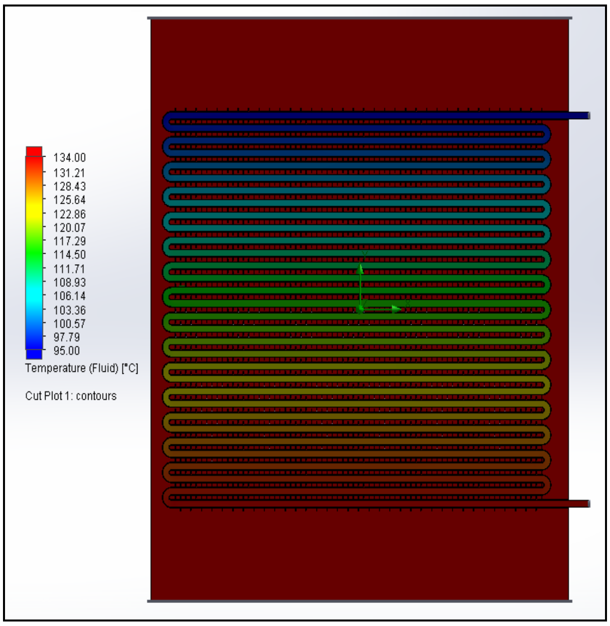
Fig.5 Mixing circuit of water

Fig.5 shows mixing circuit of water and how heat will exchange from exhaust gases to water.

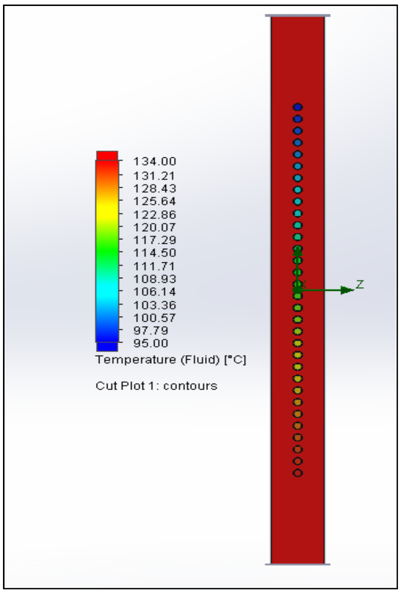
IV. RESULT & DISCUSSION

CFD analysis of different shapes of tubes was compared which shows the minimum time required for the shape to achieve the maximum temperature and these values are then compared with the physical experimental validation.

A. *CFD analysis of circular shape tube:*



(a)

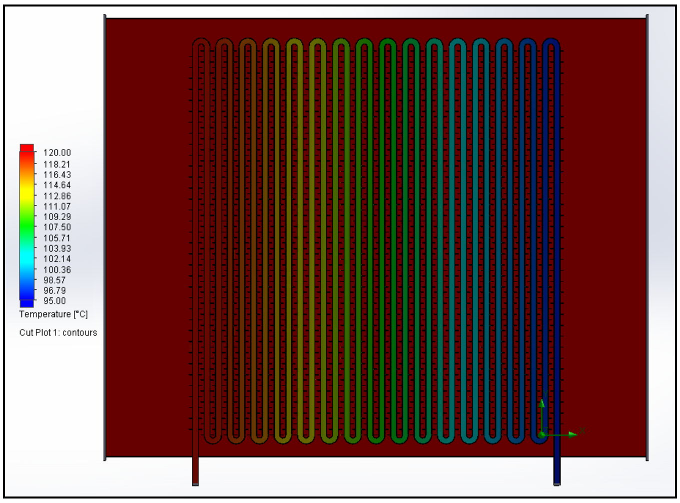


(b)

