

Effect of Waste Heat Recovery System on Performance and Emission Characteristics of Spark Ignition (SI) Engine Fuelled with Neat Ethanol (E100)



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ABSTRACT

The SI engine could not be operated efficiently with neat ethanol fuel due to its high self ignition temperature and latent heat of vaporization compared with petrol. The above issues of SI engine is turned to be an objective of this study, where the SI engine was operated with neat ethanol fuel under different inlet air temperatures. The result of this study is indicated that the neat ethanol fuel could be utilized efficiently in SI engine with waste heat recovery system. The specific fuel consumption (SFC) of SI engine has decreased with neat ethanol fuel compared with petrol fuelled engine. It is also found that the SI engine has registered almost same brake thermal efficiency (BTE) values with neat ethanol compared to petrol. The exhaust emissions such as carbon monoxide (CO) and Hydrocarbon (HC) were reduced in SI engine, at the same time there was an increase in oxide of nitrogen (NO_x).

Keywords: Spark Ignition Engine, Ethanol fuel, Waste Heat Recovery System, Preheating, Reduction of Pollutions.

1. INTRODUCTION

Ethanol is one of the suitable alternative fuels for spark ignition (SI) engine and it can be used without changing any modification in the engine. The ethanol fuelled SI engine has emitted low CO and HC emission without affecting the engine efficiency [1-4]. Most of the studies resulted that ethanol is more efficient in SI engine, when it is blended with petrol and emitted lower pollutants compared to neat ethanol fuelled engine. The properties of ethanol fuel is almost similar to petrol except latent heat of vaporization and self-ignition temperature. It made the ethanol more complex to use as neat fuel in spark ignition engine. The ethanol fuels are renewable and it can be extracted from bio-waste such as sugar cane, crop waste, fruits and vegetable waste. India is the second topmost country producing the ethanol.

The availability of ethanol in India will fulfil the fuel need for automobile in the future. There are many research being conducted on SI engine to operate efficiently with ethanol fuel and also analyse the methods

to be overcome the issues of high latent heat of vaporization and self-ignition temperature of ethanol. From the existing studies it was found that the following methods such as blending with petrol, exhaust gas recirculation (EGR), inlet air preheating and fumigation are the effective methods to utilize the ethanol in SI engine [5-8].

There are more number of studies have done on fossil fuel and ethanol blends in SI engine. The performance and emission characteristics of petrol / ethanol fuelled SI engine was studied by Yusoff, M.N. A. M., et al. [9]. The authors done their work on four-cylinder spark ignition engine and conducted the experiment with E10 and E20 blends by varying the engine parameters like speeds and torque. From the result, it was observed that the engine has produced more torque and thermal efficiency while operating with E20 blend. The result of this study proved that the addition of ethanol in the blend has improved engine performance. The similar kind of study had done by Phuangwongtrakul S et al. [10] on SI engine with different ethanol-gasoline blends. He conducted the experiments with E10, E20, E30, E40, E50, E60, E70, E85, and E100 and absorbed the performance and emission characteristics. The results indicated that an increasing of ethanol ratio in the blend has improved engine torque, especially at low engine speed.

Yaman Het al. [11] done their experimentation in a single cylinder four stroke SI engine to analyse the performance and emission characteristics with different ethanol-gasoline blends as E0, E10, E20 and E30. The engine was operated efficiently with different ethanol blends and found the reductions of carbon monoxide (CO), carbon dioxide (CO₂) and nitrogen oxide (NO_x) emissions without affecting the engine power. The methods of ethanol injection in SI engine makes significant impact on performance and emission characteristics. The port injection system normally gives enough time to the fuel to mix with air and form stoichiometric mixture before stating the combustion process. From the many experiments, it was found that the port injected ethanol fuel has resulted low CO and HC emissions with

significant improvement in the thermal efficiency [12, 13]. Kim Net al [14] studied the combustion and emission characteristics of an SI engine with ethanol port injection system. The results indicated that ethanol injection can be reduced the knock frequency and there was a reduction in particulate emission.

