THEORETICAL & EXPERIMENTAL INVESTIGATIONS ON THE PERFORMANCE OF A FOUR STROKE ADIABATIC DI DIESEL ENGINE

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ABSTRACT

Extensive research is going on in the area of improvement of the engine thermal efficiency. In diesel engines approximately only one-third of the fuel energy is converted into useful work and major part of the energy is lost to cooling water. In an adiabatic engine (or insulated engine), the energy loss through cooling system is avoided by applying a layer of insulating material over the walls of the combustion chamber. The commonly used insulating materials are ceramic coatings such as silicon nitride, silicon carbide, zirconia (zirconium oxide) etc. As per the literature the partially Stabilized Zarconium (PSZ) is quite useful for the adiabatic engine application because of its excellent insulating characteristics, adequate strength and thermal expansion characteristics. Further this improves fuel economy, reduces, emissions and further reduces noise due to a lower rate of pressure rise. In the present investigations an adiabatic engine is developed with air gap insulation over the piston and cylinder liner, PSZ coated cylinder head and valves. With the higher temperatures in the combustion chambers in an adiabatic engine, widely available low cetane fuels like alcohols (which have high latent heat of vaporization) can also be burnt so that the ever-increasing demand for imported diesel can be reduced. In the present investigations a computer program has been developed in C language for an insulated engine and with that the theoretical results are obtained and then the same thing is compared with experimental results of adiabatic engine.

KEYWORDS: adiabatic engine, air gap insulation, insulated engine, ceramic coating, PSZ

I. INTRODUCTION

Ever since the rise of fuel costs, the diesel engine manufacturers throughout the world, for the past few years, have been allocating a great deal of research for the improvement of the engine thermal efficiency. Nagesh et al [12] have highlighted the fuel handling problems which may affect the performance of the fuel injection system and also the fuel properties like spray characteristics, ignition delay and rate and duration of the combustion. Finally he suggested that VCR engine system holds out most promise for multi-fuel use. Kamo and Bryzik [2] have demonstrated the use of Partially Stabilized Zirconium (PSZ) as the insulating material and also reported reduction in carbon monoxide, carbon particulates and smoke emission levels. Woshini et. al [5] reported the performance of ceramic coated engine with PSZ to 7% improvement in fuel consumption and reduction in HC emissions due to premixed combustion. Wallance et [6] have reported the use of a thermal barrier piston in the adiabatic engine and developed the temperature distribution analysis and reported that the piston top temperature were higher by around 400^0C for the thermal barrier pistons. According to the Miyari et [7] the insulation in the combustion chamber decreases the premixed fraction and increases the diffusion phase of combustion. Sun et [11] argued that decrease in premixed combustion by 75% with the ceramic insulation increases the BSFC by 9%. The insulated high temperature components include piston, cylinder head, valves and cylinder liner. So the insulating materials used in the combustion chamber should have lower thermal conductivity, good mechanical strength and must capable of withstanding for higher temperatures [4]. With the insulation of the engine the exhaust energy is increased compared to that of the conventional engine. Therefore, more technical innovations must be developed to extract useful energy from the exhaust and to derive the maximum benefits from this insulated engine concept. Additional power and improved efficiency derived from an adiabatic engine will be possible because the energy lost to the cooling water and exhaust gas, can converted into useful power through the use of turbo machinery. Since the working gas, in a practical engine cycle, is not exhausted at ambient temperature, a major part of the energy is lost with the exhaust gases. In addition, another major part of the energy input is rejected in the form of heat via the cooling system. The requirements to cool the components of the engine combustion chamber arise because of:

1.1 Material limitations

At elevated temperatures, the strength of conventional material drops, creep and fatigue becomes more pronounced and surface burning may result.

1.2 Lubrication requirements

The performance of commercial lubricants deteriorates at high temperature and carbonization may result [3]. It can be seen from the foregoing that better utilization of waste heat is one key to a more energy efficient engine, hence limited cooled or un-cooled engines have been proposed.

II. Thermodynamics of an Adiabatic Engine

Applying the first law of thermodynamics to the diesel engine, all of the fuel energy injected in to the cylinder must appear either as brake output work, as energy in the exhaust stream or as heat rejected to the coolants (water, oil, and air). The first law suggests that if the heat rejection to the coolant were eliminated by perfectly insulating the cylinder and deleting the cooling system, the coolant energy could be converted to brake power. But according to the second law of thermodynamics, the amount of heat which is prevented from flowing to the coolant and which does not appear in the brake output will appear in the exhaust stream as increased temperature.

