© 2014 IJEDR | Volume 2, Issue 2 | ISSN: 2321-9939

# Performance Analysis of Exhaust Gas Calorimeter for Diesel Engine

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***Abstract* - A four stroke diesel engine in which water & diesel coolant are used as a reference in this study. The experiments are conducted with the purpose to test the applicability of exhaust gas calorimeter model in order to quantify the heat losses through exhaust gas. The model considered the calorimeter system components such as water reservoir, pipe for water in and out as a cold fluid and pipe connected from exhaust tail pipe to the calorimeter for the hot fluid. It is very important for I.C. Engine to find out optimum mass flow rate of cooling water & to avoid overheating of the engine & under cooling of the engine. so with this minimum fuel consumption take place by the I.C. Engine so for achieving this concept it is very important for optimization of mass flow rate of cooling water fabricate/design exhaust gas calorimeter. It is important to evaluate energy losses in the engine in order to increase the engine performance. The result showed that the rate of heat losses through the exhaust gas is increased with the increasing of engine speed. This is due to the fact that when the engine speed increase, the throttle opening will also increase in order to allow more mass of air entering the cylinder during combustion. Consequently, the mass of fuel also will be increased and affect the exhaust gas temperature. I am going to investigate about the rate of heat losses from through exhaust gas using exhaust gas calorimeter.**

***Key Words* - Diesel Engine, Exhaust gas calorimeter, fuel consumption**

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## I. INTRODUCTION

Diesel engine is the prime mover, which drives an alternator to produce electrical energy. In the diesel engine, air is drawn into the cylinder and is compressed to a high ratio (14:1 to 25:1). During this compression, the air is heated to a temperature of 700–900$^0$C. A metered quantity of diesel fuel is then injected into the cylinder, which ignites spontaneously because of the high temperature. Hence, the diesel engine is also known as compression ignition (CI) engine.

### *Four Strokes - Diesel Engine*

The 4 stroke operations in a diesel engine are: induction stroke, compression stroke, ignition and power stroke and exhaust stroke.

- **1$^{st}$**Induction stroke - while the inlet valve is open, the descending piston draws in fresh air.
- **2$^{nd}$**Compression stroke - while the valves are closed, the air is compressed to a pressure of up to 25 bar.
- **3$^{rd}$**Ignition and power stroke - fuel is injected, while the valves are closed (fuel injection actually starts at the end of the previous stroke), the fuel ignites spontaneously and the piston is forced downwards by the combustion gases.
- **4$^{th}$**Exhaust stroke - the exhaust valve is open and the rising piston discharges the spent gases from the cylinder.

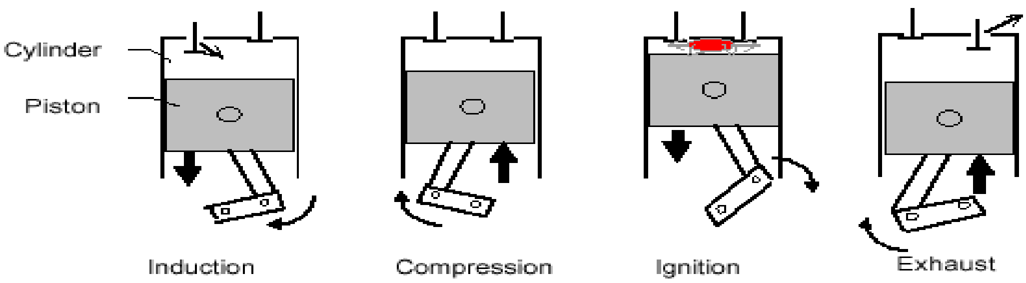


Fig. 1: Schematic Diagram of Four-Stroke Diesel Engine

Since power is developed during only one stroke, the single cylinder four-stroke engine has a low degree of uniformity. Smoother running is obtained with multi cylinder engines because the cranks are staggered in relation to one another on the crankshaft. There are many variations of engine configuration, for example. 4 or 6 cylinder, in-line, horizontally opposed, radial configurations.

