WASTE HEAT RECOVERY FROM THE EXHAUST OF A DIESEL ENGINE USING PARALLEL FLOW SHELL AND TUBE HEAT EXCHANGER

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Abstract— High temperature diesel engine exhaust gas can be an important source of heat to operate a bottoming Rankine cycle to produce additional power. In this research, an experiment is performed on a single cylinder, four stroke diesel engine to calculate the available energy in the exhaust gas of diesel engine. A shell and tube heat exchanger is used to extract heat from the exhaust gas, using water as the working fluid. Waste heat recovery technology has a great potential for saving energy, improving overall engine efficiency, and reducing toxic emission per kilowatt of power generation.

Keywords— Waste Heat Recovery, Diesel Engine, Rankine Cycle, Shell and Tube Heat Exchanger.

I. INTRODUCTION

Today’s modern life heavily relies on Internal Combustion Engines (ICEs). Despite the fact that some new technologies have been introduced in recent years, the majority of vehicles are still powered by IC engines. Diesel engines are widely used due to their abilities and advantages in industries for producing energy, transportation, etc., but a large amount of their fuel energy is wasted through the exhaust. Governments were motivated to mitigate emissions and improve fuel efficiency of diesel engines due to rising greenhouse gas emissions, fossil fuel depletion and increasing fuel costs. Under such circumstances, higher energy utilization efficiency and lower emissions are the two major development momentums for IC engine. Exhaust gas carries 25-30% of heat energy from the engine. As a consequence, substantial efforts have been made to recover the excess waste heat in the exhaust flow and convert into useful work. The energy lost in waste gases cannot be fully recovered. But by using certain devices, maximum possible heat can be recovered from the engine in turn minimizing the energy losses. DaeHee Lee et al (2010) studied the effect of secondary combustion system to improve the energy recovery and engine emissions. They reported that secondary combusted heat exchangers reached maximum efficiency of 94.4% and had produced reduced emissions of CO, NOx and particulate matters at 80%, 35% and 90% respectively. V. Pandiyarajan et al. (2011) investigated heat energy recovery from diesel engine with aid of shell and tube heat exchangers and reported that 10-15% of a fuel power was stored as heat in thermal storage system. R. Saidur et al (2012) reviewed the latest developments and technologies to recover the exhaust gas energy from IC engine. GequnShu et al. (2013) reviewed different types of waste heat recovery technologies based on methods, designs and theoretical and experimental analyses. Saitful Bari et al. (2013) conducted an experiment to recover the waste exhaust heat from diesel engine with use of heat exchangers and they reported that power increased up to 23.7%. Jianqin Fu et al (2013) proposed a steam turbo charging technique to boost IC engine intake pressure to save the energy and they reported engine power was improved theoretically at most of 7.2%. Jianqin Fu et al. (2014) developed a device called steam assisted turbo charging to assist the exhaust turbo charger to recover the exhaust energy and stated that intake gas pressure reached their desired value and torque can be increased by 25%. Also slight improvements on pumping mean effective pressure and thermal efficiency. Jianqin Fu et al. (2014) performed a comparative study among exhaust turbo charging, steam turbo charging and steam assisted turbo charging. Mohsen Ghazikhani et al. (2014) investigated diesel engine energy recovery double pipe counter flow heat exchanger and reported that energy increased with increase in engine load and speed, reduction in brake specific fuel consumption of nearly 10%. M.Hatami et al. (2014) reviewed the waste heat recovery technologies from diesel engines with use of different types of heat exchangers and also proposed heat exchangers designs to enhance the heat recovery from the exhaust of diesel engines. ShekhNisar Hassain et al. (2013) conducted an experiment to measure the exhaust heat from 40 KW diesel generators with use of series and parallel heat exchangers. They reported that the optimized heat exchanger produced 11% additional power and 12% improvement in brake specific fuel consumption (BSFC). GaoWenzhi et al. (2013) studied the performance evaluation and parameters selection of the heat exchanger to enhance the exhaust energy recovery and reported that with attachments of heat recovery system the power output of diesel engine was increased by 12%. From the research reviews, the present work was carried out to recover the exhaust energy with the aid of heat exchanger. In the present work, heat recovery system consisting of a finned shell and tube heat exchanger and a Thermal Energy
Storage (TES) tank with paraffin as PCM storage material has been designed and fabricated for waste heat recovery from diesel engine exhaust.

II. EXPERIMENTAL SETUP

The major criterion in the design of waste heat recovery system is the proper selection of heat exchanger with optimum conditions. In the present investigation, the objective is to extract heat from the exhaust gas and to store it in the storage tank. In the later case, the storage fluid may itself be used as the heat transfer fluid or a separate heat transfer fluid may be used to extract heat from the exhaust gas and deliver it to the storage medium.

The engine used in current study is a single cylinder, four stroke, 3.7 KW air cooled diesel engine which is coupled with an Eddy current dynamometer. The specification of the engine is given in the Table 1. The schematic of the experimental setup is shown on the Figure 1. The engine is run with different loads for a constant speed and exhaust temperature is recorded to calculate available heat energy from the exhaust. Then the exhaust of the engine is connected to a shell and tube heat exchanger to study the performance of the heat exchanger and those data is used to improve the design of the heat exchanger by computer simulation.

