Review and Analysis of Heat Recovery System

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Abstract— The heat recovery system for oven in paint shop is analyzed and designed. The hot flue gases formed in this oven is passed to the environment through the exhaust duct to atmosphere. Oven's unused heat is exhausted to atmosphere at High Temperature of 320°C. The system is to reuse that air for heating the water. The hot water generated will be at temperature of 110°C. Hence the potential of energy recovery & reuse is realized. Average 90% of energy can be recovered from oven exhaust. The methodology used is shell and tube type heat exchanger with gas to liquid heat transfer. This paper speaks of programming the controller and designing human machine interface screens for the design & development. HMI screen is also referred as the user interface terminal, it allows to: control manual functions, view faults and operate machine.

Key words: Heat Recovery System, PLC

I. INTRODUCTION TO PLC

Programmable Logic Controller (PLC) is a specialized industrial computers used for controlling and operating the manufacturing process and machinery. It uses a programmable memory to store instructions and execute functions including on/off control, timing, counting, sequencing, arithmetic, and data handling. The PLC accepts inputs from switches and sensors, evaluates them based on a program (logic), and changes the state of outputs to control a machine or process. Programmable Logic Controllers (PLC's) are used in every aspect of industry to expand and enhance production. Where older automated systems would use hundreds or thousands of electromechanical relays, a single PLC can be programmed as an efficient replacement. Programming is carried out using "LADDER LOGIC".

II. OVEN

The main part is oven so we will shortly brief about oven in the following part and an Oven system. 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 later of rock wool and an external plate panel. To prevent escape of gases and vapors, the internal paneling and the circulation ducts of the Oven should be welded to make them gas-tight. The installed insulation layer is for energy saving as well as for avoiding heat bridges.

The factor of the heavy temperature fluctuations necessarily needs requirements on the construction. The tunnel must this be movable. As steel expands on heating, the tunnel must provide for this expansion at compensation points. On an average, each meter of the Oven expands by 1 mm on heating by 100°C. This means a total expansion of about 140 mm must be borne by the compensators for the Oven length of 100 m and a working temperature of 140°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 must be countered by appropriate movement. 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 insulation must be fire-proof and water-repellent. Under no circumstances should silicon-containing materials be used.

In convection, the heat energy is transferred by direct heating of the body with hot air. The air is heated in a heat exchanger and then blown into the Oven. The air is then suctioned to the heat exchanger. For this reason, there is circulation air here too. The heat energy heats up the ambient air by the heating gas the TAR. Circulation air and hot gas have no direct contact with each other. The energy transfer takes place through a heat exchanger. This heat exchanger can be in a separate unit outside the Oven or as in an IRC Oven (Integrated Radiation and Convection) in the Oven tunnel. The circulation air is heated in the Oven to the requisite temperature and gives this energy to the body when flowing around it. There is an air movement in the convection zones. The air flows through nozzles (heating zone) at a high flow speed or filter boxes (Holding zone) at low flow speed in the interior of the Oven.

III. RELATED WORK

Paint oven consume typically over 20% of the total energy spent in the paint shop. It was observed that the carriers are almost as heavy as the bodies they carry, and hence a significant portion of energy is spent to heat them up within the oven. A detailed analysis and physical tests are required to determine the extent of this potential throughput increase. Following are two methods implemented previously:

A. *Systematic Approach*

- Energy reduction within the manufacturing sector has a role to play in reducing global energy consumption. The research presented addresses the energy consumption of industrial ovens, which use a considerable proportion of energy associated within manufacturing.
- The systematic methodology guides an engineer from the basic understanding of an oven to optimization for energy saving. The stages include define, measure, analyze, improve and control. Combining process and product understanding with consideration of physical & engineering constraints is a powerful tool which can deliver significant energy savings.

B. *Regenerative Heat Recovery*

- Regenerative heat recovery has many industrial applications such in VOC treatment of automobile painting booth. A generalized thermal regeneration process coupled with a process and a pre-process was reviewed. Heat transfer and energy balance of the processes were analyzed and heat gain in the cycles is presented with relation to the efficiency of the regenerator.