2.1 Concept of the Adiabatic Engine

Thermodynamically the adiabatic process is defined as a no heat loss process; hence, the name adiabatic engine implies a no-heat loss engine. The insulated high temperature components include piston, cylinder head, valves and cylinder liner. Adiabatic engine, semi adiabatic engine, uncooled engine. Limited cooled engine, low heat rejection engine and differentially cooled engine are the terms being applied today to the heat insulated engine. This adiabatic engine concept is being tried out in all sizes of diesel engines ranging from 5hp to 1500hp. When the combustion chamber of a diesel engine is insulated by using high temperature materials to allow hot operation with minimum heat transfer, only about one –third of the heat saved is given out as useful power output and the remaining part goes out as exhaust heat [7]. Hence the exhaust energy is increased in the case of adiabatic engine compared to that of the conventional engine. Therefore, more technical innovations must be developed to extract useful energy from the exhaust and to derive the maximum benefits from this adiabatic engine concept. Additional power and improved efficiency derived from an adiabatic engine are possible because thermal energy, normally lost to the cooling water and exhaust gas, is converted into useful power through the use of turbo machinery and high temperature with standing materials.

III. Details of Present the Investigation

The important aspect of this work is to determine how important it is to insulate different parts of the combustion chamber. For theoretical analysis, a computer model is developed to find the effect of insulation for various degrees of adiabatic conditions in steps of 25% and for that, the heat balance sheets are prepared and analyzed. The computer results are obtained for the normal engine and for fully/partially insulated engines.

Tests are carried out to check the effect of insulation. With the investigations, it is found that the experimental results obtained from the existing engine are falling in between the theoretical results corresponding to 25% and 50% degree of adiabatic conditions.

3.1 PHASES OF PRESENT INVESTIGATIONS

The present work is planned accordingly

PHASE 1: Development of mathematical model for an adiabatic engine and further preparing of software program in C language

PHASE 2: Conducting the experiments on test engine (adiabatic engine) for experimental results

PHASE 3: Generate pressure-crank angle plots, performance parameter plots from the program and compare with the predicted ones from program.

The effect of insulation is studied at each stage of this investigation.

3.1.1 MATHEMATICAL MODEL

General: The period during which both inlet and exhaust valves remain closed is the most significant part of the engine cycle as it represents the power development period. The period of an engine cycle comprises of a part of the compression stroke, combustion stroke, and a part of the expansion stroke.
The assumptions made in developing this model for the compression ignition engine are as follows [1,8,10]:

- The charge inside the cylinder at any instant consists of a non- reacting mixture of air and residual gases.
- The fuel is assumed to mix homogeneously with air.
- The pressure and temperature are spatially uniform.
- The heat transfer-coefficient is spatially uniform throughout the combustion chamber.

For the purpose of heat transfer model, the combustion chamber area is divided into three parts. The amount of heat transferred through piston, liner and head are calculated combindly. Provision is made for different models. The rate of heat release is calculated using an empirical relation suggested by WIBE [1].
Dissociation is the name given to the disintegration of burnt gases at high temperatures. During dissociation, considerable amount of heat is absorbed. This will result a reduction in the cylinder pressure, which in turn affects the power developed by the piston. In this model, the dissociation effects due to five species are considered. Dissociation is assumed to start when the cylinder gas temperature reaches 1600^0 K. The five species considered in this model are CO, CO_2, H_2O, N_2.O_2.. Friction is calculated using empirical relation suggested by BISHOP and GOSCH. For the purpose of investigations the program is written in C language and further computer graphics has been developed to plot various output parameters on the monitor.

3.1.2 INSULATED ENGINE COMPONENTS PREPARATION

For the development of the Insulated engine (IE) in the present investigations the coating material selected must withstand for higher temperature and should also have sufficient strength. Among all the coating materials searched the partially stabilized Zirconium (PSZ) is found to be quite useful for adiabatic engine application because of its excellent insulating characteristics, adequate strength and thermal expansion characteristics [2, 5,]. The insulated engine developed is having an air gap piston and liner, PSZ coated cylinder head and valves. The coating thickness on the components was based on the theoretical analysis and recommendations made by Woshini et al [5]. The insulation methodology is explained in detail as follows.

