Thermal Performance Analysis for a Remodified Diesel Engine to Improve Fuel Efficiency.

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Abstract:
Heavy trucks, buses, lorries, and other vehicles require over Rs. 4 lakh crores of diesel each year, which is imported at a cost of approximately Rs. 5 lakh crores annually. These cars' engines use water cooling, which keeps the internal engine components below 100°C.For the following reasons, the material temperature is kept below 100°C. The water in the radiator will boil if the cylinder temperature exceeds 100°C. The liquid lubricant burns and becomes sticky over 140°C, which causes the engine to seize. As a result, the need for a liquid lubricant, the need to cool the radiator and engine cylinders, and the loss of 35 to 40% of the heat equivalent of the diesel can all be avoided. In order to accomplish this, a second stainless steel cylinder is added above the existing conventional engine cylinder. A stainless steel piston then glides inside the stainless steel cylinder, maintaining a very small clearance and requiring no lubrication. A stainless steel piston rod guided by bearings connects the stainless steel piston to the traditional engine piston, and the two pistons reciprocate as a single unit. The traditional cylinder and piston are now just utilized to guide the piston assembly and bearings; the firing has been relocated to a stainless steel cylinder. As a result, the engine's heat flow will be reduced, increasing efficiency. As a result, the radiator is turned off because the traditional cylinder isn't burning, saving 35 to 40 percent of the gasoline that would have been lost to heat dissipation through the radiator. As a result, improving the efficiency of all large trucks could save up to 40 to 50% of the diesel used by large trucks, as well as 1.5 to 2 lakh crores of rupees per year, making this research of national significance.

Keywords: ic engine, performance, efficiency, diesel cycle, remodified engine.
DOI Number: 10.14704/Nq.2022.20.17.Nq88001 **Neuroquantology 2022; 20(17):01-06**

I. Introduction

Fossil fuels are increasingly being used to produce energy for several industries, including transportation, agriculture, building, and power generation. These fuels' supplies are soon depleted since they are refined from non-renewable energy sources.Internal combustion engine thermal efficiency and energy saving are continually being improved upon by engineers. The law of conservation of energy states that every engine turns energy into work. According to this theory, the diesel engine turns 30% of the energy into work, while the remaining energy is lost as heat in the exhaust and coolant. Practically, we may infer from the data that more heat is transferred by the exhaust gas in diesel engines when the exhaust gas temperature is higher than the ambient temperature. The coolant also receives a small quantity of heat. As the requirement for coolant has diminished over time, this research activity is currently attempting to virtually completely eliminate it in order to maximize efficiency.

II. Improving Engine Efficiency

A. Engine design with low heat rejection

A fuel's heat potential that cannot be utilized by an engine. If the thermal efficiency of a CI engine is just 40% at its best, then 60% of the fuel's heat energy must be lost as rejected heat. Figure 1.10 displays the fuel's % heat potential. Half of the rejected heat is typically transferred to the engine hardware by the engine cooling system so that it can be released into the atmosphere, and the other half is retained in the exhaust gas. The idea of segregating

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

combustion chamber components forms the basis of the Low Heat Rejection Engine's fundamental design. These combustion-related components. Due to the coolant's ability to store heat energy, the greater cycle temperature and insulation enhance performance and efficiency. Since they perfectly adhere to the first rule of thermodynamics, engines without thermal transfer are theoretically superior to standard engines. This energy idea stimulated research and, in fact, cleared the route for the creation of engines with constrained cooling.

B. Engine design with Zero heat rejection

As a result of the zero heat rejection idea, a stainless steel piston glides inside a stainless steel cylinder with a very small clearance and without the use of lubricant. This additional stainless steel cylinder is installed above the current conventional engine cylinder. A stainless steel piston rod connected to a traditional engine piston by bearings allows the two pistons to move together as a single unit. The conventional cylinder and piston are no longer utilized for anything other than guiding the piston assembly and bearings; the firing has been moved atop the stainless steel cylinder. Because the traditional cylinder is not burning, the radiator is turned off, saving 35 to 40 percent of the fuel that would have been lost to heat loss through the radiator. As a result, the engine's efficiency will increase due to the reduction in heat flow.

