Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 08, August - 2017

Analysis of heat recovery from Primer Oven Exhaust in paint Shop

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***Abstract-*: Currently in automotive paint shop uses the three oven namely as Electro-deposition (ED), Top Coat (TC) & primer oven to bake the car body in conditioned environment. Our focus is on Primer oven. Current system gives the exhaust gases directly to the atmosphere without using for other purpose. The exhausted flue gas is around 280^{0}C -340^{0}C. This heat source can be used for various purposes in paint shop like as heated water for clean the car body, chilling system, etc. The proposed system is to reuse exhaust air for hot water generation. The hot water generated will be at temperature of approx. 110^{0}C. The generated hot water can be used for pre-treatment process. Heat energy for total hot water heating is 1253 KW. So realize the energy potential of waste heat and use it in proper way. About approx. 843 KW of energy can be recovered from primer oven exhaust. The proposed system consists of shell & tube heat exchanger with counter flow arrangement. Shape of tube 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 primer oven for generation of hot water. The exhaust energy from primer 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 12000 nm3/hr. The unused heat from oven is use to generate hot water (110^{0}C) which will be supplied to pretreatment. This reuse of exhaust heat will save the energy along with the CNG consumption required for boiler to heat the water.**

Keywords— Heat Recovery, shell & tube heat exchanger, paint curing oven, reuse of exhaust, Computational fluid dynamics.

I. INTRODUCTION

In paint Industrial ovens are called as heated chambers used for a variety of industrial applications, such as drying, curing, or baking components & parts or final products. These ovens can be used for in batches or continuously with a conveyor line large or small volume applications, and a variety of temperature ranges, sizes and configurations & Such ovens are used in many different applications, like as chemical processing, food production, and even in the electronics industry, where circuit boards are run through a conveyor oven to joint surface mount components [2-3]. The oven tunnel is one of the part of the oven unit visible from outside, the drying process takes place inside it. The oven tunnel has an internal paneling, the hot air circulation ducts, a thick insulation of rock wool and an external plate panel [8]. To prevent escape of hot gases and vapors, the internal paneling & the hot air circulation ducts of the oven are welded to make them gas-tight. The installed insulation layer is for energy saving. The heavy temperature fluctuations factors are necessarily requirements in the oven construction. So for that the oven tunnel is movable means oven is expanded at compensation point provided in oven construction on heating. 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. In 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 inside to outside. To avoid twisting during expansion, the doors are installed at the fix points of the oven. Thermal expansion is not so drastic at these point in oven. 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 & 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 very high temperature from the incinerator (Air heated chamber through CNG gas) exchanges the heat exchanger with ambient air which is taken inside the oven & there is no direct contact between the heat energy from incinerator & the air inside the oven. Only exchanging of heat takes place.

II. LITERATURE REVIEW

Jongyeok Lee, Kwan-Soo Lee, [1] 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, & 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. T. G. Walmsley, M.R.W. Walmsley, M. J. Atkins, J. Hoffman- Vocke, J. R. Neale, [2] 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, [3] this research presented the simplified & accurate model for temperature distribution in the shell & tube heat exchanger. Two examples of BEU & AES heat exchangers with single-phase fluid are analyzed to demonstrate the application & 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. F. Pask, J. Sadhukhan b, P. Lake, S. McKenna, E.B. Perez, A. Yang, [4] 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, [5] 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. Wang Yongqing, Gu Xin, Wang Ke, Dong Qiwu, [6] 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 tubeheat 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 ongitudinal 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, [7] 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 AND MECHANISM

A. Concept:

As the cost of energy & energy demand is increased day by day, so the basic need of any industry is the conservation of energy. Behind the concept of heat recovery is to reuse the heat which has been exhausted to atmosphere without using it. Use of exhaust which has high heat energy approx. 932kW we can recover around 840kW of energy considering 90% efficiency. This heat energy can be used to heat the water which is used for pre-treatment process. Presently, temperature of exhaust gases from oven is ranged between 290-340 $_{o}$C. The shell & tube heat exchanger will be used to exchange the heat from exhaust gases at high temperature to heat the water which is pre-heated by boiler. So finally the CNG gas energy is saved which is used to heat the water.