– Applications in regenerative thermal oxidizer are discussed. It was found that in applications when the recovery efficiency is increased to 90%, the system in operation can save tremendous amount of burner heat and can have excess amount of heat recovery that could be used in other applications.

C. Design and Analysis of an HVAC based Heat Recovery System

– Tube shape has a significant impact on the j/f the design of a heat recovery system is presented and analyzed. It allows recovering the heat waste from Heating, Ventilating, and Air Conditioning (HVAC) systems to obtain hot water.
– The flattened round tube is also promising, given A code is developed for this purpose, which allows simulating the heat transfer in the system. The outlet temperature is studied in terms of the water flow rate and the amount of ton refrigerant in the system. It is shown that the water can be heated up to 347 K with a HVAC system of 9 tons of refrigerant (108 000 Btu/hr).

IV. PROPOSED SYSTEM

Heat recovery provides the realization of energy recovery and reuse. This main motive of this proposal is to reuse the heat generated by oven for generation of hot water. The equivalent exhaust energy from top coat oven is 932KW. According to proposed system we will get 95% efficiency in heat recovery i.e. 885KW energy.

The exhaust air flow rate is 12000nm3/hr. The heat carrying flue gas is exhausted to atmosphere at 340°C after exchanging heat with individual heating zones of the oven. The use of heat from oven is to generate hot water (110°C) which will be supplied to pretreatment and oil conservation process.

This proposed system is shown in Fig.1. It will be done with the particular gas to liquid heat exchanger along with feedback from temperature indicator and controller to control the flow of flue gases in heat exchanger.

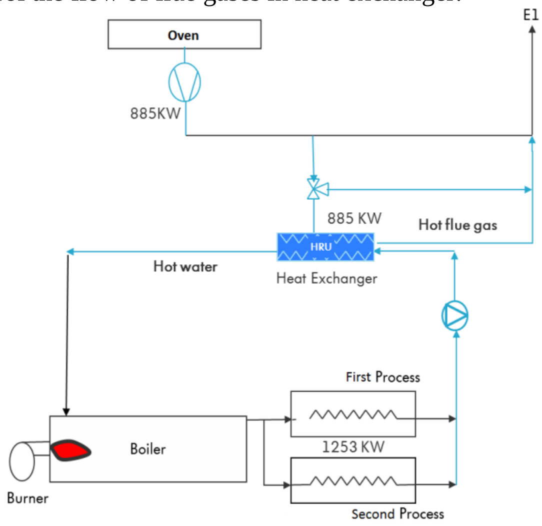


Fig. 1: Exhaust along with Heat exchanger

V. DESIGN METHODOLOGY

The design flow is shown in Fig.2 as it will firstly start with the specifications. Once the specifications are defined then the next step comes into the picture that is the control layout .i.e. the actual connection of control with all the zones of oven. After the control layout there comes the schematic diagram with each detailed connection of inlet, outlet, and flow. Depending on the schematic diagram flow of the system is defined and represented in flowchart. Flowchart will lead to the further step that is electrical diagram which will help in installation and commissioning. Hence the flow will move step by step ahead.

The Heat exchanger design will depend upon the calculations of the exhaust energy and the efficiency of the design. This is given by equation (1):

$$Q = M * C_P * \Delta t \qquad (1.1)$$

Here, 'Q' is the equivalent exhaust energy; 'M' is mass of the flue gas blowing through the exhaust; 'C_P' is the specific heat of air and 'Δt' is the difference between inlet and outlet temperatures.

The main part in the calculation is exhaust air flow rate and its density along with the temperature difference between inlet and outlet temperatures. The table for the calculations is shown below in TABLE I as:

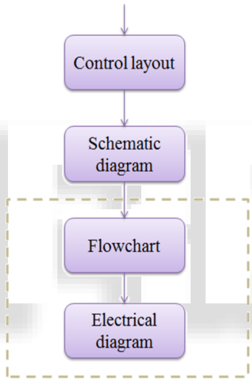


Fig. 2: Exhaust along with Heat exchanger

Heat Recovery Calculations		
Description	**Unit**	**Oven**
Exhaust air flow rate	Nm^3/hr	12000
HRU inlet temprature	Degree°C	320
Density of air	Kg/ Nm^3	1.2
HRU outlet temprature	Degree°C	110
Specific heat of air	Kcal/Kg°C	0.24
Equivalent Exhaust energy	KW	844
Considering 95% efficiency	KW	760
Total Recoverable Exhaust Energy = 760 KW		
Heat load requirment		
Average CNG consumption for Hot water generation / day		1253KW
Average CNG consumptio / hour		129 M

Table 1: Heat Recovery Calculations

VI. ALGORITHM

– Step 1: Cycle start
– Step 2: Turn on the pumps.
– Step 3: Check for Pre- Condition. If the condition doesn't satisfy, then go to Step 2.