The performance, emission and combustion behaviour of ethanol fuelled SI engine has varied based on injection systems. Cohn et al. [15] conducted the experiment on direct injected spark ignition engine with different ethanol blends. The experimental investigations were carried out by varying the engine load with constant engine speed. From the experimental result, it was concluded that the engine was consumed minimum amount of fuel, when it operated with high ethanol blends. Stein et al. [16] compared the performance and emission characteristics of ethanol fuelled engines having different injection systems such as DI and PFI systems. From the result, it was found that DI with E85 engine has given better results compared to PFI engine. There are many reasons for increasing engine efficiency with direct injection system, air turbulence and high injection pressure allow ethanol to mix properly with air and it shorten the combustion duration. Zhuang et al. [17] is also done his work on SI engine with ethanol fuel, the author investigated the effect of DI on engine fuel consumption (FC), combustion and emission characteristics. The experimental was conducted in single cylinder, four stroke spark ignition engine. During the experimentation, the engine was allowed to operate with different petrol – ethanol blends. From the result, it was observed that the volumetric efficiency of the engine is increased due to the enhanced charge cooling effect and the rate of fuel consumed by the engine was being increased, if increasing the percentage of ethanol in the blends. The exhaust pollutants such as HC and CO emissions were drastically decreased due to availability of oxygen and high octane number of fuel.

Most of the studies on ethanol with spark ignition engine have done by varying the injection methods, blend with petrol and changing the operating parameters of spark ignition engine like compression ratio, injection timing and adopting EGR. Meanwhile some of other studies have done with neat ethanol fuel in SI engine. This study investigate the performance and emission characteristics of neat ethanol fuel in spark ignition engine with waste heat recovery systems, Where the inlet air has to be preheated with engine exhaust gas. The experimental investigation will be conducted with different inlet air temperature such as 50°C, 52°C, 54°C, 56°C, 58°C and 60°C and identify the optimum air temperature for effective utilization of neat ethanol.

2. FUEL PROPERTIES

Ethanol is the suitable alternative fuel for spark ignition engine, the properties of ethanol is almost similar to the petrol except latent heat of vaporization and self-ignition temperature. The properties of ethanol and petrol are compared in the **table 2.1**. In general, ethanol has some oxygen molecules, it is around 34.7 %. The ethanol fuel has high octane value compared to petrol and it favours for

high anti knocking characteristics and creates more heat power during the combustion.

Table 2.1: Properties of Fuels

Properties	Petrol	Ethanol
Carbon content %	86	52.2
Hydrogen content%	14	13.1
Oxygen content%	0	34.7
Freezing point	-60	-114
Boiling point	85	78
Latent heat of vaporization (KJ/Kg)	461	904
Octane number	87	108.6
Auto ignition temperature	280	420
Calorific value (KJ/Kg)	45000	29300
Stoichiometric air/fuel ratio	14.7:1	9:1
Density (Kg/m ³)	0.742	0.79

3. EXPERIMENTAL SETUP AND PROCEDURE

The line diagram of the experimental setup is shown in **figure 3.1**. The experimental investigation was conducted in a single-cylinder, four-stroke SI, air cooled engine. The specification of the engine is listed in the **table3.1**. For the experimentation, the two-wheeler silencer was slightly modified to extract the waste heat from the exhaust gas. Where the fresh inlet air is allowed to flow through the modified silencer and it carries some amount of heat energy to preheat the ethanol. These preheated ethanol will be created as homogeneous mixture before stating the combustion process. The properties of both ethanol and petrol fuels are listed in **table2.1**.

Table 3.1: Engine Specification

S.No	Engine specification	
1.	Engine Type	Air Cooled, 4 Stroke, SI Engine
2.	No. of Cylinders	1
3.	Max Power	10.30 PS @ 7500 rpm
4.	Max Torque	10.30 Nm @ 5500 rpm
5.	Displacement	124.73 cc
6.	Cooling System	Air Cooled
7.	Gear Box	4 Speed
8.	Bore	52.4 mm
9.	Stroke	57.8 mm
10.	Max Speed	93 kmph

The line diagram of designed silencer is shown **figure 3.2**. It contains two air flow controller, one of the controller is placed at exhaust pipe to control the flow of exhaust gas to the regenerative chamber to preheat the fresh air and next one is fixed at the engine inlet side to control the temperature of air admitted to the engine by mixing of atmosphere air. The flow controllers are controlled manually and it is used to change the temperature of preheated air for the experimentation. The temperature of preheated air is measured by the thermocouple placed at engine inlet pipe. The use of both flow controller and thermocouple, the temperature of inlet air is varied as 50°C, 52°C, 54°C, 56°C, 58°C and 60°C and the experimentation was conducted.