B. Mechanism:

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

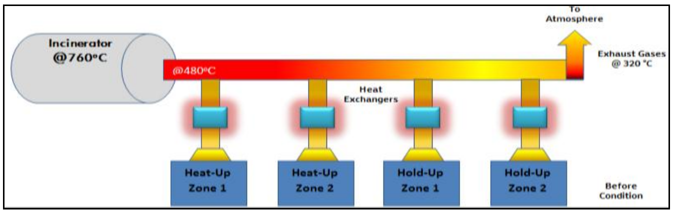


Fig.1 Current Oven exhaust system [source: VW India]

By installing heat recovery system ~840kW of heat energy equivalent can be recovered. This will be used to heat the water as shown in fig 2.

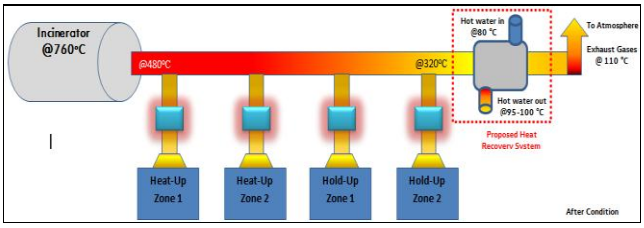


Fig.2 Proposed Heat recovery system for the oven exhaust [source: VW India]

Fig. 3 shows the schematic of heat recovery system for ED Oven. In which shell and tube heat exchanger will be used to recover the heat from the high temperature oven exhaust gases which is ranged at 280$_{o}$C to 340$_{o}$C. Water Pump is used to draw water from hot water return line which will be connected & fed into the heat exchanger at around 80 $_{o}$C - 90$_{o}$C & then it will be heated around 110 $_{o}$C. This hot water will be again connected to the main hot water line so that less CNG will required for boiler to heat the water so that conservation of energy takes place along with saving in CNG cost.

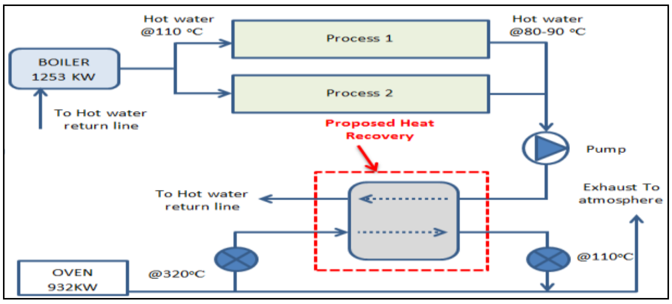


Fig. 3 Schematic of heat recovery system [source: VW India]

Heat exchanger is the main heart of the proposed heat recovery system 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:

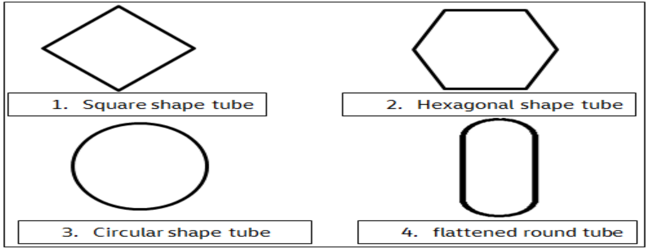


Fig.4 Different types of Tube Shape

Heat recovery calculations:
Exhaust Energy (Q) = ρ x V x Cp x ΔT ……………. (1)
Exhaust flow rate of flue gas (V) = 12000 Nm3/hr
Density of air (ρ) = 1.2 kg/Nm3
Exhaust temp. Inlet (T2) = 320oC
Exhaust temp. Outlet (T1) = 110oC
Specific heat of air (Cp) = 0.24 Kcal/KgoK
Exhaust Energy (Q) = 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 ED oven/year = total production hours x 760 kW/hr
Total production day = 291 days
Total production hrs/day = 22 hrs
Total available energy in ED oven/year = 291 x 22 x 760
= 4865520 kW/year