***Heat Exchanger***

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

1. *Spiral Tube Heat Exchanger* - Spiral tube heat exchanger has excellent heat exchanger because of far compact and high heat transfer efficiency. Spiral-tube heat exchangers consist of one or more spirally wound coils which are, in circular pattern, connected to header from which fluid is flowed. This spiral coil is installed in a shell another fluid is circulated around outside of the tube, leads to transfer the heat between the two fluids.
2. *Shell And Tube Heat Exchanger* - Shell and tube heat exchangers are built of round tubes mounted in large cylindrical shells with the tube axis parallel to that of the shell. These are commonly used as oil coolers, power condensers, pre-heaters and steam generators in both fossil fuel and nuclear-based energy production applications. They are also widely used in process applications and in the air conditioning and refrigeration industry. Although they are not specially compact, their robustness and shape make them well suited for high pressure operations. They have larger heat transfer surface area to volume ratio than the most of common types of heat exchangers, and they are manufactured easily for a large variety of sizes and flow configurations

## II. LITERATURE REVIEW

**J.R. McBride,et al**,[1] Presented A large demand exists for sensors which are capable of measuring the various gas constituents that are present in automotive exhaust. Future advancements in engine control systems and on-board diagnostics for monitoring tailpipe emissions rely critically on the development of such devices. Sensors designed to employ the principle of differential calorimetry have been identified as among the more promising candidates for near-term automotive use in the detection of hydrocarbons and other combustible species. These calorimetric devices essentially consist of two temperature sensing elements, one of which has been coated with a catalytic layer. Heat generated from oxidation of combustible species raises the temperature of the catalytically coated element relative to the other, thus providing a measure of the concentration of combustibles in the exhaust. To date, several different prototype calorimetric devices have been evaluated under laboratory and dynamometer conditions. The sensitivity of the devices tested, measured as temperature rise per concentration of combustible, has typically been about an order of magnitude less than that theoretically possible. In this paper, we examine how the choice of calorimeter design affects the optimum achievable sensitivity. Simple physical arguments are applied to explain why the sensors tested thus far have demonstrated sensitivities substantially lower than theoretical limits. Results are presented from an analytical model describing this calorimeter design and from a simple experiment which validates the salient features predicted by the model.

**Robert Filipczak, Sean Crowley, et al**,[2] The Ohio State University (OSU) apparatus and the cone calorimeter are two devices commonly used to measure the heat release rate (HRR) of materials and products in forced flaming combustion. Each operates on a different principle but is calibrated in the same way. However, HRR results from these two test methods do not agree in most cases. For the present study, the OSU was modified to measure oxygen consumption and sensible enthalpy (temperature rise) of the apparatus in addition to the usual sensible enthalpy of the exhaust gases during the test. After calibration, total sensible heat (exhaust gases+apparatus) and oxygen consumption methods gave similar results for thin samples in the OSU. However, OSU results for thin samples did not agree with results from the cone calorimeter (ASTM 1354/ISO 1556) unless the HRR history in the cone calorimeter was corrected for smearing that results from dilution of the combustion gases with air in the sample chamber, exhaust duct, and scrubbers and the response time of the oxygen analyzer.

**LUAN Zhi-jian, et al**, [3] A new-type corrugation Plate Heat Exchanger (PHE) was designed. Results from both numerical simulations and experiments showed that the flow resistance of the working fluid in this new corrugation PHE, compared with the traditional chevron-type one, was decreased by more than 50%, and corresponding heat transfer performance was decreased by about 25%. The flow field of the working fluid in the corrugation PHE was transformed and hence performance difference in both flow resistance and heat transfer was generated. Such a novel plate, consisting of longitudinal and transverse corrugations, can effectively avoid the problem of flow path blockage, which will help to extend the application of PHEs to the situation with unclean working fluids.

**PerttiKauranen, et al**,[4] PresentedModern automotive diesel engines are so energy efficient that they are heating up slowly and tend to run rather cold at subzero temperatures. The problem is especially severe in mail delivery operations where the average speed is low and the drive cycle includes plenty of idling. The problem is typically solved by adding a diesel fuelled additional engine heater which is used for the preheating of the engine during cold start and additional heating of the engine if the coolant temperature falls below a thermostat set point during the drive cycle. However, this additional heater may drastically increase the total fuel consumption and exhaust gas emissions of the vehicle. In this study the additional heater was replaced by a combination of exhaust gas heat recovery system and latent heat accumulator for thermal energy storage.

