Analysis of Preheat ignition of air on engine performance using waste exhaust heat recovery

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ABSTRACT

Since the inception of industrial revolution, a continuous attempt has been made to recover and minimize the waste heat. In the present research paper review on heat pipe is done. Through heat pipe the hot air is used to pre heat the inlet air of 4 stroke diesel engines. Further, the different performance parameter is calculated for the analyzing the effect of pre heat inlet air in comparison of normal air. Variation of Performance is discussed and salient conclusion is drawn which indicates that, a wide scope is available for further research on heat pipe and especially in the relation of IC engine exhaust heat recovery system to preheat the inlet air.

1. Introduction

A heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently control the transfer of heat among two solid interfaces. A heat pipe is basically a sealed slender tube containing a wick construction lined on the inner surface and a small quantity of fluid such as water at the saturated state. It is composed of three sections: the evaporator section at one end, a condenser section at the other end and the adiabatic section in between them. In the evaporator heat is absorbed and the fluid is vaporized; in a condenser section the vapor is condensed and heat is rejected; and in the adiabatic section the vapor and the liquid phases of the fluid flow in opposite directions through the core and the wick respectively, to complete the cycle with no significant heat transfer between the fluid and the neighboring medium.

At the hot boundary of a heat pipe a liquid get in touch with a thermally conductive solid face turns into a vapor by absorbing heat from that face. The vapor then travels down the heat pipe to the cold boundary and condenses back into a liquid – releasing the latent heat. The liquid then returns to the hot boundary via capillary action, centrifugal force, or gravity, and the cycle repeats. Due to the very high heat transfer coefficients for boiling and condensation, heat pipes are highly effective thermal conductors. The effective thermal conductivity varies with heat pipe length, and can approach 100 kW/m-K for long heat pipes in comparison of 0.4 kW/m-K copper.

For the heat pipe to convey heat, it must contain saturated liquid and its vapor (gas phase). The saturated liquid vaporizes and moves towards the condenser, where it is cooled and turned back to a saturated liquid. In an ordinary heat pipe, the condensed liquid is returned to the evaporator using a wick structure exerting a capillary action on the liquid phase of the working fluid. In heat pipes wick structures used to contain sintered metal powder, screen, and grooved wicks, which enclose a series of grooves parallel to the pipe axis.

When the condenser is situated above the evaporator in a gravitational field, gravity can return the liquid. In this case, the heat pipe is a thermo-siphon. Finally, rotating heat pipes make use of centrifugal forces to return liquid from the condenser to the evaporator [1-2].

Heat Pipe

A heat pipe is a novel device that can transfer large quantities of heat through a small area with small temperature difference. The first heat pipe was constructed in 1934. Initial efforts were directed towards space heat applications. Major factors are high reliability, its capability to work under weightless condition in space as well as workability under isothermal conditions without the need for any external power input.

A heat pipe is basically a sealed container normally in the form of a tube containing wick lining in the inside wall. It is used to transport heat from source to sink by means of evaporation and condensation of a fluid in the sealed system.

Specifications of the Heat Pipe Fabricated

Diameter	= 430 mm
Length	= 450 mm
Thickness of the cylinder	= 4.5 mm
Diameter of the copper pipe used	= 12.6 mm
Diameter of the short MS pipe used	= 25.4 mm
Length of the short MS pipe used	= 152.4 mm
Length of the copper pipe	= 2134 mm

Modification in the Engine

The inlet air is circulated through heat pipe to engine inlet manifold. The heat pipe arrangement is made in such a way that it utilizes the exhaust gas heat energy. It is accomplished by direct link between the exhaust and the intake air tank. Therefore, the exhaust back pressure is maintained slightly above the intake manifold pressure such that air flow could occur. The quantity of this circulated inlet air is to be measured and controlled accurately; hence a by-pass for the exhaust gases is provided along with the manually controlled valve in the circulation line between the exhaust gases

manifold and the intake surge tank. The exhaust gases come out of the engine during the exhaust stroke at high pressure. It is pulsating in nature. It is desirable to remove these pulses in order to make the volumetric flow rate measurements of the recirculation gases possible. For this purpose, exhaust gases goes through water jacket and inlet air is directed to air box line before entering engine cylinder to improve mixing process with fresh air. An orifice plate is used for measuring air flow rate using differential pressure transducer model Setra 239 having differential pressure range of 0-12.7 cm water column with accuracy of 1%. Thermocouples are provided at the intake manifold, exhaust manifold and along the EGR route. This work studies the interaction resulting from the application and control of air flow rate and its effectiveness on emissions as well as engine performance parameters.

