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A Review on Additional Power Generation from Exhaust Gas of Diesel Engine using Parallel Flow Shell and Tube Heat Exchanger

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Abstract

The increasingly worldwide problem regarding rapid economy development and a relative shortage of energy, the internal combustion engine exhaust waste heat and environmental pollution has been more emphasized heavily recently. Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work; the remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work. The study shows the high temperature diesel engine exhaust gas can be an important source of heat to operate a bottoming Rankine cycle to produce additional power using a shell and tube heat exchanger at exhaust system of a diesel engine; therefore, the main objective of this paper is to assess this waste heat recovery technology based on current developments, research trends and its future in an automotive application. As a result, the article drew the conclusion that waste heat recovery and its utilization will remain a good prospect in future automotive engine application.
Keywords- Waste Heat Recovery, Diesel Engine, Rankine Cycle, Shell and Tube Heat Exchanger, Exhaust Gas Energy Recovery

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 the 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 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. Waste heat is generated in a process by the way of fuel combustion or chemical reaction, and then dumped into the environment even though it could still be reused for some and economic purpose. Large quantity of hot flue gases is generated from boilers furnaces and IC engines etc. if some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. Depending on the temperature level of exhaust stream and the proposed application, different heat exchange devices, heat pipes and combustion equipments can be employed to facilitate the use of the recovered heat. The shell and tube heat exchanger is the most widely used type of industrial heat transfer equipment. Initially, only plain tubes were used in shell and tube heat exchangers. The heat transfers coefficient (h) for gases is generally several times lower than that for water, oil and other liquids, in order to minimize the size and weight of a gas to liquid heat exchanger, thermal conductance (ha) on the both sides of the exchanger should be approximately the same. Hence the heat transfer surface on the gas side needs to have a much larger area and be more compact than can be realized practically with the circular tubes commonly used in shell and tube heat exchangers. 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, NO_X 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. Saiful Bari et al. (2013) conducted an experiment to recover the waste 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 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 Hossain 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). Gao wenzhi 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 this paper, a brief review of the waste heat from stationary diesel engine, waste heat recovery system using parallel flow shell and tube heat exchanger.

II. EXPERIMENTAL SETUP AND METHODOLOGY

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 set up is shown in 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.

At first the baseline engine experiment is conducted without connecting the heat exchanger. The engine is tested at different loads with variable speed (1500 rpm). The exhaust temperature and air flow rate is recorded to calculate available heat energy from the exhaust. A baffled shell and tube heat exchanger with parallel flow is designed to obtain the better heat transfer is shown in the figure 2. Is installed into the exhaust system of the engine to study the heat recovery potential and performance of the heat exchanger. Water mass flow rate, water temperature, and pressure is recorded to calculate the effectiveness of the heat exchanger. the exhaust from the engine is flowed through the tubes of the heat exchanger and water flowed through the shell side. Parallel flow heat exchanger orientation is selected for this study.

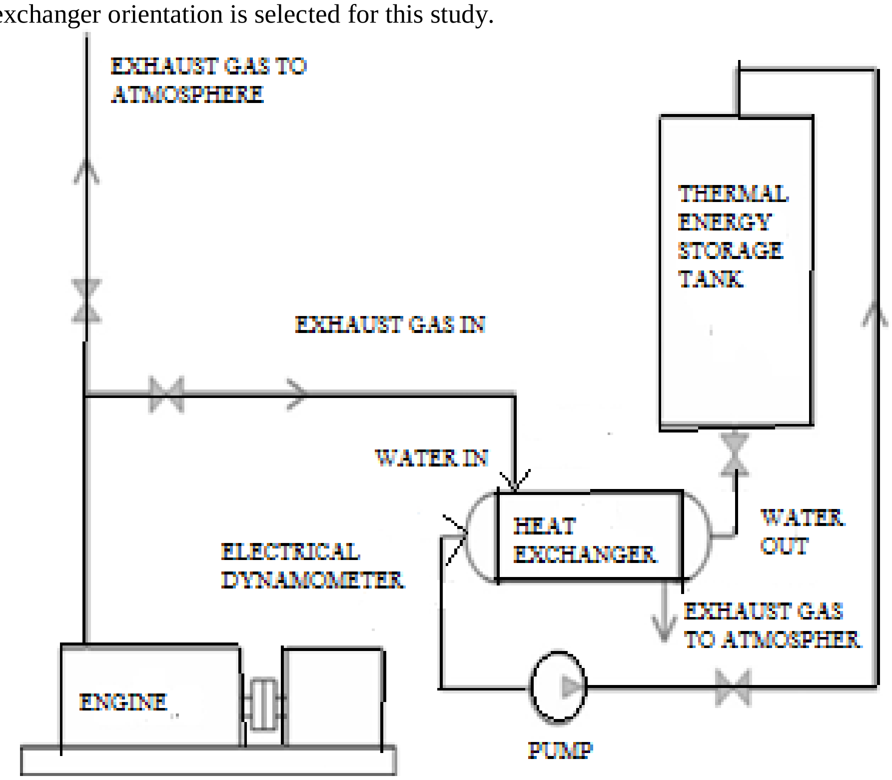

Fig. 1: Experimental setup

Table 1: Engine Specifications

Manufacture	*Rocket engineering corpn. Pvt ltd., Kolhapur*
Engine	*Single cylinder, 4- stroke, stationary C.I. Engine*
Bore	*80 mm*
stroke	*110mm*
Compression Ratio	*16:1*
Power output	*5 HP(3.7KW) at 1500 rpm*
Specific fuel consumption	*251 g/KW-hr*

A. 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 specification of the model of the proposed shell and tube heat exchanger is shown in the Table 2.