![Fig.1: Schematic diagram of the experimental setup.](image)

Table 1: Engine specification

<table>
<thead>
<tr>
<th>Manufacture</th>
<th>Rocket Engineering Corp. Pvt. Ltd., Kolhapur</th>
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<tbody>
<tr>
<td>Engine</td>
<td>Single cylinder, 4- stroke, stationary C.I. Engine</td>
</tr>
<tr>
<td>Bore</td>
<td>80mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>110mm</td>
</tr>
<tr>
<td>Comp. Ratio</td>
<td>16:1</td>
</tr>
<tr>
<td>Power output</td>
<td>5HP(3.7 kW) at 1800 rpm</td>
</tr>
<tr>
<td>Sp. Fuel consumption</td>
<td>251g/Kw-hr</td>
</tr>
<tr>
<td>RPM</td>
<td>1500 rpm</td>
</tr>
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</table>

III. CALCULATION FOR WASTE HEAT FROM I.C. ENGINE

A. Available waste heat

The quantity of waste heat contained in exhaust gas is a function of both the temperature and the mass flow rate of the exhaust gas:

\[ Q = m \cdot C_p \cdot \delta T \]  

Where, \( Q \) is the heat loss (kJ/min); \( m \) is the exhaust gas mass flow rate (kg/min); \( C_p \) is the specific heat of exhaust gas (kJ/kgK); and \( \delta T \) is temperature gradient in K. In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature. Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat’s utility or “quality”. The source and sink temperature difference influences the rate at which heat is transferred per unit surface area of recovery system, and the maximum theoretical efficiency of converting thermal from the heat source to another form of energy (i.e., mechanical or electrical). Finally, the temperature range has important function for the selection of waste heat recovery system designs.

IV. HEAT EXCHANGER DESIGN

The data found from the experiment is used to optimize the design of shell and tube heat exchanger by computer simulation. Effect of important parameter of heat exchanger like diameter of the shell, no of tubes, length of the heat exchanger, pressure drop is investigated and final model of the heat exchanger is proposed. The pecification of the model of the proposed shell and tube heat exchanger is shown in the Table 3.

Table 3: Heat exchanger Model specifications

<table>
<thead>
<tr>
<th>Sr.no</th>
<th>parameters</th>
<th>size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Length of heat exchanger</td>
<td>600 mm</td>
</tr>
<tr>
<td>2.</td>
<td>Inner diameter of shell</td>
<td>100 mm</td>
</tr>
<tr>
<td>3.</td>
<td>Tube outer diameter</td>
<td>20 mm</td>
</tr>
<tr>
<td>4.</td>
<td>Tube thickness</td>
<td>3 mm</td>
</tr>
<tr>
<td>5.</td>
<td>No. of tubes</td>
<td>07</td>
</tr>
<tr>
<td>6.</td>
<td>No. of baffles</td>
<td>04</td>
</tr>
</tbody>
</table>

V. CFD MODEL

The optimized design of the shell and tube heat exchanger is modeled for heat transfer between hot and cold fluid in Flow Simulation which is CFD simulation module of CATIA V5 R20. The computational mesh used to solve the model heat
exchanger contained 109,992 cells. The Standard k-ε, a two-equation Reynolds-Averaged Navier-Stokes (RANS) model that is currently the most widely used for calculating industrial flow problems has been used in this model.

VI. RESULTS

To design an effective heat exchanger for heat recovery from the exhaust of an engine, it is required to know how much energy is available in the exhaust. So some base line tests are performed. The exhaust gas temperature at various speed and engine power is presented in the Figure 2. It is found from the figure that engine power and the temperature of the exhaust gases for all three engine speeds show an approximately linear relationship. Exhaust gas temperature increases with increase of power output and speed of the engine. This indicates that heat recovery will be more viable for higher powers.

In the relationship between power and temperature there is a definite relationship between engine power and the amount of recoverable energy present in the exhaust gases. The relationship this time is not linear but there is still a general upward trend, revealing that, as the engine power increases, so does the amount of recoverable energy. This is clearly seen in Figure 3. This finding is highly significant in terms of the focus of this research project. In particular, the potential applications which formed the original thinking behind this project are given credibility, in that the amount of energy which may be tapped is of an order that justifies the attempt to capture and exploit it. For example, even if the results of just the lowest speed (1400 rpm) are considered, the potential to capture and use what is currently wasted energy, is extremely significant - the maximum recoverable energy for this speed is approximately 17 kW from the exhaust gas with the engine running at 33 kW (which is half the engine’s power). Similarly, at 1800 rpm, a maximum value of approximately 21 kW was obtained from the exhaust gases, with the engine running at approximately 39 kW. At 2200 rpm the results show a maximum recoverable potential of approximately 23 kW when running at 45 kW. These results indicate that some 50% of the engine’s running load is currently wasted but could be recoverable and converted to a usable form. All the above calculations were based on the abilities of a heat exchanger to be able to reduce the initial exhaust temperature at any particular speed and load to 50°C.

CONCLUSION

A significant amount of input energy of a diesel engine is expelled through the exhaust gas to the environment. This energy can be captured by an exhaust recovery system, and additional power can be generated. A bottoming Rankine cycle can be a good option for such a type of exhaust recovery, which will reduce the fuel consumption and, thereby, will also reduce the Green House gases and toxic emissions per KW of overall power produced.

ACKNOWLEDGMENT

At the outset, I would like to take this opportunity to express my sincere gratitude to my mentor Mr. H. S. Farkade (Assistant professor, Mechanical Engineering Department, GCOEA Amravati) for his valuable guidance, meticulous approach and gracious engagement at each and every stage to make analysis a reality and success.

REFERENCES


Fig.2: Exhaust gas temperature variation with engine load from experiment.

Fig. 3: Recoverable energy variation with engine load from experiment.
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