- Step 4: Press cycle start button.
- Step 5: Check for Alarms. If there are any active alarms, then go to Step 20.
- Step 6: Start Heat Recovery unit.
- Step 7: Check whether the temperature is achieved at the exhaust duct.
- Step 8: Check whether the water flow is started in HRU.
- Step 9: Switch ON the heat.
- Step 10: Check whether PS2 and PS 3 is low.
- Step 11: Switch OFF the heat.
- Step 12: Wait till PS 3 becomes high.
- Step 13: Switch ON the heat exchanger.
- Step 14: Wait till temperature of exhaust duct becomes low.
- Step 15: Switch OFF the heat exchanger.
- Step 16: When all conditions satisfied switch on HRU
- Step 17: With the TIC control the dampers in the HRU.
- Step 18: Wait till we achieve the final outlet water temperature.
- Step 19: Check if Emergency/Cycle stop/Reset button is pressed. If yes, then go to step 20. If no, then repeat the steps from step 7.
- Step 20: Stop.

VII. SIMATIC MANAGER

Fig.3 represents the elements present on the “Simatic Manager” window. Simatic Manager is the tool used to carry out PLC programming. Programmable Logic Controller (PLC) is a specialized industrial computers used for controlling and operating the manufacturing process and machinery. It uses a programmable memory to store instructions and execute functions including turning ON/OFF the control, timing, counting, sequencing, arithmetic, and data handling. The PLC accepts inputs from switches and sensors, evaluates them based on a program (logic), and changes the state of outputs to control a machine or process. Programmable Logic Controllers (PLC’s) are used in every aspect of industry to expand and enhance production.

Programs are written on the editor window. On completing the programming part, the programs are compiled ( ), and then the programs are downloaded to the PLC. To download the program, click on download button . And then the program can be put to run mode ( ).

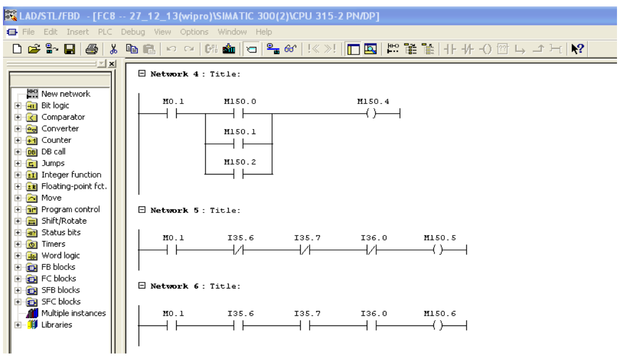


Fig. 3: PLC editor window

VIII. COMMUNICATION BETWEEN PLC AND PC/PG

Using the STEP 7 software, S7 program can be created within a project. The S7 programmable controller consists of a power supply unit, a CPU, and input and output modules (I/O modules). MPI is used to communicate between PC and PLC. Through this, the Ladder logic or the programs from PC/PG is downloaded to PLC.