Where,

Exhaust air flow rate (V) Nm3/hr

HRU inlet & outlet temperature (ΔT) °C

Density of air (ρ) Kg/ Nm3

Specific heat of air (Cp) Kcal/Kg °C

Equivalent Exhaust energy (Q) KW

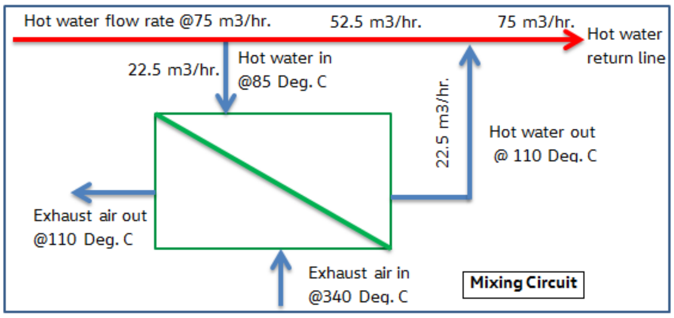
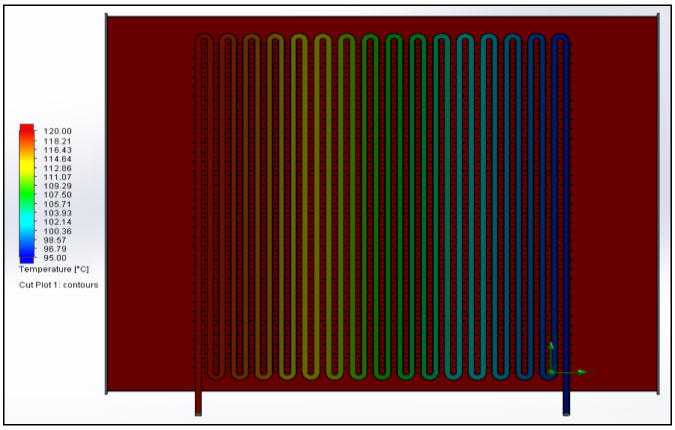


Fig.5 Mixing circuit of water

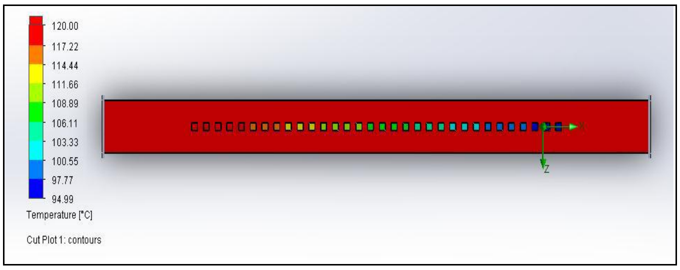
IV. RESULT & DISCUSSION

Analysis of different shapes of tubes was done with CFD to compared to shows the minimum time required for the tube shape to achieve the maximum temperature & these values are then compared with the physical experimental validation.

A. CFD analysis of square shape tube:



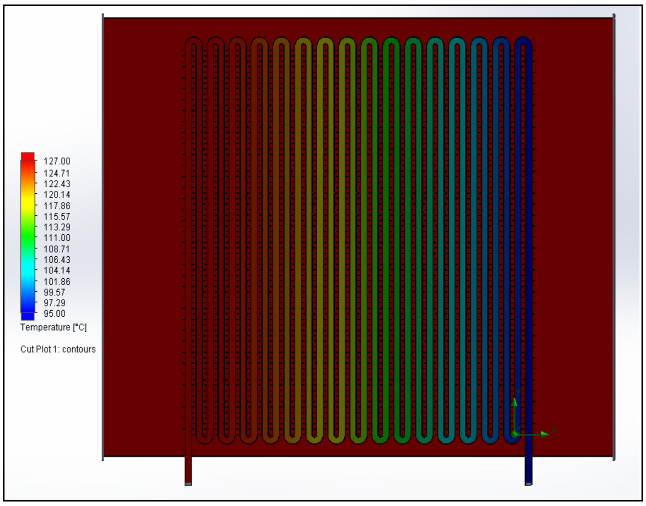
(a)



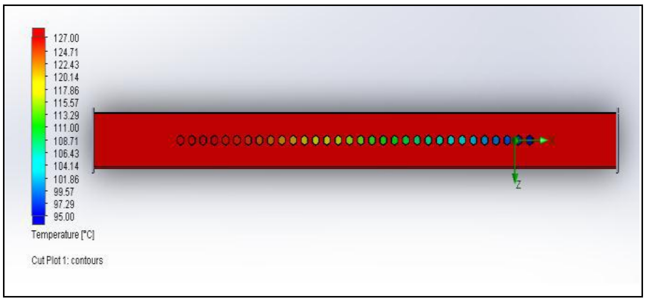
(b)