III. LITERATUTRE REVIEW

R. T. Sarathbabu et al. (2022) analyzed and studied modified diesel engine thermodynamics compared to that of conventional diesel engines. Energy and exergy analysis for diesel, B20 (a blend of 80% diesel by volume and 20% mahua biodiesel), LHR modification, and LTC 15% EGR fuelled with B20 blend and 5% ethanol are used to research thermodynamics under varying loads, from no load to full load. It included two technologies to improve engine performance. The Low Heat Rejection (LHR) concept, often known as the "Adiabatic" engine, is one of the main methods. Alumina (Al_2O_3) ceramic was employed to modify the Low Heat Rejection in the engine cylinder (LHR). Another method involves adding low-temperature combustion (LTC) modes by connecting the inlet and exhaust pipes with valves in order to regulate the exhaust gas at an ideal rate of 15%. Using fuel mixes like 20% mahua biodiesel and 5% ethanol, the results of the energy and exergy distribution in the engine were compared. Best shaft power (QBP) (2.8kW) is converted from heat input seen in the most optimally modified engine under full load conditions as compared to others. As a result of fuel and engine adjustments, Diesel's maximum unexplained energy (QUN) loss (44 percent). And the highest thermal efficiency (31.2%) is found in B20E5 (LHR+15 percent LTC). The energy distribution revealed a similar pattern, with the lowest (8.45 kW) in B20E5 (LHR+15 percent LTC) and highest (12.54 kW) in diesel operating at 100% load (Ain). The highest available conversion rate in brake power (Abp) (0.61 kW) for B20 (LHR). When compared to diesel, B20E5 (LHR+15 percent LTC) has a higher second law or energetic efficiency. The B20E5 (LHR+15 percent LTC) is discovered to be superior to diesel and other combinations (B20, B20 (LHR)) due to the best engine and fuel modifications used. Jerald A. Caton (2018) investigates and further develops engines with internal combustion (IC) in order to achieve higher performance and efficiencies. A key aspect of achieving higher performance and efficiencies is based on fundamental thermodynamics. Both the first and second laws of thermodynamics provide strategies and limits for the thermal efficiencies of engines. The current work provides three examples of the insights that thermodynamics provides for the performance and efficiency of an internal combustion engine. The first example evaluates engine concepts with low heat dissipation and uses thermodynamics to demonstrate the difficulty of this concept in increasing efficiency. The second example compares and contrasts the thermodynamics associated with external and internal exhaust gas dilution. Finally, the third example begins with a discussion of the Otto cycle analysis and explains why this is an incorrect model for the internal combustion engine. Specific heat is an important thermodynamic property responsible for many of the observed effects. Md. Nurun Nabi et al. (2009) analyzed theoretically on engine thermal efficiency, specific heat at constant pressure (Cp), gas temperature, molecular number, adiabatic flame temperature, nitrogen oxides (NOx) emission, and some basic combustion-related parameters, such as theoretical air fuel ratio (AFR), lower calorific value (LCV), and ratio of LCV and theoretical AFR for various oxygenated fuels, are covered in this paper. Atmospheric conditions that are considered typical are used for the computations. In this calculation, pentadecane (PD) was used as the base fuel. The findings demonstrated that the oxygen content of the fuels is directly correlated with almost all of the combustion-related parameters listed above. No matter how much oxygen is present in a fuel's molecular structure, the ratio of LCV to theoretical AFR remains constant. One of the study's interesting findings is that the adiabatic flame temperature decreases linearly as the amount of oxygen in the fuel increases, and as a result, NOx emission decreases linearly. Below a 30 percent weight-weight oxygen content, the engine thermal efficiency is almost unchanged, but it gradually declines above that level. The decrease in adiabatic flame temperature for oxygenated fuels is related to the reduction in NOx emission, whereas the decrease in engine thermal efficiency above 30%of oxygen is related to the increase in gas specific heat.

Thiruselvam et al. (2015) investigate the depletion of fossil fuel resources at a faster pace in today's world of economic competitiveness, which is generating a significant demand for increased efficiency of internal combustion engines. It has been found that the use of coatings in the automotive industry has a significant impact on engine efficiency. The higher the operating temperature, the more efficient the system becomes. The application of thermal barrier coatings to various components of an engine's combustion zone, such as piston liners, has led to a significant improvement in thermal and mechanical efficiency and other performance parameters of the engine, such as specific fuel consumption and exhaust emissions.

IV. DESIGN CONSIDERATIONS

A. Test Engine

The most extensively used and fuel-efficient engine is the Kirloskar Engine. Since it won't be difficult to make the necessary tweaks, it is picked as a test engine.

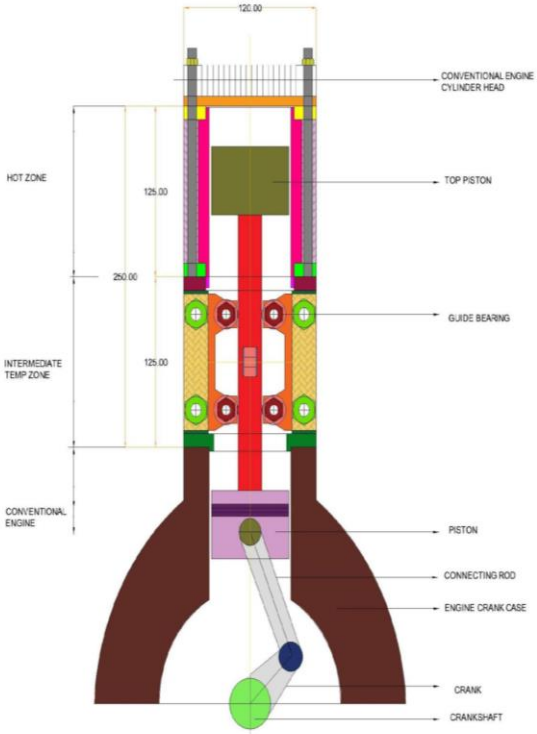

Fig. 1.1 Kirloskar engine coversion work (overall assembly)