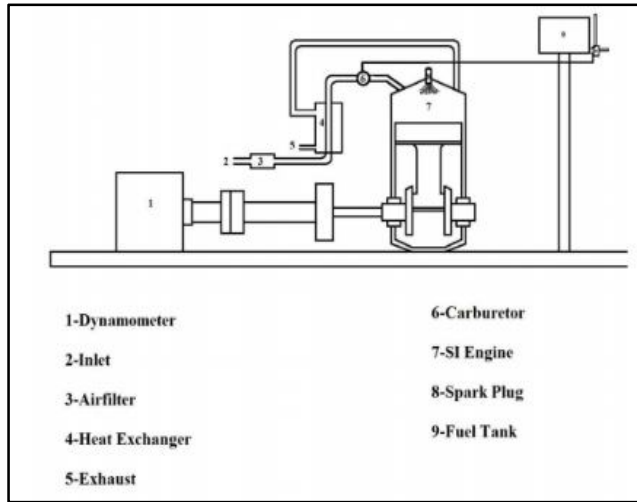


Fig 3.1: Experimental Setup

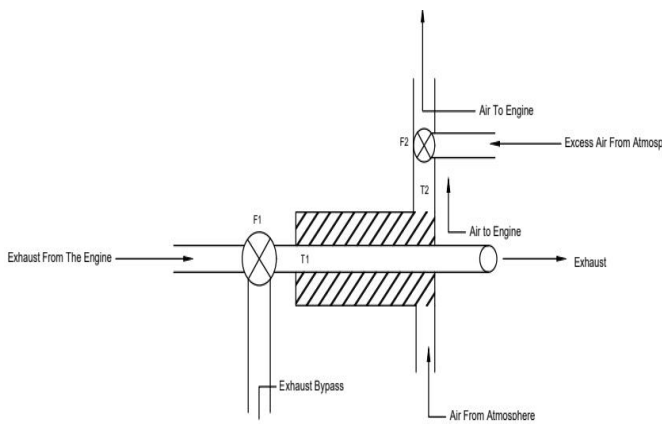


Fig 3.2: Setup of Waste Heat Recovery

During the experimentation, the ethanol fuel was mixed with air in the carburettor. The preheated air passes through the carburettor, where the injected ethanol observed the heat from the air and got vaporized. At suction stroke, the air-fuel mixture enters to engine as partially homogeneous and in the second stroke of compression, the whole mixture turned to be completely homogeneous due to the compression of piston.

4. RESULT AND DISCUSSION

The petrol engines are more efficient than diesel engine due to its cleaner combustion. The SI engines are operated with homogeneous mixture for all mode of operations. The specific fuel consumption (SFC) of the engine is calculated by the rate of combustion. That is amount of heat liberate by the fuel when it has combust. **The figure 4.1** shows the variation SFC values with engine speed for different inlet air temperatures such as 50°C, 52°C, 54°C, 56°C, 58°C and 60°C. From the figure, it was found that the SFC values are continuously decreasing with increasing preheating temperature.

From the result of this experiment, it was found that the SI engine was operated efficiently at 56°C and 58°C air temperatures. The SI engine was operated with lower SFC values at 56°C and 58°C air temperatures for different engine speed conditions. During the

experimentation the SI engine was operated with different speeds such as 1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm, 5000 rpm and 6000 rpm. Meantime the rate of fuel consumed by the engine was calculate by the stop watch.