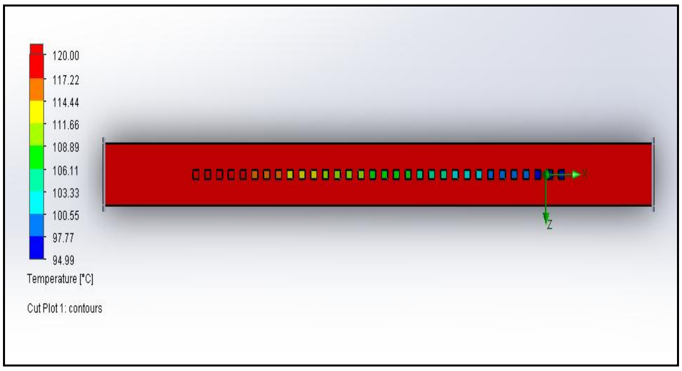
Fig. 6 (a) Top view (b) front view of CFD of circular shape of tube showing increasing temperature of water from inlet to outlet

Analysis of circular tube shows how temperature of water inside the tubes reaches its maximum temperature and flow towards the outlet with maximum temperature requirement. Also researches on the round tube suggest that this shape has a maximum surface area exposed to heat therefore it is mostly used in shell & tube heat exchanger and for maintenance point of view these circular shapes is also easy than other complicated shapes

B. *CFD analysis of square shape tube:*



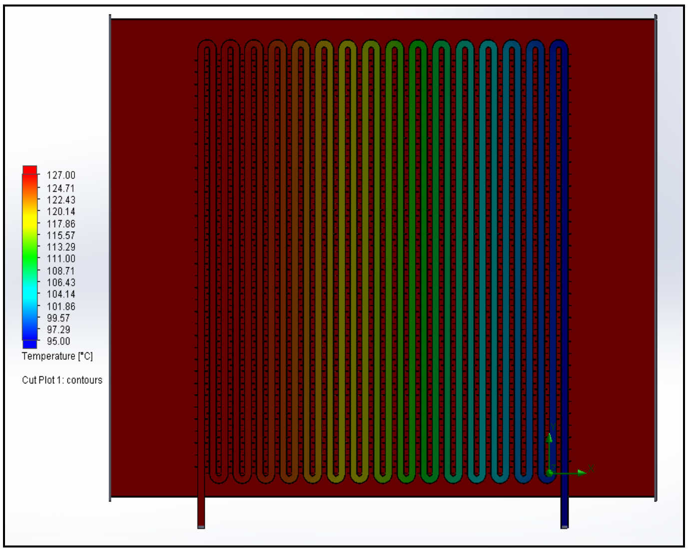
(a)



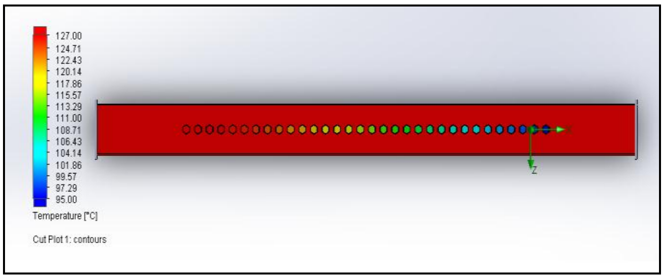
(b)

Fig. 7 (a) Top view (b) front view of CFD of square shape of tube showing increasing temperature of water from inlet to outlet

C. *CFD analysis of Hexagonal shape tube:*



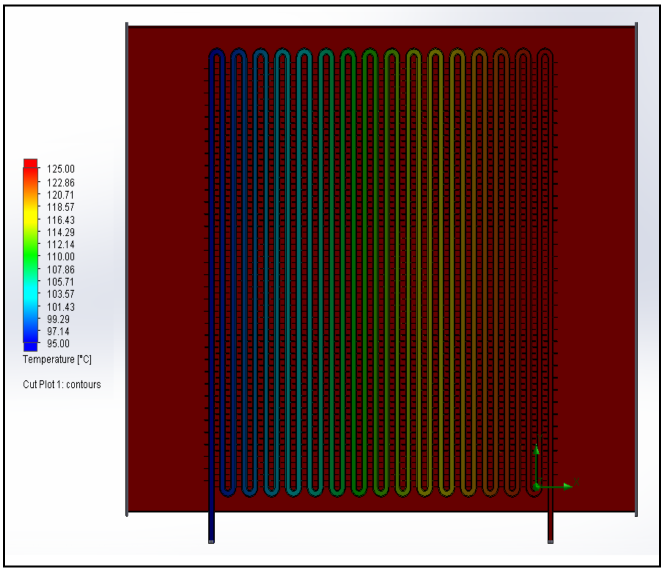
(a)