**G. E. kondhalkar& V. N. Kapatkat**,[5] the performance analysis of spiral tube heat exchanger over the shell and tube type heat exchanger. They found that the cost saving using spiral tube heat exchanger is around 15 – 20 % as compared to shell and tube type heat exchanger and to establish that improvement in overall heat transfer coefficient as compared to shell and tube type heat exchanger from 400 to 650W/m$^2$K. The process at higher velocity was not suitable. So it is decided to keep the low velocity with more turbulence which is reduced fouling and increases the heat transfer rate as well as oil will not stick to the inner surface of the tubes. This is achieved by using spiral tube heat exchanger instead of other type heat exchanger.

## III. EXPERIMENTAL SETUP

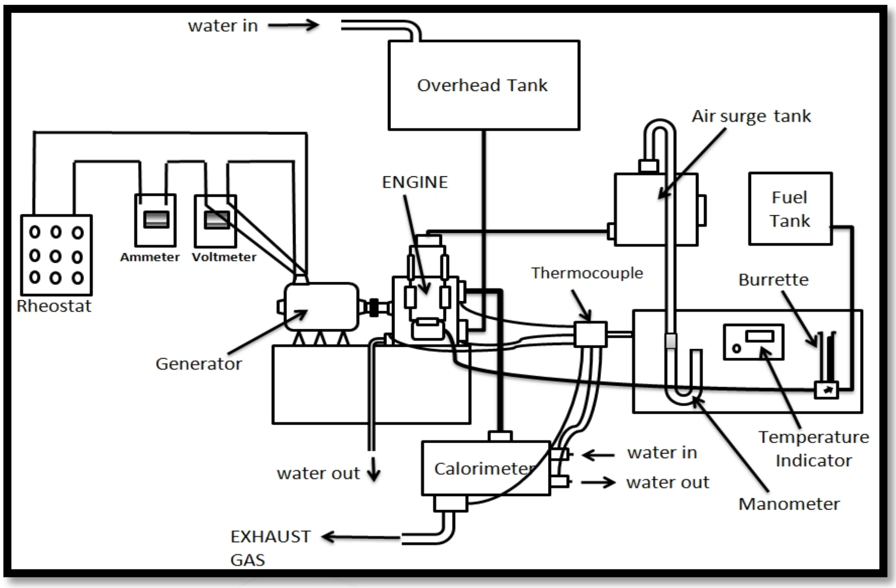


Fig 2: Line Diagram of Experimental Set-Up

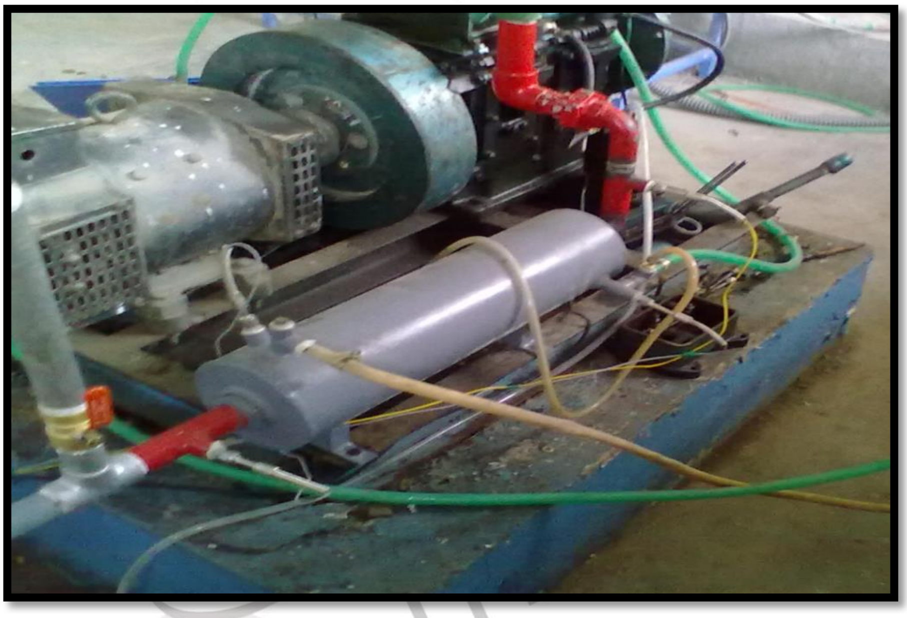

Fig 3: Experimental Set-Up

**Table 1: Characteristics Of Instrumentation**

| Measured variable | Instrument | Range |
|---|---|---|
| Voltage | Voltmeter | 0 to 250V AC |
| Current | Ammeter | 0 to 30A |
| Engine speed | Tachometer | 0 to 9999 rpm |

## IV. EXPERIMENTAL PROCEDURE

1. Fill up sufficient diesel in the diesel tank.
2. Check oil level in the engine. It should be set up to top edge of the flat portion provided over the oil dipstick. If oil level is reduced, add up clean 20w/40 oil to the tank case by opening the valve cover after oil.