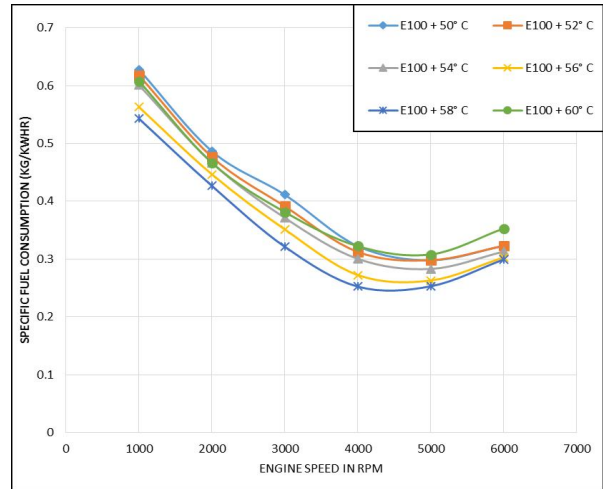


Fig 4.1: Variation in SFC with Engine Speed

From the result, it was understood that the preheated air vaporize the ethanol fuel and it makes the mixture as homogeneous in SI engine before occurring the combustion process. In addition, increasing preheating temperature reduces the pollutions such as Carbon monoxide (CO) and Hydrocarbon (HC).

The variation in brake thermal efficiency (BTE) with engine speed of SI engine is shown in **figure 4.2**. The brake thermal efficiency of SI engine could be calculated by the amount of heat liberate by the specific amount of fuel. The SI engine has high BTE compared to diesel engine due to it cleaner combustion. In this study, the SI engine was operated with neat ethanol fuel with the help of air preheating system. The result of this study has proved that ethanol was an effective alternate fuel for SI engine and it could be controller by the air preheating system. The above graph indicated that the brake thermal efficiency of ethanol fuelled SI engine was increasing with increasing air temperature.

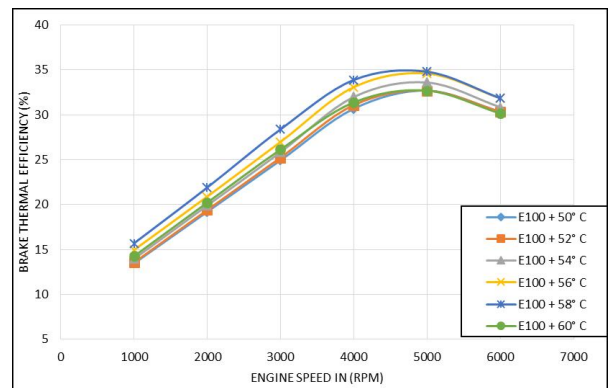


Fig 4.2: Variation in Brake Thermal Efficiency with Engine Speed

From the experimental result, it was observed that the SI engine has lower brake thermal efficiency at lower speed and it has been increasing with engine speed. In

addition, the engine has produced higher thermal efficiency during the speed of 4000 rpm to 5000 rpm. From the result, it was found that the SI engine has registered high thermal efficiency at 56°C and 58°C air temperatures.

The oxides of nitrogen (NO_x) is one of the harmful pollutants emitted by the SI engine. The reason for NO_x formation in SI engine is high combustion temperature. In general, the SI engines are operated with homogenous air-fuel mixture and it create high combustion temperature. It cause more NO_x formation in SI engine, these NO_x emissions create impact on environment and living beings as well. From the result of this experiments, it is found that the ethanol fuelled SI engine has produced high NO_x emission. In addition, the NO_x formation is increased with increasing engine speed and air temperature.

The figure 4.3 shows the variation in NO_x emission with different engine speed and air temperature of ethanol fuelled SI engine. The NO_x emission is increased with increasing engine speed, the reason is high engine speed increases combustion temperature. If the combustion temperature is reached beyond the 1500 degree centigrade. It starts to create NO_x emission in the SI engine. From the result it was observed that the increasing preheating temperature of air increasing combustion temperature and NO_x emission as well.