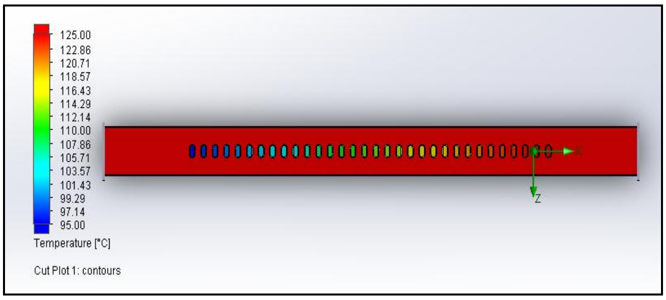
(b)

Fig. 8 (a) Top view (b) front view of CFD of Hexagon shape of tube showing increasing temperature of water from inlet to outlet

D. *CFD analysis of flattened round shape tube:*



(a)

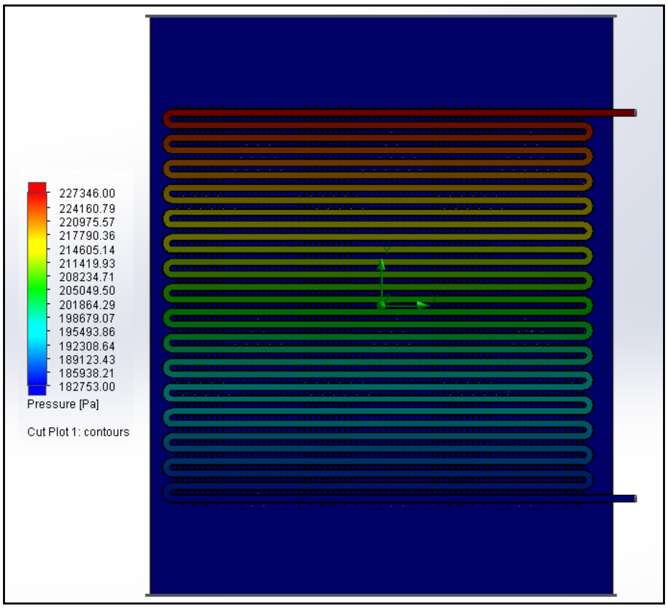


(b)

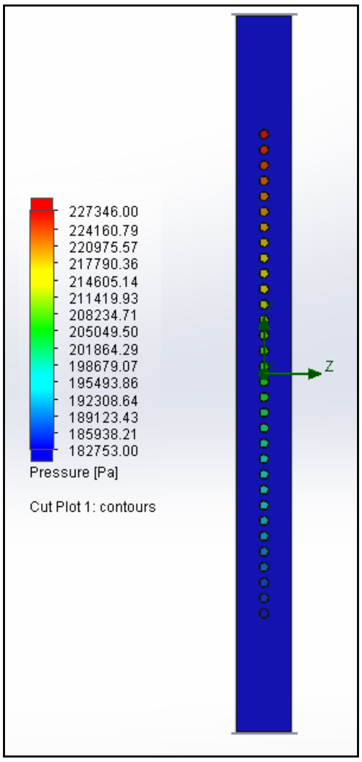
Fig. 9 (a) Top view (b) front view of CFD of flattened round shape of tube showing increasing temperature of water from inlet to outlet

From the analysis shown above of temperature profile of different shapes of tube shows that the final temperature of 120^0C is achieved with all the shapes of tube when we compare it with the same surface area for all but when we compare tubes on the basis of quickest temperature achievement it is shown that circular and hexagonal shape of tubes achieve faster temperature than the other tubes. So to conclude the one shape for heat recovery let us compare pressure drop due to each shape of tube.