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

B. *CFD analysis of temperature in Hexagonal shape tube:*



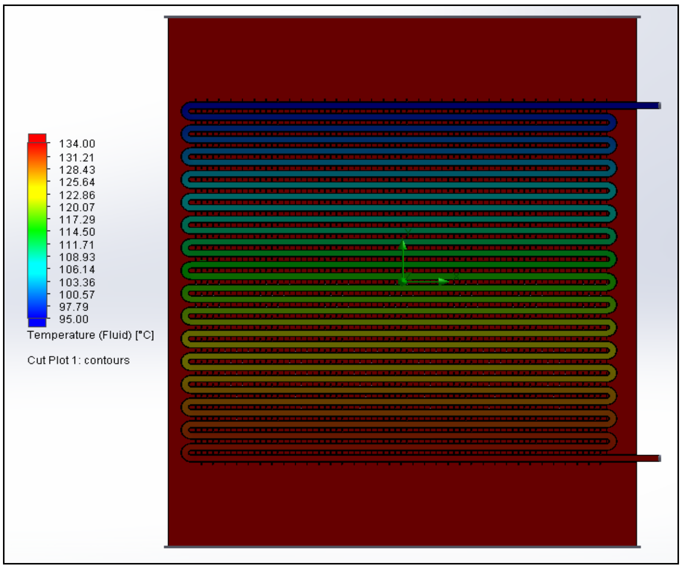
(a)



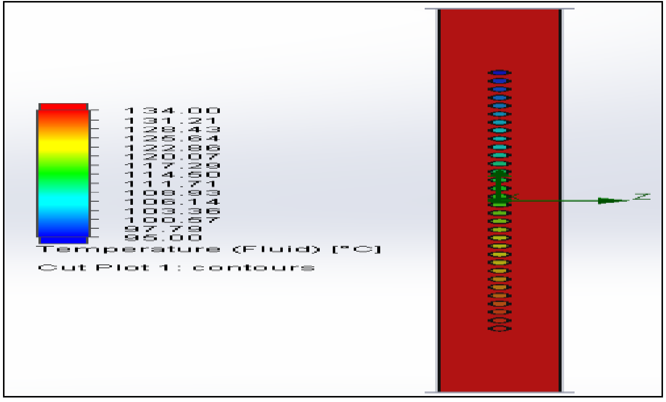
(b)

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

C. *CFD analysis of temperature in circular shape tube:*



(a)

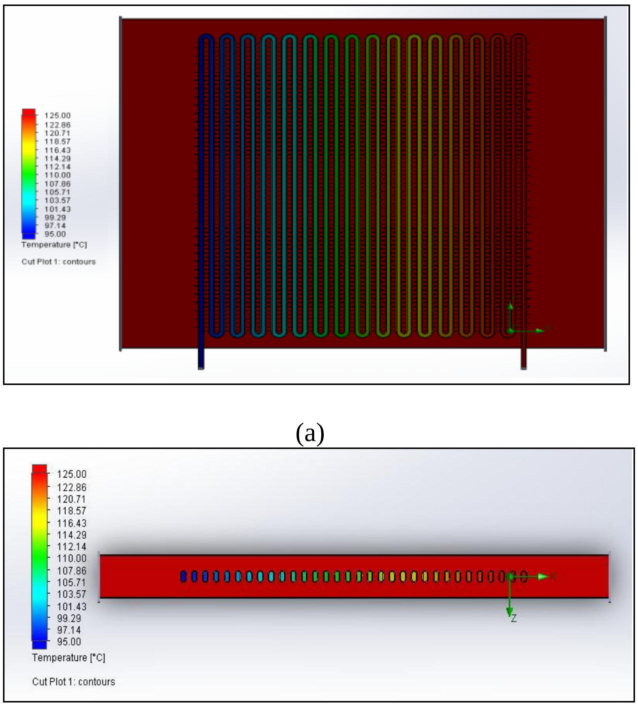


(b)

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

CFD analysis of circular tube shows how the temperature of water inside the circular tube reaches its maximum temperature & flow towards the outlet with maximum temperature requirement. Also, most of the researches on the round tube suggest that this shape has a maximum surface area exposed to heat transfer therefore it is commonly used in shell & tube heat exchanger. Circular shape tube has easy to maintain compared to other complicated shape of tube.