3. Fill up water in manometer up to half of the manometer height.
4. Fill up the water in the water rheostat to a required height and add salt. (approximately 500g in filled water tank)
5. Start water supply and see that water is flowing through engine jacket and calorimeter.
6. If diesel tank was empty before filling the diesel, remove air bubbles in fuel pipe by opening the vent screw provided at the right top side of the fuel pump.
7. Lift up decompression lever present at the sides of the valve covers, put the handle over the starting the shaft and rotate the shaft. As engine picks up sufficient speed drop the decompression lever.
8. As the engine picks up the speed, "ON" the main switch.
9. Now slowly turn loading hand wheel in the anticlockwise direction so the engine gets loaded. (take sufficient load)

10. Open the valve at the bottom of the burette. Take sufficient diesel in the burette, close the valve of tank line so that diesel in the burette passes to the engine. Note down the time required to consume 100 ml of diesel.
11. Note down speed, voltmeter, ammeter, manometer difference, various temperatures and water flow through the engine jacket and calorimeter.
12. Repeat the procedure for different loads.
13. After completion of the test, remove all the loads by turning a hand wheel of rheostat clockwise direction "OFF" the main switch and "OFF" the engine by pressing the governor lever near the flywheel. Shut off the water supply and the drain water from the water rheostat.