E. *CFD analysis of pressure drop in circular tubes:*



(a)

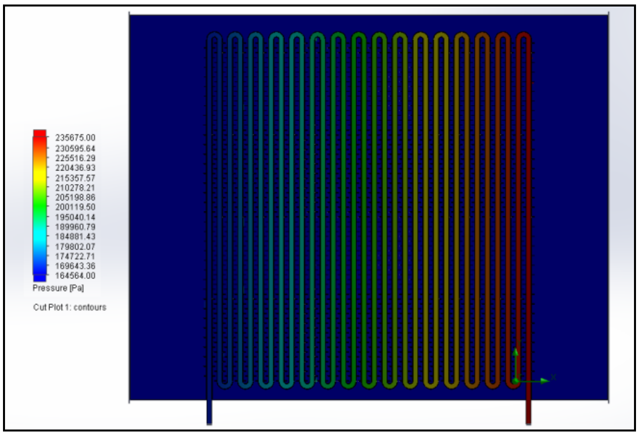


(b)

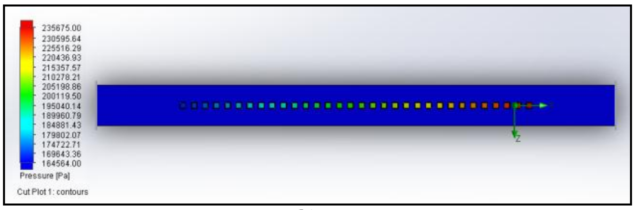
Fig. 10 (a) Top view (b) front view of CFD of circular shape of tube showing pressure of water inside the tube at different locations

Pressure gauges are mounted before and after the pump so that proper working and monitoring of the flow through the line can be done so that constant pressure throughout the line can be maintained and it also helps to avoid back pressure on the system. Filter is installed before the pump as shown in fig. 10 so that any unwanted particles will be arrest before pump to avoid pump failure and constant working of pump. Filter need to be change if more pressure drop observed on pressure gauges which are installed before and after the pump as shown in fig.10.

F. CFD analysis of pressure drops in square shape tube:



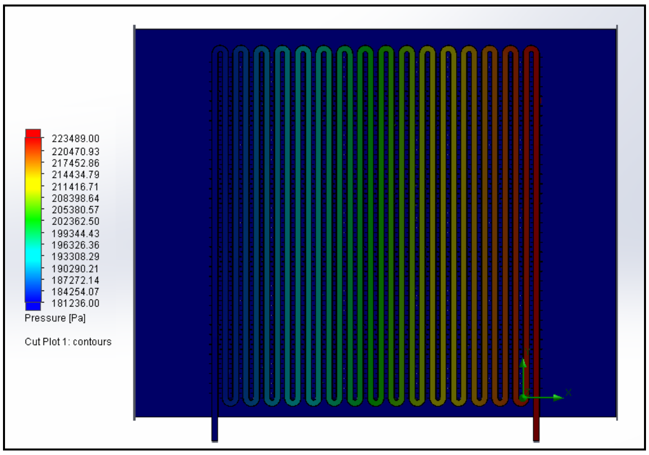
(a)



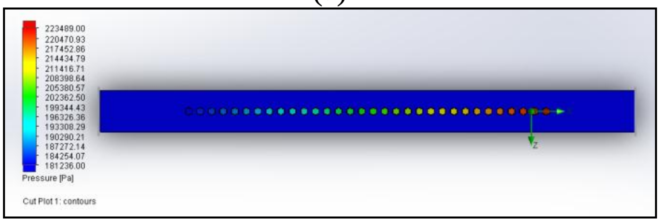
(b)

Fig.11 (a) Top view (b) front view of CFD of square shape of tube showing pressure of water inside the tube at different locations