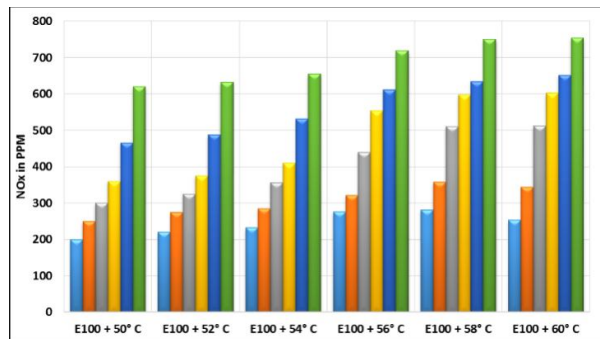


Fig 4.3: Variation in NO_x with Engine Speed

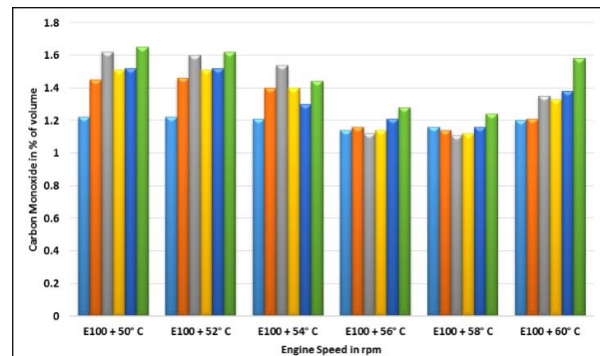


Fig 4.4: Variation in CO with Engine Speed

The Carbon monoxide (CO) is the emission created by the SI engine due to incomplete combustion and it might be lead due to cold starting and low combustion teperature. The CO is the intermediate product, it can be formed due to lagging of oxygen in the cylinder. The figure 4.4 shows the variation in CO emission with engine speed and air temperature. Where the engine was operated

with different speed and preheating temperatures. From the graph, it is observed that the SI engine has emitted high CO emissions at lower and higher speed and it has lower CO emission in the average speeds. The ethanol fuelled SI engine has regestered low CO emission at 56°C and 58°C preheating temperature.

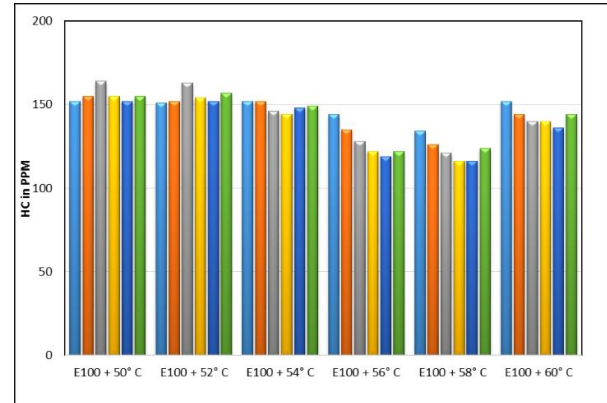


Fig 4.5: Variation in HC with Engine Speed

Hydrocarbon (HC) is the harmful emission created in the SI engine due to incomplete combustion. The variation in HC with engine speed and preheating temperature are shown in figure 4.5. It is found that the SI engine has emitted high HC emissions at the time of starting and higher speed. In addition, it is also found that the HC emission in SI engine has reduced with increasing the air temperature. The preheating temperature about 56°C and 58°C operated SI engine has low HC emissions compared to other air temperate.

CONCLUSION

From this study, it was proved that ethanol has an efficient alternative fuel for spark ignition engine. The neat ethanol fuel could be used in spark ignition engine with waste heat recovery system. The following points were conclude from this experimental investigation,

- ✓ Specific fuel consumption of SI engine was decreased with increasing inlet air temperature. The preheating temperature 56°C and 58 °C operated SI engine has registered lower specific fuel consumption values.
- ✓ Brake thermal efficiency of SI engine was increased with increasing engine speed and preheating temperature. The SI engine has registered higher BTE at 4000 rpm and 5000 rpm.
- ✓ The SI engine has emitted high NO_x emission with ethanol fuel. The rate of NO_x emission in SI engine was increased with increasing speed and preheating temperature. The air temperature 60°C operated SI engine has registered high NO_x values compared to other temperatures.
- ✓ Carbon monoxide emissions were created due to incomplete combustion of the charge. The ethanol fuelled SI engine has higher CO emissions at low and high speed conditions. At average speed conditions, the SI engine has emitted low CO emission due to complete combustion of ethanol fuel.
- ✓ The SI engine has emitted lower hydrocarbon emissions for various engine speed. It has been further decreased with increasing the air preheating

temperature. The air temperature such as 56°C and 58 °C operated SI engine has low HC emissions.

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