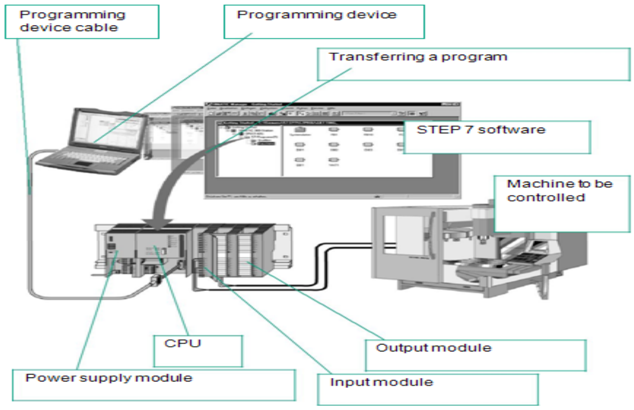
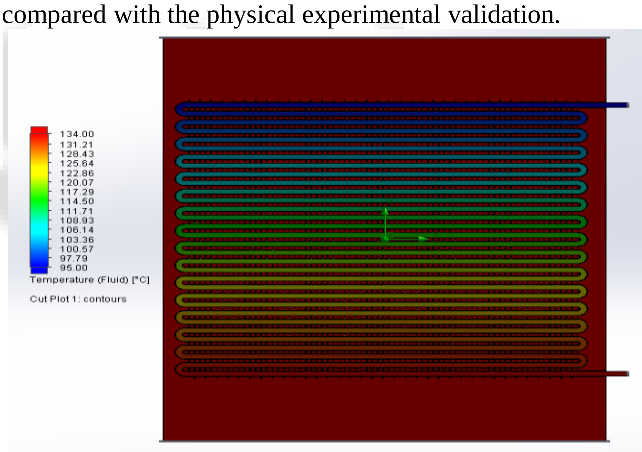


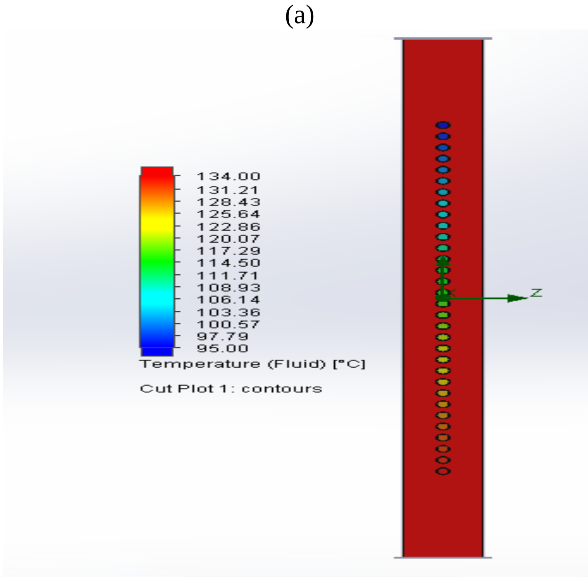
Fig. 4: Communication between PC and PLC

IX. RESULTS AND 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)



(b)

Fig. 5(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

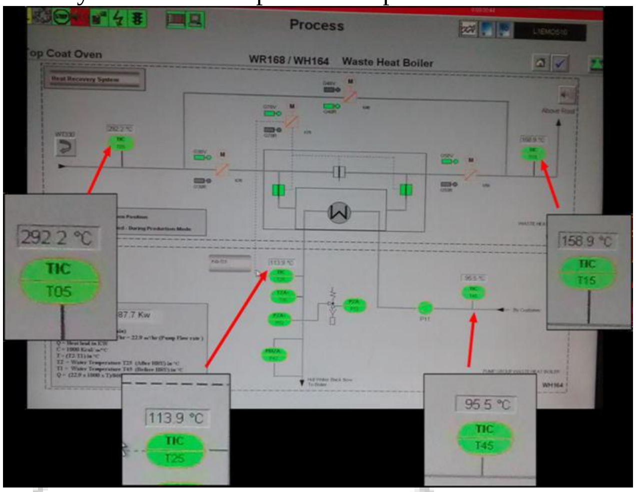


Fig. 6: Schematic view of heat recovery system on ECO screen Showing actual readings of water & exhaust gases.

X. 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 approximately 500 kW/h heat energy is recovering from exhaust. Existing 1253 kW energy equivalent used in boiler for hot water generation will get reduced to ~500 kW. Total CNG & electricity saving is 4, 56, 58,144 rs. which is a very huge cost. ROI for this project is 0.9 years. The potential of energy recovery & reuse is realized. Maximum energy can be recovered with an efficiency of 90%. The current situation is that the boiler system runs only for startup and CNG saving is at very high content. PLC is very versatile and effective tool in industrial automation. It cuts the production costs, improves the quality. Cycle time taken is 90 seconds. Troubleshooting is easy in PLC.

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