***Experimentation and Analysis***

*Experimental Results Of Water with spiral tube heat exchanger*

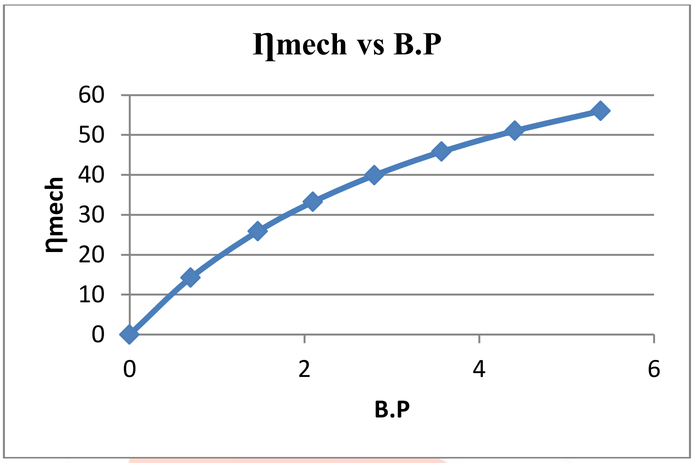


Fig 4: Mechanical efficiency VS Brake power

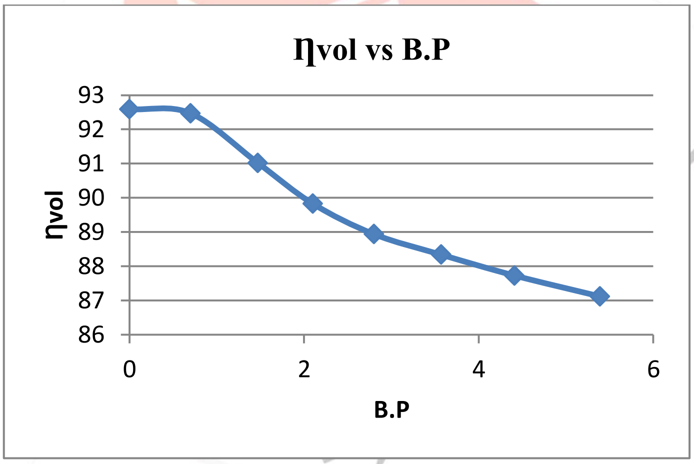


Fig 5: volumetric efficiency VS Brake power

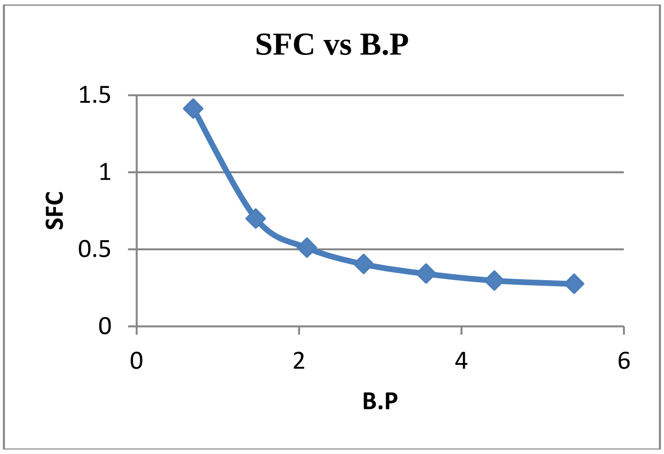


Fig 6: Specific Fuel Consumption VS Brake power

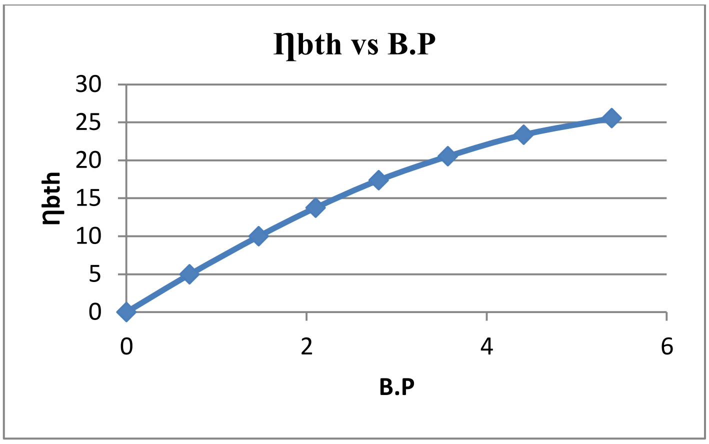


Fig 7: Brake Thermal efficiency VS Brake power

The results obtain from water as cooling medium is shown in fig 4 to 7, also the variation in Mechanical efficiency with Brake power is shown in fig 4. As the brake power increases mechanical efficiency is also increases. The variation in volumetric efficiency with Brake power is shown in Fig 5. As Brake power increase the Specific Fuel Consumption is decreases. Brake Thermal efficiency is also increases with increases in Brake power as shown in Fig 7.

The results suggest that there is with increase in Brake power the fuel consumption, mechanical efficiency, Brake thermal efficiency, Indicated thermal efficiency are increases up to full load due to specific fuel consumption are decreases but over load condition Brake thermal efficiency and Indicated thermal efficiency are decreases.