System Description

In this study, single cylinder 4-stroke compression ignition engine was used for experimental analysis. This is a 12-liter, compression ignition, single-cylinder engine with linear arrangement. The studies were performed with engine load of 100% and engine speeds of 800 to 1600 rpm that consumes diesel oil. Its technical characteristics and specifications were presented in table 3.1 as main engine characteristic. The speed is measured by Digital RPM Indicator. The temperature is measured through multi - Channel digital Temperature Indicator. Also, every desired point is connected with thermocouple which indicates the temperature digitally. Clearance Volume (Vc) is 35 Cm^3 and Swept Volume (V) is 256 Cm^3. Loading (BHP, Maximum) of the engine is measured by Rope Brake Dynamometer. The cooling system is water cooling for auxiliary Head. Exhaust gas calorimeter is used Shell and Tube Type Calorimeter for calculation of energy and making Heat balance sheet. Further Engine Output (Kg) is measured by spring balance for dynamometer. Air flow is measured by mild steel tank, Orifice plate, and a Manometer. At the last the fuel flow rate is measured through glass Burette with cover installed in the experimental setup. The whole setup is fitted on M.S. Frame & Control panel, with Proper Rigid Concrete foundation.

The engine fuel system is modified by adding a custom tank and a flow metering system which is used for fuel consumption measurement. A two glass burette of known volume is used to measure the fuel. A large air box fitted with an orifice plate is used for measuring air consumption rate using differential pressure transducer model Setra 239 having differential pressure range of 0-12.7 cm water column with accuracy of 1%. The exhaust gases temperature is measured using calibrated K type thermocouple with accuracy of 0.5%. Ambient air temperature, intake air temperature inside the intake air manifold is measured using calibrated K-type thermocouple probes. The cylinder pressure is measured using piezoelectric pressure transducer model Kistler 6123, 0-200 bar as pressure range with sensitivity of 16.5 pc/bar and accuracy of 1.118 %. A slotted disk is fitted to the end of the crankshaft and an optical sensor for measuring engine speed and crankshaft angle position. The signals from the pressure transducers, optical sensors, and thermocouples are digitized and recorded. The brake mean effect pressure (BMEP) is calculated from engine power, speed and engine geometry specification. Table 1, gives the detail description of modified engine specification under the research.

Table 1. Specification of Engine.

S. No.	Parameter	Specification
1	Make	COMET Type
2	Engine type (model)	VRC1, single cylinder, four stroke Compression Ignition engine
3	Rated power output (H.P)	5
4	Bore [mm]	80
5	Compression ratio	18.5:1
6	Stroke [mm]	110
7	Loading type	Rope brake dynamometer
8	Moment arm (m)	0.2
9	Orifice diameter (for air box) (mm)	25
10	Co-efficient of discharge of orifice	0.64
11	Rated speed (N) (R.P.M.)	1500
12	Starting	manual cranking

Theoretical Analysis

An experimental study is carried out to investigate engine performance parameters and methods of improving the performance while using warm inlet air through heat pipe in diesel engine. The used engine is four stroke single cylinder diesel engines. The detailed description of the engine and modification made for the experiment is being already well documented in the previous chapter. The present chapter will discuss about the theoretical aspects which will be used to determine the performance of engine and thereafter the comparisons before and after the application of hot air. The engine performance parameters are presented with and without inlet air circulation recirculation through heat pipe. Engine cylinder pressure measurements and engine geometry are used for calculating indicated engine performance parameters. The important investigated parameters are indicated and brake engine performance parameters, and inlet air temperature (T_{inlet}).

Properties of Fuel

In the present research work diesel is being used as a working fuel for the selected IC engine. Table 2, gives the technical specification of diesel fuel

Table 2. Properties of Diesel.

Sl. No	Properties	Diesel
1	Density(kg/m^2)	850
2	Calorific value (kJ/kg)	46,500
3	Kinematic viscosity@40ºC (cst)	3.05
4	Cetane number	55
5	Flash point ºC	52
6	Fire point ºC	56
7	Specific gravity	0.84
8	Sulphur content (%)	<0.035

Performance of Ic Engine

There are various parameters which indicate the performance of an IC engine. It is beyond the scope of the thesis to discuss all kind of parameters. The most common parameters are used in the present research work to evaluate the performance and make the comparisons of two cases with and without the use of warm inlet air. The brake power is one of the most important parameter in the engine experiment. The eddy current dynamometer was used for loading the engine. The fuel consumption is measured by determining the time required for consumption of given volume of fuel using glass burette.