G. CFD analysis of pressure drops in Hexagon shape tube:



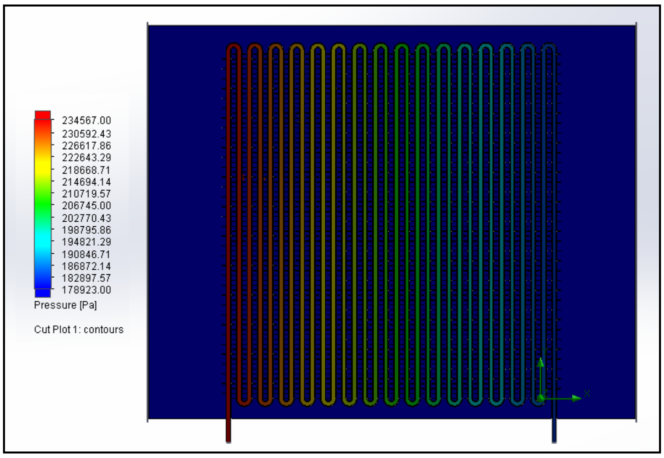
(a)



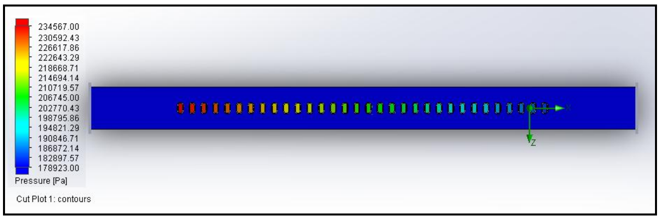
(b)

Fig.12 (a) Top view (b) front view of CFD of Hexagon shape of tube showing pressure of water inside the tube at different locations

H. CFD analysis of pressure drops in Flattened round shape tube:



(a)



(b)

Fig.12 (a) Top view (b) front view of CFD of flattened round shape of tube showing pressure of water inside the tube at different locations

So from the above figures it is conclude that for circular and hexagonal shape pressure inside the tubes is maintained faster and it is nearly about 2 bars which is the required condition for tubes. So from the temperature and pressure diagrams it is concluded that circular tubes are suitable for because, the first advantage in circular tubes is that we get more surface area than hexagon shape and it is easy for maintenance as well as manufacturing point of view. Previous researches also suggest that circular tubes are best suited shape for tube side.

Physical Experimental Validation

Readings on day 1:

Table1: Observation table of day 1

Parameter	Readings
Inlet temperature of gas going into heat exchanger	292.2°C
Outlet temperature of gas from heat exchanger	158.9°C
Inlet temperature of water going into heat exchanger	95.5°C
Outlet temperature of water going from heat exchanger	113.9°C
Pump flow rate	22.9 m^3/hr
Specific heat of water (kcal/hr)	1000

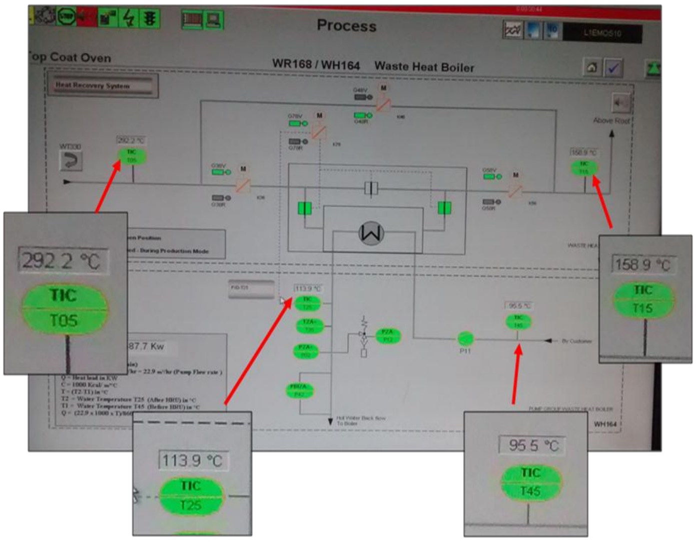


Fig.13 Schematic view of heat recovery system on ECO screen showing actual readings of water & exhaust gases.