3.1.2.1 Insulated Air Gap Piston

In this a 2 mm air-gap (whose thermal conductivity is low) is provided between a metallic crown and the standard piston made of Aluminum alloy. This air gap is optimized based on the literature available [3]. The metallic crown and standard piston were separated by copper and steel gaskets. Figure.1 shows the air gap insulated piston with brass insert.

Figure1: An air-gap insulated piston

3.1.2.2 Insulated Cylinder Head and valves

The combustion chamber area of the cylinder head and the bottom surfaces of the valves are machined to a depth of 0.5 mm and are coated with PSZ material for the same depth [2].The details of cylinder head and valves are as shown in the Fig 2.

Figure 2: PSZ coated cylinder head and valves

3.1.2.3 Insulated Cylinder Liner

A thin mild steel sleeve is circumscribed over the cast iron liner maintaining a 2mm layer of air in the annular space between the liner and the sleeve [5]. The joints of the sleeve are sealed to prevent seepage of cooling water into the air-gap region.

3.1.3 EXPERIMENTAL MEASUREMNETS

A stationary, four stroke, 3.68 Kw direct injection Kirloskar water cooled single cylinder diesel engine is used to conduct experiments. This engine is insulated as explained above and the experiments are conducted at the rated speed of 1500 rpm with an injection timing of 29^0 bTDC. The experimental set up used is as shown the following Figure 3.

For the exhaust gas temperature measurement, a calibrated Ni-Ni Cr thermocouple was used and voltage readings from a milli-voltmeter were converted to ^{0}C. The thermocouple was positioned in the exhaust line immediately downstream of the exhaust port. The fuel used in the present work is diesel. The level of the lubricating oil in the sump was checked periodically. Constant water flow was maintained through the engine to prevent overheating. All the readings were taken under steady running conditions.

Figure. 3. Experimental set up of Insulated Engine

IV. RESULTS AND DISCUSSION

4.1 Theoretical results

The engine heat balance of an adiabatic engine, with various levels of insulation is given in Fig.4. Various levels of insulation are attained by insulating the engine components in combination at an increment of 25% .It is clear from the figure that the amount of heat saved from being lost to the cooling system is equally divided between the indicated power and exhaust energy. With reference to the water cooled engine, the efficiency of the fully insulated engine increased from 38.01% to 53.38 % and the exhaust energy from 25.03% to 46.72%.This clearly implies that all the heat energy, saved by blocking off the heat flow to the cooling system, does not appear as indicated work. In fact, 50 % of the energy saved, appears in the exhaust stream.

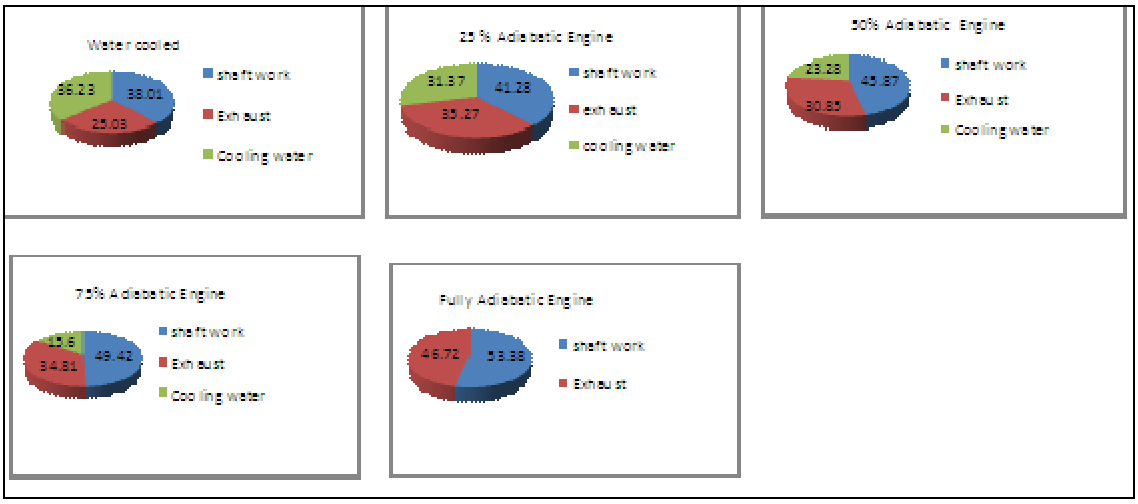

Figure 4: Variation of Heat balance with insulation (Predicted)

Figure 5 shows the pressure- crank angle traces of a normal engine and for various levels of insulation. It is evident from the figure that the pressure throughout the cycle is clearly higher for the fully insulated engine. It should also be noted that the peak pressure occurs at about 2 degrees later than the normal engine. This is due to the higher temperatures in the combustion chamber with insulation.