B. Rationale for choosing the engine

1. The heavy-duty diesel engines used in trucks and buses must meet a number of market expectations, including those for size, weight, price, durability, performance, and fuel efficiency.
2. The engines of the truck, bus, and speciality vehicles must fit inside them. Engine size and package become more efficient as they get smaller.
3. The weight of the engine is quite important. Striking a balance between strength and carrying capacity is crucial.
4. Overall cost objectives must be set early in the design process. Setting goals for durability and reliability must consider cost and customer satisfaction in addition to reducing material costs.
5. Fuel efficiency affects performance. The market has demanded both higher power and increased fuel efficiency. Power and fuel efficiency are traded off. Fuel economy is determined by how much gasoline is used at both partial and full capacity.

C. Material Selection

In order to achieve the requirements and goals of the product, stainless steel 304 grade was selected as the best material out of all those that

eISSN: 1303-5150

were accessible using material selection procedures.

Elements	Weight %
C	<=0.080
Cr	18-20
Fe	66.345-74
Mn	<=2.0
Ni	8.0-10.5
P	<=0.045
Si	<=1.0
S	<=0.030
N	<=0.10

Table 1. Weight percentage of elements in SS304 Grade Stainless steel

The austenite-phase field is expanded and made stable at room temperature when nickel and chromium are added to austenitic stainless steels. The popular SAE/AISI 304 austenitic stainless steel has 18 percent Cr and 8 percent Ni. At ambient temperatures, austenite is stable. Because of this, nickel and manganese are known as austenite stabilisers. As ferrite stabilisers, other elements such as molybdenum, silicon, and chromium. The ferrite-phase field is enlarged by a ferrite-stabilizing device, while the austenite-phase field is limited by a so-called gamma loop (gamma, is the symbol for austenite).

D. Overall Assembly

An overall assembly drawing of a product showing the constituting parts is drawn to explain its complete design. This overall assembly in figure 1.1 shows Kirloskar engine conversion work. Basic engine construction varies little, regardless of the size and design of the engine. The temperature at which an engine will operate has a great deal to do with the materials used in its construction. The converted diesel engine is designed to have closely related cylinder and piston sizes to the existing conventional engine. However, they are designed so that the same piston, connecting rods, bearings, valve, and valve mechanism can be used.

The overall assembly engine is a contrivance designed to convert heat losses to the tune of 30 to 40% diesel equivalent. It consists of three zones, namely the hot zone, the intermediate temperature zone, and the conventional engine. Here, there is no change in the conventional engine; only the firing is shifted to the hot zone with the help of the intermediate temperature zone. The overall assembly drawing may be broken into further assemblies, sub-assemblies, and parts determined mainly by production requirements.

The overall assembly is categorized by

- Piston assembly
- Intermediate assembly
- The top cylinder assembly

The firing is transferred over a stainless steel top piston, which has no piston rings, mounted over a normal piston that is reciprocating in a stainless steel cylinder. Since there is no liquid lubricant and no radiator, only a small clearance is kept between the cylinder and the stainless steel piston. A stainless steel piston rod that is guided by bearings connects the stainless steel piston to the conventional engine piston, allowing the two pistons to reciprocate as a single unit. Now, the traditional cylinder and piston serve just to direct the piston assembly. The removal of the radiator will result in a 30 to 40% diesel equivalent reduction in heat losses, which will result in fuel savings. When a stainless steel cylinder and piston are employed, it is possible to reach a material temperature of 650^{o}C and the engine efficiency can reach over 50%. From these drawings, the workman will fabricate the product to its actual size and shape.

V. THERMAL PERFORMANCE

THE AIR STANDARD DIESEL CYCLE

In order to get close to a carnot cycle and hence reach that efficiency, Diesel's first engine concept relied on constant temperature heat addition. A theoretical cycle of this type now goes by the diesel because the improved design used constant pressure heat addition. The pressure limit of the original CI engines still applies to very big engines, which can be somewhat modeled by a diesel cycle. The spray mixing procedures do regulate some of the burning, but the overall rate is high enough for the constant pressure heat addition to be erroneous since there is actually a significant pressure rise. However, a study of the diesel cycle is crucial since it demonstrates the impact of combustion rate on engine performance.