Mass flow rate of green diesel coolant for modified calorimeter is 58 % less Mass flow rate of green diesel coolant require than old calorimeter other side Mass flow rate of green diesel coolant for old calorimeter is 37 % more Mass flow rate of green diesel coolant require than modified calorimeter. From the experiment concluded more brake power found in modified shell & tube type exhaust gas calorimeter for both water & diesel coolant than old spiral tube type exhaust gas calorimeter

*Experimental Results of Coolant with spiral tube heat exchanger*

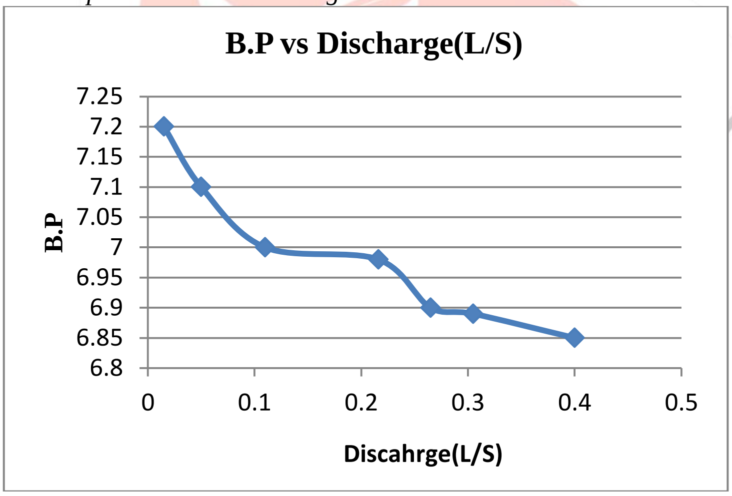


Fig 8: Brake power VS Discharge (L/S)

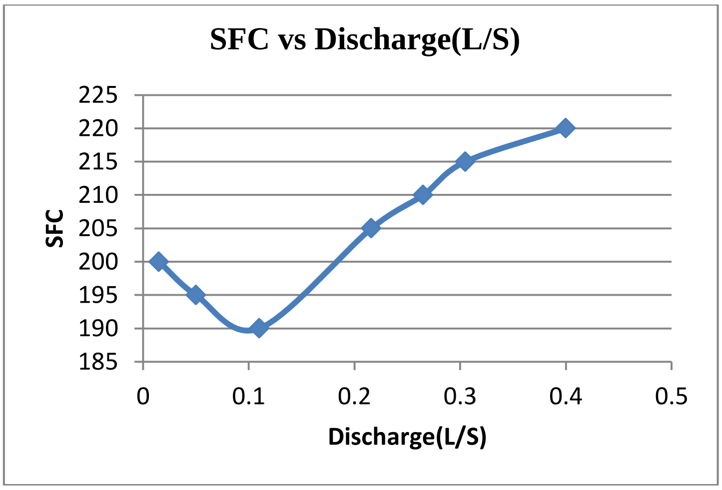


Fig 9: Specific fuel consumption VS Discharge (L/S)