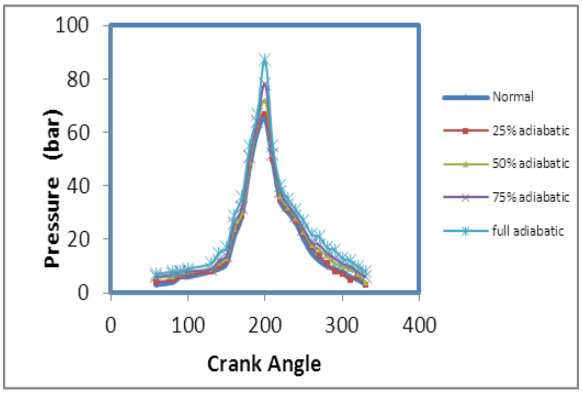

Figure 5: Variation of Cylinder Pressure With Crank Angle

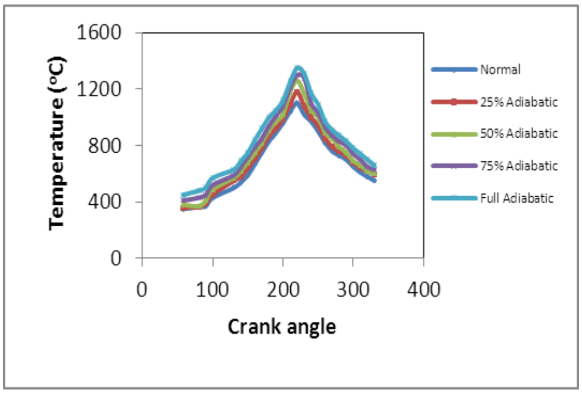

Figure 6: Variation Of Cylinder Pressure With Crank Angle

The variation of temperature in the combustion chamber for various levels of insulation with the crank angle is shown in the Figure 6**.** It is evident from the figure that the Temperature throughout the cycle is clearly higher for the fully insulated engine. With the heat lost to the cooling system is avoided, the heat in the combustion chamber is increased and this further provided the complete combustion. It should also be noted that the peak cycle temperature for fully insulated engine occurs at about 2-3 degrees later than the normal engine.

4.2 Experimental Results

The results obtained by the experimental testing on the insulated engine are discussed in this section. Figure 7 shows a plot representing the relation between the Brake Power and the Specific Fuel Consumption. It is clear from the plot that the S.F.C. of the L.H.R. Engine is less than that of the conventional engine. This is possible due to high temperature prevailing in the cylinder, which increases the combustion efficiency and further leads to the instantaneous high pressure in the chamber. The other reason may be the removal of some material from the crown of the piston, which reduces the weight of the piston, which causes reduction in the inertia of piston.