SUMMARY (50% Overloaded condition)

Ceramic cylinder (ID)	= 73.1 mm
Stroke length (L)	= 74 mm
Engine brake power (P)	= 2.94 kW

= 2.94 + (2.94 x 0.5)
= 4.41 kW

Engine speed = 1800 rpm

Variables involved

V_1 = 0.000325399 m^3

V_2 = 0.000014790 m^3

V_3 = 0.000034795 m^3

V_4 = 0.000325399 m^3

T_1 = 30 °C + 273 = 303 K

T_2 = 1043.305 K

T_3 = 2454.36 K

T_4 = 1003.64 K

T_{ave} = 1201.07 K = 928.077 °C

m = 0.0003478 kg/cycle

Q_S = 493.33 J/cycle

Q_R = 175.00J/cycle

Assumed η cycle = 65 %

Calculated η cycle = 64.525 %

η Overall = 59.27 %

Thermal design calculation:

Engine brake power = 2.94 kW
= 2.94 + (2.94 x 0.5)
= 4.41 kW

Engine speed = 1800 rpm

No. of cycle/min. = (1800/2)
= 900 cycle/min

No. of cycle/sec. = (900/60)
= 15 cycle/sec

Type of engine = 4 stroke

Total work done = Shaft work + Frictional loss/cycle

Frictional loss = 400 W
= (4410 + 400)/15
= 320.66 J/cycle

Heat energy to be supplied (Qs) = Total work done/Assumed η cycle = 3320.66 /0.65
= 493.33 J/cycle

Solution:

Bore diameter (ID) = 73.1 mm = 0.073 m^2

Bore area (A) = π/4 $(0.073)^2$
= 0.0041974 m^2

Stroke length (L) = 74 mm = 0.074 m

Stroke volume (Vs) = Stroke length (L) x Bore area (A)
= 0.074 x 0.0041974
= 0.000310608 m^3

Compression ratio of the diesel engine
= (Vs+ Vc) / Vc = 22

Therefore, (Vs/Vc) = 21

Therefore, Clearance volume (Vc) = (Vs)/21
= 0.000310608 /21

Vc = 0.000014790 m^3

V_1 = Vs + Vc

V_1 = 0.000310608 + 0.000014790

V_1 = 0.000325399 m^3

Estimation of (T_2) & (T_3)

$T_2/T_1 = (V_1/V_2)^{0.4}$

$T_2 = T_1 (V_1/V_2)^{0.4}$

$T_2 = 303\ (0.000325399 /0.000014790)^{0.4}$

T_2 = 1043.305 K

Mass flow rate/ cycle (m) = Stroke volume (Vs) x Density of air (kg/m^3)
= 0.000310608 x 1.128
= 0.000347 kg/cycle

Heat supplied (Q_s) = m Cp (T_3-T_2)

493.33 = 0.000347 x 1005 (T_3-1043.305)

T_3 = 2454.36 K

Check for heat supplied (Q_S)

Heat supplied (Q_s) = m cp (T_3-T_2)

= 0.000347 x 1005 (2454.36 -1043.305)

Q_S = 493.33 J/cycle

Estimation of (V_3)

$P_3V_3 = P_2V_2$ -------------- (1)

$mRT_3 = mRT_2$

$T_3 = T_2$ ----------------- (2)

Dividing equation (1) & (2),

$P_3V_3 / T_3 = P_2V_2/ T_2$
($P_2 = P_3$)

$V_3 / T_3 = V_2/ T_2$

i.e., $V_3 = (V_2/T_2) \times T_3$
= (0.000014790/1043.305) x 2454.36

V_3 = 0.000034795 m^3

Estimation of (T_4)

$T_4/T_3 = (V_3/V_4)^{0.4}$

Therefore $T_4 = T_3 (V_3/V_4)^{0.4}$

$= 2368.112 \times (0.000034795 /0.000325399)^{0.4}$

T_4 = 1003.644 K

Estimation of (Q_R)

Rate of Heat Rejection

$Q_R = m\ Cv\ (T_4 - T_1)$
= 0.000347 x 718 x (1003.644 – 303)

Q_R = 175.00 J/cycle

Determination of η

Work done = Q_s - Q_R
= 493.33 – 175.00
= 318.327 J/cycle

Therefore η = (Work done/heat supplied) x 100
= (318.327/ 493.33) x 100

η cycle = 64.525 %

Determination of η Overall

Shaft work/cycle = Brake power at rated load/ No. of cycle/sec.

= 4410 /15

= 294 J/cycle

Therefore,

$\eta_{Overall}$ = [(Shaft work/cycle) /heat supplied] x 100

= [(274/493.33) x 100]

$\eta_{Overall}$ = 59.59 %

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