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



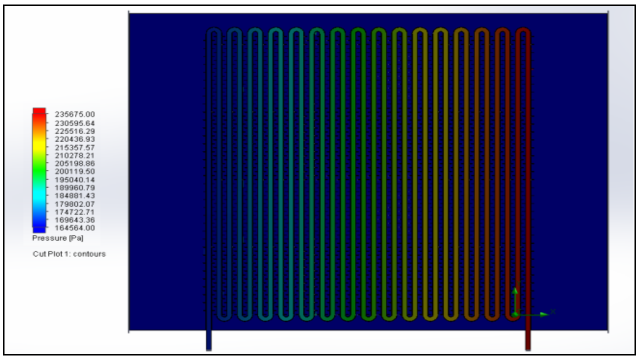
(a)

(b)

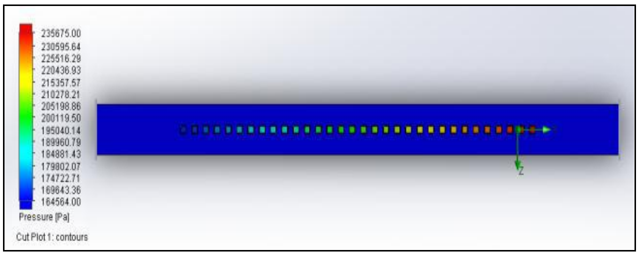
Fig. 9 (a) Top view (b) front view of CFD of flattened round shape of tube showing increasing temperature of water from inlet to outlet

From the analysis of temperature profile as shown above for the different shapes of tube shows that the final temperature of 1200C is achieved with all the shapes of the tube when we compared with the same surface area for all tube shapes, but when we compares tube on the basis of quickest temperature achievement then it shown that circular & hexagonal shape of tube achieve faster temperature than other two tubes of shapes. So to conclude the one shapes of tube for heat recovery let us compare tubes on the basis of pressure drop for all shapes.

E. *CFD analysis of pressure drops in square shape tube:*



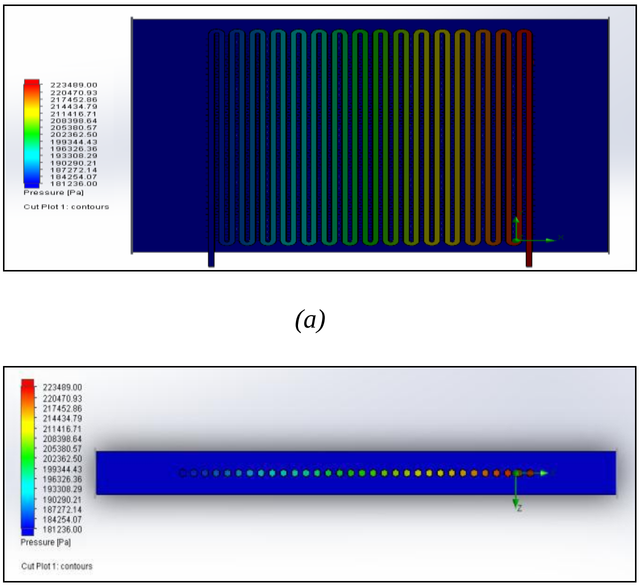
(a)



(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

F. *CFD analysis of pressure drops in Hexagon shape tube:*

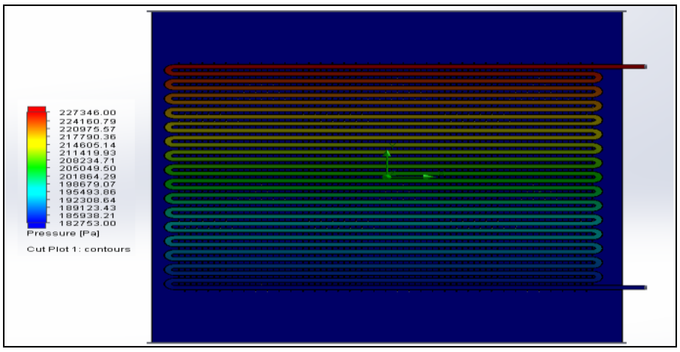


(a)