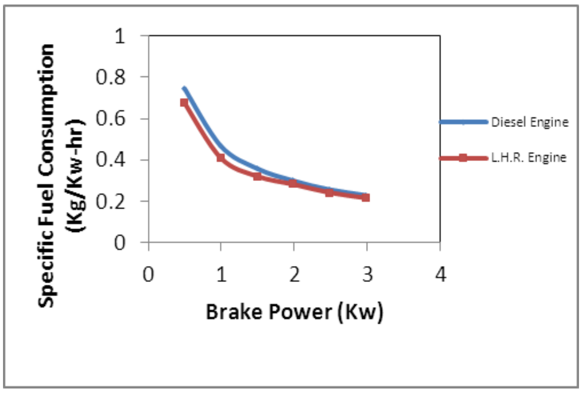

Figure 7: Variation of brake power with specific fuel consumption

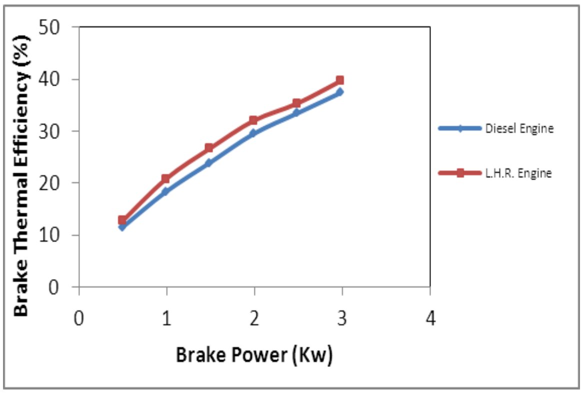

Figure 8: Variation Of Brake Power with Brake Thermal efficiency

The plot representing the relation between the Brake Power and the Brake Thermal Efficiency is shown in the Figure 8. It reveals that the thermal efficiency is more for air gap insulated engine than that of conventional engine. This is due to the absence of cooling system, the amount of heat transfer to the engine components is reduced and further the heat retained in the combustion chamber increases the combustion. Thus some part of the saved energy is converted into useful work. This increases the thermal efficiency.

The Heat Balance Sheet on minute basis for conventional engine and the air gap insulated engine (adiabatic engine) are shown in Figure 9 and Figure 10 respectively.

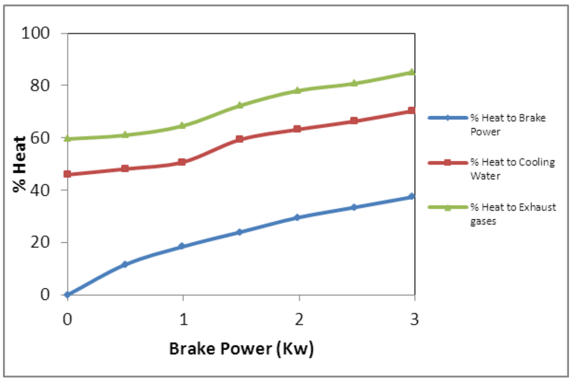

Fig 9: Heat balance sheet for conventional diesel engine

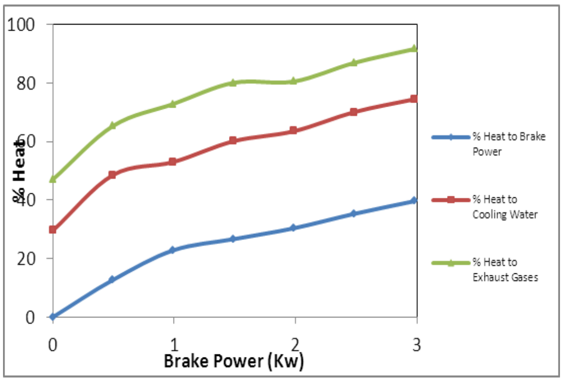

Fig 10: Heat Balance sheet for adiabatic diesel engine

It is observed from the above figures that

- Heat supplied to air gap insulated engine is less compared to conventional engine.
- Heat to brake power is more in the air gap insulated engine.
- Heat to cooling water is more in air gap insulated engine. This may be due to the absence of liner insulation.
- Heat to exhaust gas temperature is more in the air gap insulated engine.

V. Conclusions and Future Scope

- ➢ The theoretical investigations with the program indicate that the results obtained theoretically are comparable with experimental results
- ➢ With the complete insulation, the energy lost to the cooling system is avoided and the exhaust gas temperature increases proportionately. This increases the thermal efficiency by 2.35%.
- ➢ The energy lost to the exhaust can be retrieved with turbo charging.
- ➢ With the higher temperatures in the combustion chambers, the low cetane fuels can be burned and this reduces the demand of fossil fuel.
- ➢ Because of high latent heat of vaporization alcohols may not able to burn in the normal diesel engine which operates at lower pressure and temperatures. Due to alcohols high self ignition and latent heat of vaporization, the peak pressure and temperatures in the combustion chambers occur 2 degrees later than the normal engine.
- ➢ Though the advantages of an adiabatic engine are promising, it is also accompanied with some of the limitations. The main limitation is difficulty of using lubricating oil at high temperatures because at high temperatures, the performance of lubricating oil deteriorates resulting in more friction. This problem can be overcome by going for solid lubricants.
- ➢ Another disadvantage of this engine is the reduction in the volumetric efficiency. This is because of low density of air due to high temperatures in the combustion chamber. This problem can be overcome by going for turbo-charging.

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