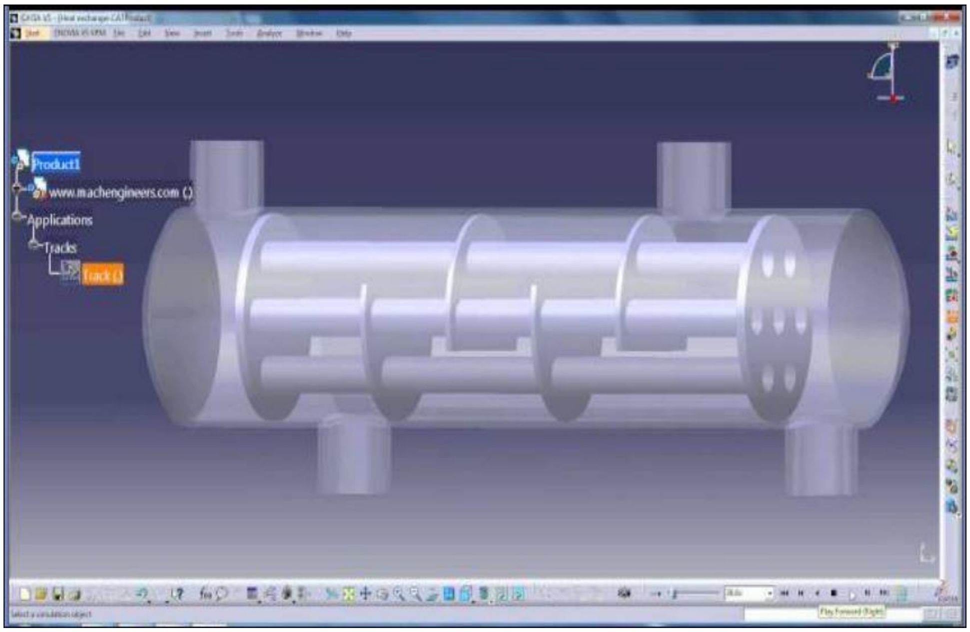

Fig. 2: Heat exchanger

Table 2: Heat exchanger Model specifications

Sr.no.	*parameters*	*size*
	Length of heat exchanger	*600 mm*
	Inner diameter of shell	*100 mm*
	Tube outer diameter	*20 mm*
	Tube thickness	*3 mm*
	No. of tubes	*07*
	No.of baffles	*04*

B. 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:

$$Q = m * Cp * \delta T \qquad (1)$$

Where, (Q) is the heat loss (kJ/min); (m) is the exhaust gas mass flow rate (kg/min); (Cp) is the specific heat of exhaust gas (kJ/kgK); and (δT) 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.

C. Heat Loss through the Exhaust in Internal Combustion Engine

Heat loss through the exhaust gas from internal combustion is calculated as follows. Assuming,

- Volumetric efficiency (η_V) is 0.8 to 0.9
- Density diesel fuel is 0.84 to 0.85 gm/cc
- Calorific value of diesel is 42 to 45 MJ/kg
- Density air fuel is 1.167 kg/m3
- Specific heat of exhaust gas is 1.1-1.25 KJ/kg.K

Exhaust heat loss through diesel engine

Compression ratio (Vr)

$Vr = \frac{Vc+Vs}{Vc}$

$16Vc = Vc + 6.61*10^{-4}$

$Vc = 4*10^{-5}$

Total volume (Vr) = Vc + Vs

$= (4*10^{-5})+6.61*10^{-4}$

$=7.01*10^{-4} m^3$

Mass flow rate of fuel can the basis of specific fuel consumption (mf)

$s.f.c = \frac{mf}{Vpower}$

mf = s.f.c. * power

= 251*3.7

=0.37177 gms/sec

Volume rate = swept volume * speed

Volume rate(V)= Vs*N

$V = 6.61*10^{-4}*\frac{1500}{2}$

$V = 0.4957\ m^3/min$

$V = 8.262*10^{-3}\ m^3/sec$

Volumetric efficiency (η_v) $= \frac{ma}{\text{swept volume}}$

$= \frac{ma}{\varrho*n*Vs}$

$m_a = \eta_{v*}\varrho_a*n*Vs$

$= 0.9*1.16*750*6.61*10^{-4}$

=0.5175 gm/min

= 8.625 gm/sec

Mass flow rate of exhaust gas (m_E)

$m_E = m_f + m_a$

= 8.625 + 0.3177

= 8.9427 gm/hr

$= 8.9427*10^{-3}$ gm/sec

Heat loss in exhaust gas (Q_E)= m_E *Cp * Δt

$= 8.9427*10^{-3}*1.1*(450-30)$

= 4.13 KJ/sec

Therefore, the total energy loss by diesel engine is 29.21%. Hence the loss of heat energy through the exhaust gas exhausted from I.C. engine into the environment 29.21% energy.

III. CONCLUSIONS

The exhaust gas of a diesel engine carries a lot of heat and this energy can be recovered efficiently using HRHE. However the major technical constraint that prevents successful implementation of such a system is intermittent and time mismatched demand and availability of energy. The thermal energy storage system will eliminate the above constraint. A suitable WHR system with a large capacity of TES tank can store heat energy and this energy can be utilized for many applications like process heating etc; in industries.

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