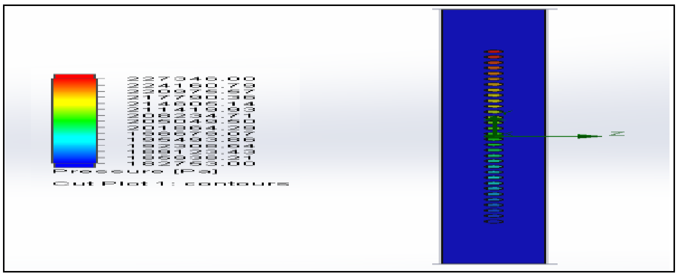
(b)

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

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



(a)

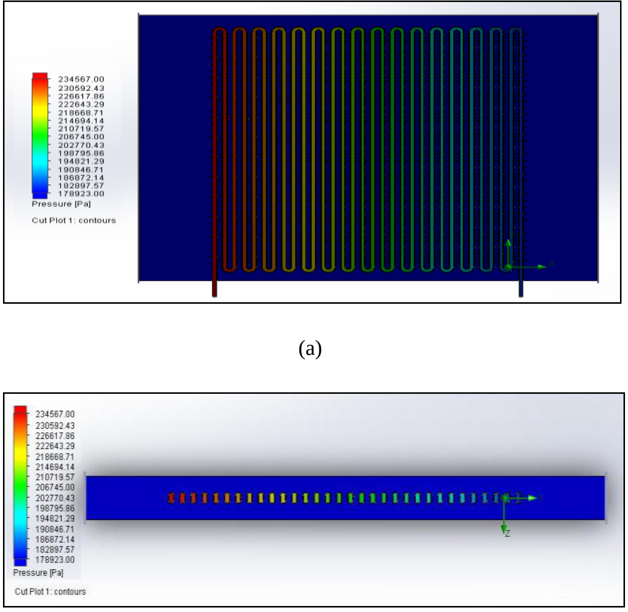


(b)

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

For proper working & monitoring of the flow through the line can also be done by mounting a pressure gauge before & after the pump, so that constant pressure throughout the line can be maintained & also it helps to avoid back pressure on the system. To arrest the foreign or unwanted particles before the pump the filter are installed to avoid the failure of pump & constant working of pump. If more pressure drop observed on the pressure gauges which are installed before & after the pump, then need to be change filter which are installed before the pump inlet.

B. *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

From the above pressure drop analysis by CFD it is conclude that circular & hexagonal shape of tube maintained faster pressure inside the tube & is nearly about 2 bars, which is required condition for the heat recovery tubes. So from the temperature & pressure drop CFD analysis it is concluded that circular shape tubes are suitable for heat recovery system. Advantage of circular shape tube has it gets more surface area than hexagon shape tube & it is easy for maintenance as well as manufacturing point of view. Also, some researchers suggest that circular tubes are best suited for tube side.

PHYSICAL EXPERIMENTAL VALIDATION

Following table shows the day reading , as follows:

Reading on day 1:

Parameter	Reading	Unit
Inlet temperature of gas going into heat exchanger	278.9	oC
Outlet temperature of gas from heat exchanger	137.0	oC
Inlet temperature of water going into heat exchanger	93.1	oC
Outlet temperature of water going from heate xchanger	110.8	oC
Pump flow rate	22.9	m3/hr
Specific heat of water	1000	kcal/hr

Therefore,

Actual heat gain will be

Q = m x C_p x ΔT

Q = 22.9 x 1000 x (110.8 – 93.1)