Therefore,
Actual heat gain will be

$Q = m \times C_p \times \Delta T$

$= 22.9 \times 1000 \times (113.9 – 95.5)$

$= 421360/860$

$Q = 489.9$ kW

Readings on day 2:

Table 2: Observation table of day 2

Parameter	Readings
Inlet temperature of gas going into heat exchanger	295.5°C
Outlet temperature of gas from heat exchanger	197.8°C
Inlet temperature of water going into heat exchanger	101.7°C
Outlet temperature of water going from heat exchanger	119.4°C
Pump flow rate	22.9 m^3/hr
Specific heat of water (kcal/hr)	1000

Therefore,
Actual heat gain will be,
Q = 471.3 kW

Table 3: Observation table of day 3

Parameter	Readings
Inlet temperature of gas going into heat exchanger	280.2°C
Outlet temperature of gas from heat exchanger	151.9°C
Inlet temperature of water going into heat exch.	97.5°C
Outlet temperature of water going from heat exchanger	115.5°C
Pump flow rate	22.9 m^3/hr
Specific heat of water (kcal/hr)	1000

Therefore,
Actual heat gain will be,
Q = 479.3 kW

Table 4: Observation table of day 4

Parameter	Readings
Inlet temperature of gas going into heat exchanger	280.2°C
Outlet temperature of gas from heat exchanger	151.9°C
Inlet temperature of water going into heat exchanger	97.5°C
Outlet temperature of water going from heat exchanger	116.5°C
Pump flow rate	22.9 m^3/hr
Specific heat of water (kcal/hr)	1000

Therefore,
Actual heat gain will be,
Q = 505.9 kW

Table5: Observation table of day 5

Parameter	Readings
Inlet temperature of gas going into heat exchanger	280.2°C
Outlet temperature of gas from heat exchanger	151.9°C
Inlet temperature of water going into heat exchanger	98.5°C
Outlet temperature of water going from heat exchanger	117.5°C
Pump flow rate	22.9 m^3/hr
Specific heat of water (kcal/hr)	1000

Therefore,
Actual heat gain will be,
Q = 505.9 kW

For safety concern and for low and high temperature fault some temperature parameters are given to TIC (Temperature Indicator & Controller) which are installed on tube side inlet and outlet of heat exchanger gives the signal to three motorised dampers to close and open accordingly. If such abnormal situation occurs then all heat recovery system will bypassed and exhaust will be directly gone into atmosphere. From the readings taken it is clear that approx 500 kW/hr heat energy is recovering from exhaust. Existing 1253KW energy equivalent used in boiler for hot water generation will be reduced to ~500KW. CO2 footprint is reduced by 5Kg/car. Hot water generated is used for pretreatment and oil conservation process in the plant. Thus the large content of prevention from high heat content loss is taking place. The current situation is that the start of production is achieved and the boiler in utility system just runs only at the start of process. This proves that the heat recovery for top coat oven is utilized fully for serving our purpose. Therefore our analysis was successful and CFD is very versatile and effective tool for analysis.

V. CONCLUSION

The main factor here is heat recovery which was led out of the factory and now is reduced to a very high extent. As the heat recovery from the system is huge so the potential of energy recovery can be realized so that the CNG gas which is required to heat the water will be very less. So the energy conservation takes place in the paint shop which consumes more energy in the automobile plant than the other shops. The recovered heat can be used to heat the water which can be used for the pre-treatment and oil conservation process. The detailed CFD analysis of different shapes of tubes gives the correct shape of tube which will give maximum heat recovery. From the readings taken it is clear that approx 500 kW/hr heat energy is recovering from exhaust. Existing 1253 kW energy equivalent used in boiler for hot water generation will get reduced to ~500 kW. The current situation is that at the start of production the boiler in utility system just runs only at the start of process. CO2 footprint is reduced by 5Kg/car. Both circular and hexagon shapes tube gives the good results. The circular shape tube which has 34mm dia. with fins gives the best results for heat recovery because it has larger surface area than the hexagon and circular shape tubes are also easy for maintenance than the other complicated shapes of tubes. So therefore the wastage of such a high heat content energy can be prevented or can be recovered. Total CNG & electricity saving is 2, 58, 46,152 Rs. which is a very huge cost. ROI for this project is 0.9 years.

ACKNOWLEDGMENT

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