The mass of fuel was calculated by multiplying it by the specific gravity of fuel. An air box method was used to find air consumption. In this method orifice meter and manometer was used for accurate volumetric measurement of air consumption and finally mass flow rate was determined. The digital temperature sensor was used for temperature measurement.

Power and mechanical efficiency

Indicated power

The total power developed by combustion of fuel in the combustion chamber is called indicated power.

$$I.P = \frac{np_{mi}LANk \times 10}{6} \ kW$$

Where

n= numbers of cylinder

p_{mi} = indicated mean effective pressure, bar

L = Length of stroke, m

A = Area of Piston (m^2)

k = $\frac{1}{2}$ for 4-stroke engine

= 1 for 2 stroke engine

Brake Power

The power developed by an engine at the output shaft is called the brake power.

$$B.P = \frac{2\pi NT}{60 \times 1000} \ kW$$

Where,

N = Speed in RPM

T = Torque in N-m

Frictional Power

The difference between I.P and B.P is called frictional power, F.P,

i.e, F.P = I.P – B.P

Mechanical Efficiency

The ratio of Brake power to indicated power is called mechanical efficiency

Mechanical efficiency,

$$\eta_{mech} = \frac{B.P}{I.P}$$

Specific Output

It is defined as the brake output per unit of piston displacement and is given by;

$$Specific \ output = \frac{B.P}{A \times L}$$

$$= constant \times p_{mb} \times R.P.M$$

For the same piston displacement and brake mean effective pressure (p_{mb}) and engine running at higher speed will give more output.

Volumetric Efficiency

It is defined as the ratio of actual volume (reduced to NTP) of the charge drawn in during the suction stroke to the swept volume of the piston. The average value for this efficiency is from 70 to 80 percent.

Fuel Air Ratio

It is the ratio of the mass of the fuel to the mass of air in the fuel air mixture. Relative fuel air ratio is defined as the ratio of the actual fuel air ratio to that of stichiometric fuel air ratio required to burn the fuel supplied.

Specific Fuel Consumption

It is defined as the fuel flow rate per unit brake power output. It is a measure of efficiency of the engine consuming fuel to produce work. It is desirable to be low SFC meaning engine used less fuel to produce same work output. It is most important parameter to compares the different fuel or the same fuel under different conditions.

$$s.f.c = \frac{m_f}{B.P} \ kg/kWh$$

Thermal Efficiency

It is the ratio of indicated work done to energy supplied by the fuel. In other words it is the ratio of the thermal power available in the fuel to the power deliver to shaft. It is depends on how the energy converted. It is also depends on fuel heating value.

Let; M_f = mass of fuel used in kg/sec

C = calorific value of fuel (Lower)

Indicated Thermal efficiency (based on I.P)

$$\eta_{th}(I) = \frac{I.P}{m_f \times C}$$

The Brake thermal efficiency (based on B.P)

$$\eta_{th}(B) = \frac{B.P}{m_f \times C}$$

Performance analysis

Torque

The graph (Figure 1) for torque shows the decreasing curve as the engine speed increases for normal inlet air i.e. cold air. The same trend is being followed for the warm inlet air. However, for normal inlet air and warm inlet air, the curve is quite constant with a small gap between maximum and minimum value. The starting torque is always high at low engine speed and keeps on decreasing as the engine speed increased. For diesel fuels when mixed with warm inlet air (12°C higher than Normal air temperature), torque was higher than diesel fuel mixing with cold air.
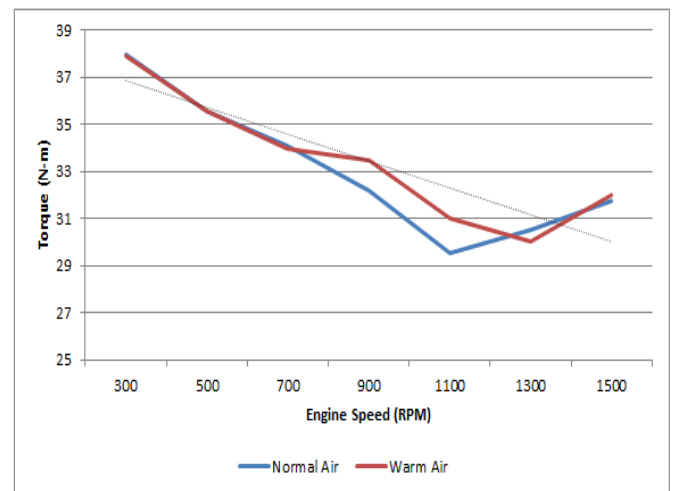