Q = 405330/860

Q = 471.3 kW

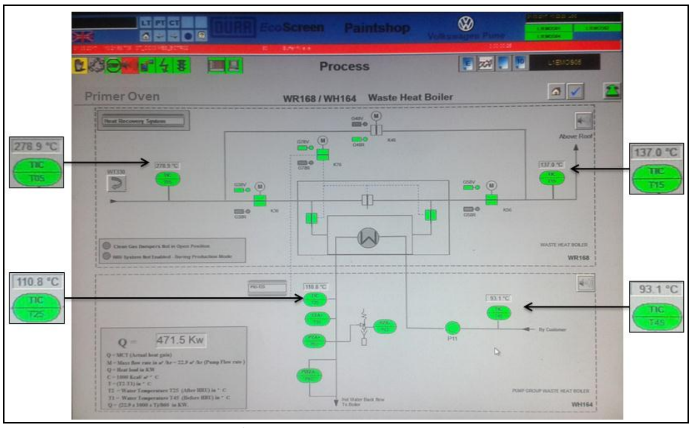


Fig.13 Schematic view of heat recovery system on ECO screen showing actual readings of water & exhaust gases.

Reading on day 2:

Parameter	Reading	Unit
Inlet temperature of gas going into heat exchanger	292.2	oC
Outlet temperature of gas from heat exchanger	158.9	oC
Inlet temperature of water going into heat exchanger	97.4	oC
Outlet temperature of water going from heate xchanger	115.9	oC
Pump flow rate	22.9	m3/hr
Specific heat of water	1000	kcal/hr

Therefore,

Actual heat gain will be

Q = m x C_p x ΔT

Q = 22.9 x 1000 x (113.9 – 95.5)

Q = 421360/860

Q = 489.9 kW

Reading on day 3:

Parameter	Reading	Unit
Inlet temperature of gas going into heat exchanger	290.1	oC
Outlet temperature of gas from heat exchanger	155.8	oC
Inlet temperature of water going into heat exchanger	98.5	oC
Outlet temperature of water going from heate xchanger	117.5	oC
Pump flow rate	22.9	m3/hr
Specific heat of water	1000	kcal/hr

Therefore,
Actual heat gain will be

Q = m x C_p x ΔT
Q = 22.9 x 1000 x (117.5 – 98.5)
Q = 435100/860
Q = 505.9 kW

Reading on day 4:

Parameter	Reading	Unit
Inlet temperature of gas going into heat exchanger	291.1	oC
Outlet temperature of gas from heat exchanger	157.8	oC
Inlet temperature of water going into heat exchanger	97.9	oC
Outlet temperature of water going from heate xchanger	117.2	oC
Pump flow rate	22.9	m3/hr
Specific heat of water	1000	kcal/hr

Therefore,
Actual heat gain will be

Q = m x C_p x ΔT
Q = 22.9 x 1000 x (112.8 – 94.5)
Q = 441970/860
Q = 513.9 kW

Reading on day 5:

Parameter	Reading	Unit
Inlet temperature of gas going into heat exchanger	291.1	oC
Outlet temperature of gas from heat exchanger	157.8	oC
Inlet temperature of water going into heat exchanger	96.3	oC
Outlet temperature of water going from heate xchanger	116.4	oC
Pump flow rate	22.9	m3/hr
Specific heat of water	1000	kcal/hr

Therefore,
Actual heat gain will be

Q = m x C_p x ΔT
Q = 22.9 x 1000 x (112.8 – 94.5)
Q = 460290/860
Q = 535.2 kW

Considering a safety concern & for high and low temperature fault, some temperature parameters are given to TIC is called Temperature Indicator & Controller. These TIC are installed at inlet & outlet side of heat exchanger on tube side to gives signal to three way motorized dampers to close & open accordingly. If such abnormal situation occurs due temperature fluctuation, then heat recovery system will bypassed & the oven exhaust gases will be directly into the atmosphere. From overview of readings it is clear that approximately 505 kW/hr heat energy is recovering from oven exhaust gases. For hot water generation existing system 1253 kW energy equivalent used in boiler room will be directly reduced to ~500 kW. Reduction in CO2 footprint is 5kg/car body. Generated hot water from this process used for pretreatment process in the paint shop. 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 once at the start of process for some minute. This proves that the heat recovery system for primer oven is run successfully & utilized fully for serving our purpose in paint shop. Finally our analysis was successful & for this Computational fluid dynamic is effective & versatile tool for analysis.

SAVING CALCULATIONS

Production hours/year calculation:

Number of days for the projected production = 305 days
Number of working hours = 18 hr/day
Total production hours = 305 x 18
Total production hours = 5490 hrs/year

Energy Availability:

Exhaust Energy (Q) = 725760 Kcal/hr
As, 1 kW= 860Kcal
Therefore, Exhaust Energy = (725760/860)
= 843.2 kW/hr
Considering 90% efficiency = 843.90 x 0.9
= 760 kW/hr
Total available energy in Primer oven/year
= total production hours x 760 kW/hr
Total available energy in Primer oven/year
= 41,69,744 kW/year

CNG gas saving:

Calorific value of CNG = 9.8 kW/scm
Where, scm = standard cubic meter
Saving in terms of CNG = (Total available energy in Primer oven/year ÷ Calorific value of CNG)
= (4865520 ÷ 9.8)
Saving in terms of CNG = 496482 scm/year
Cost of fuel = 60 Rs./scm
Saving in terms of CNG in Rs./year = (Cost of fuel x savings in CNG)
= (60 x 496482)
Saving in terms of CNG in Rs./year = 2,97,88,920 Rs./year

Electricity savings:

Running time of blower motor for burner = 0.53 hrs/hr of boiler operation
Running heat load condition of boiler = 980 kW
Proposed heat load condition of boiler = (980 – 760)
= 220 kW
% of heat load reduction = [1-[Proposed heat load condition of boiler/Running heat load condition of boiler]]

= [1- (220/980)]

% of heat load reduction = 77.50%
Running time reduction of blower motor =(Running time of blower motor for burner) ÷ (% of heat load reduction)
Running time reduction of blower motor = (0.53/0.7750)
Running time reduction of blower motor = 0.41 hr/hr of boiler operation
Therefore,
Burner running hours = (Running time reduction of blower motor x Total production hours)
= 0.41 x 6402
Burner running hours = 2624.8 hr/year
Motor capacity = 14.2 kW
Total energy consumption of motor = burner running hours × motor capacity
= 14.2 × 2624.8

Total energy consumption of motor = 37272.4 kWh/year
Cost of electricity saving = 7.9 Rs./kW.hr
Total electricity saving = (Cost of electricity saving × Total energy consumption of motor)
= 7.9 × 37272.4
Total electricity saving = 2,94,452.3 Rs./year

Total saving in CNG & electricity

Total CNG & electricity saving = (Saving in terms of CNG in Rs./year + Total electricity saving)
= (29788920 + 294452)
Total CNG & electricity saving = 3,00,83,372 Rs
ROI is 0.9 years

V. CONCLUSION

Heat recovery is the main moto which was led out of the factory & the out exhaust gas temperature 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. Energy consumption takes place in paint shop which is more energy consumer in the automobile sector than other shops. The recovered heat can be utilized to heat the water which can be used for the pre-treatment. The detailed analysis of CFD was done on different tubes shape & gets correct shape of tube which will gives maximum heat recovery through the system. From overview of readings it is clear that approximately 505 kW/hr heat energy is recovering from oven exhaust gases. For hot water generation existing system 1253 kW energy equivalent used in boiler room will be directly reduced to ~500 kW. Reduction in CO2 footprint is 5kg/car body. The current situation is that the start of production is achieved and the boiler in utility system just runs only once at the start of process for some minute. Both shape circular & hexagonal tube gives the best results. We have selected circular shape tube which has diameter of 34 mm with its fins gives best result in heat recovery system because it has larger surface area than hexagonal shape of tube. Also, circular shape tube has easy to maintain than other complicated shapes of tube. Wastage of high heat content energy can be prevented to goes in atmosphere or can be recovered. The cost saving in CNG is Rs. 2, 97, 88,920 & electricity is Rs. 2,94,452. Total cost of saving through this project is Rs 3,00,83,372 which are very huge cost in a year. The return of investment for this project is 0.9 years.

VI. ACKNOWLEDGEMENTS

This work has been done only because of constant guidance and efforts of my project guide Dr. Jaware V. B. He not only showed me the way but molded my inexperience ideas and gave it practical outlook. I am thankful to him for keen interest and supervision, which help in successful completion of my work. I am also obliged to Head of Mechanical Engineering Department for his constant encouragement. Also I am thankful to Mr. Pranaya Satapathy, manager (Paint shop-Planning) at Volkswagen India for his constant guidance in my project work.

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