Fig. 1 Engine torque vs. engine speed with and without warm inlet air

Output Power

The output power of single cylinder comet type 4 stroke diesel engines with the warm inlet air varies significantly. The output power for normal air is lower compared to warm inlet air at any ratio. The efficiency of the engine is about 40 % which is very low for a compression ignition engine. Basically, the efficiency of compression ignition engine is high due to its compression ratio. In the testing, the input power cannot be determined accurately because the brake power is fixed at certain amount. The power output of diesel engine increases with the amount of fuel injected with warm inlet air but it is usually limited by the increased smoke emissions. Figure 2 shows the comparisons of hot and cold air in inlet and its effect on output power.
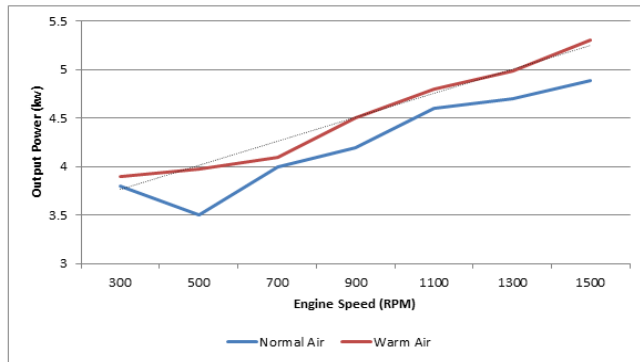
Fig 2. Output power vs. engine speed.

Exhaust Gas Temperature

The total heat recoverable at 145°C final exhaust can be calculated as

$$Q = V \times \rho \times C_p \times \Delta T$$

Where, Q is the heat content in kCal

V is the flow rate of substance in m³/hr

ρ is the density of the flue gas in Kg/m³

Cp is the specific heat of the substance in kCal/Kg/°C (0.24 kCal/kg/°C)

ΔT is the temperature difference in °C

The variation of exhaust gas temperature with respect to brake power for different air inlet temperature is shown in figure 3. The exhaust gas temperature increases with increase in brake power at full load only. The exhaust gas temperature at no load is 6% and at part load 15% higher than diesel.
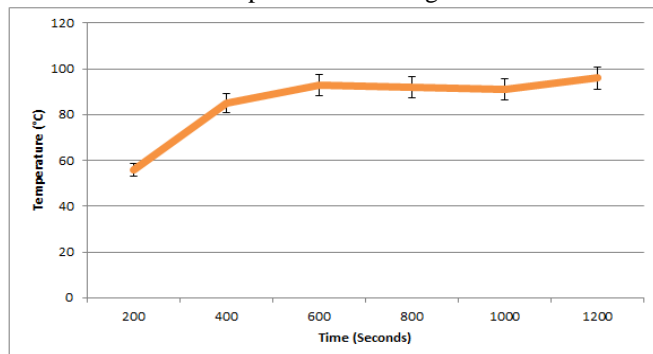

Figure 3. Variation of Exhaust Temperature with No Load.

Conclusion

After an exhaustive review of paper published in the repute journal indicates that the recovery of waste heat is very important. At one hand it saves and utilizes energy while other hand it saves the environment. As literature indicates that, there are various heat recovery systems but the heat pipe is in the infant stage. But in spite of all, very less research has been done on the heat pipe. Salient conclusion of the present research using pre heat inlet air coming from heat pipe indicates that it has ample scope for future research. As noted, the initial tests were done with the Heat Pipe described under system description, simply placed over the exhaust arrangement. In these tests the brake power never exceeded too much comparatively, limited by the small heat transfer area (the interface between the hot plate and the lower tip of the Heat Pipe). Nevertheless, the restriction of the heat transfer caused by the small areas for vaporization and for condensation (restricted to the extremities of the HP, that is, their bottom and top surfaces) was too limitative to provide acceptable results. With the help of graph various engine parameters are compared. Further it has wide scope for future research under different circumstances.

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