*Experimental Results Of Water With Modified Exhaust Gas Calorimeter*

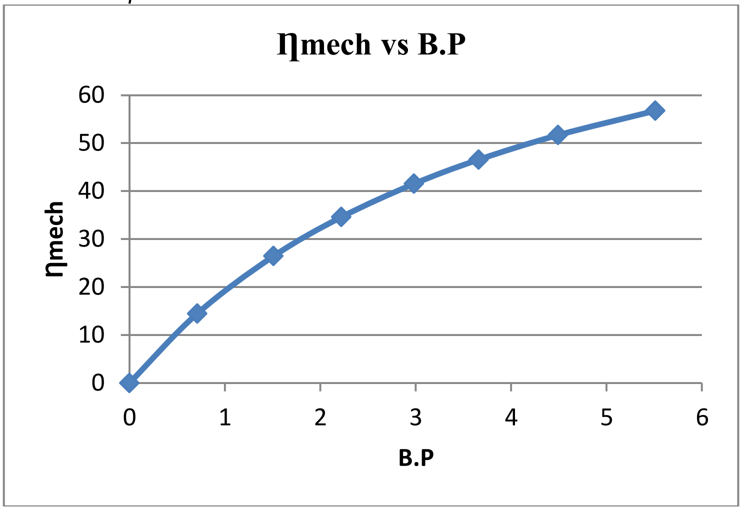


Fig 10: Mechanical efficiency VS Brake power

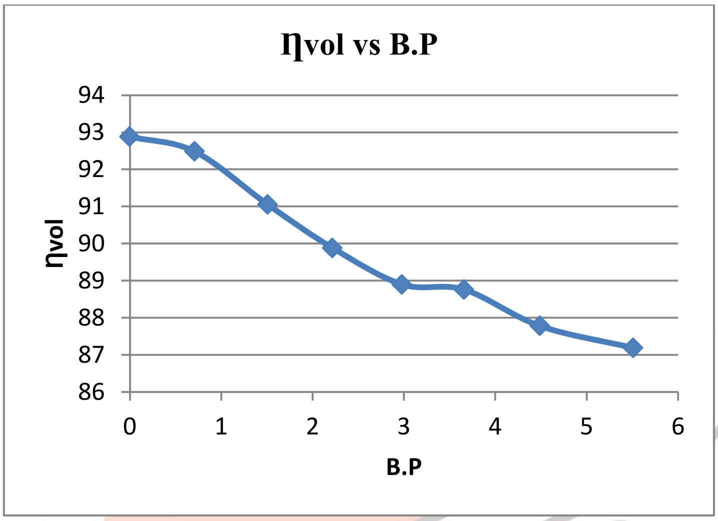


Fig 11: volumetric efficiency VS Brake power

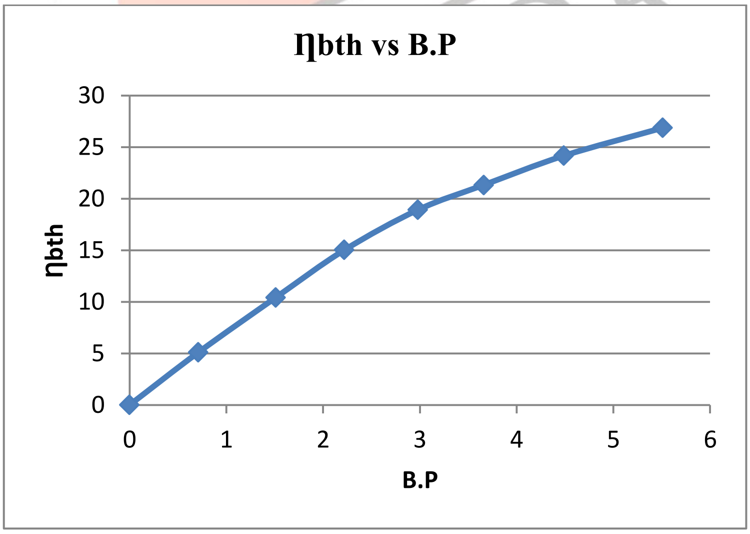


Fig 12: Brake Thermal efficiency VS Brake power

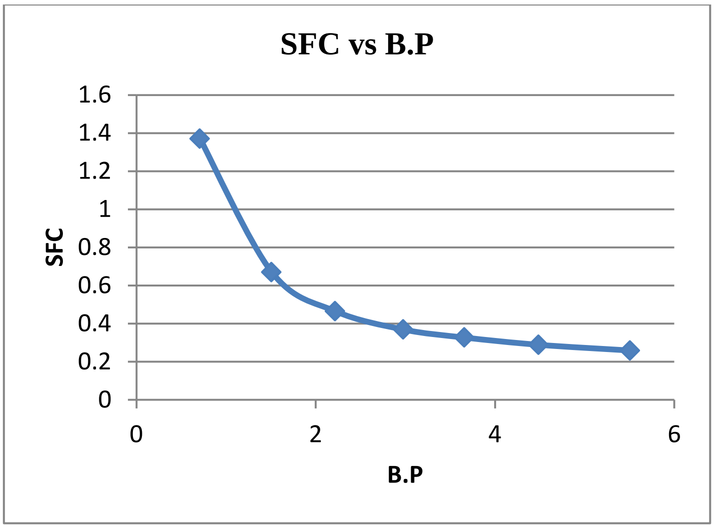


Fig 13: Specific Fuel Consumption VS Brake power

*Experimental Results of Coolant With Modified Exhaust Gas Calorimeter*

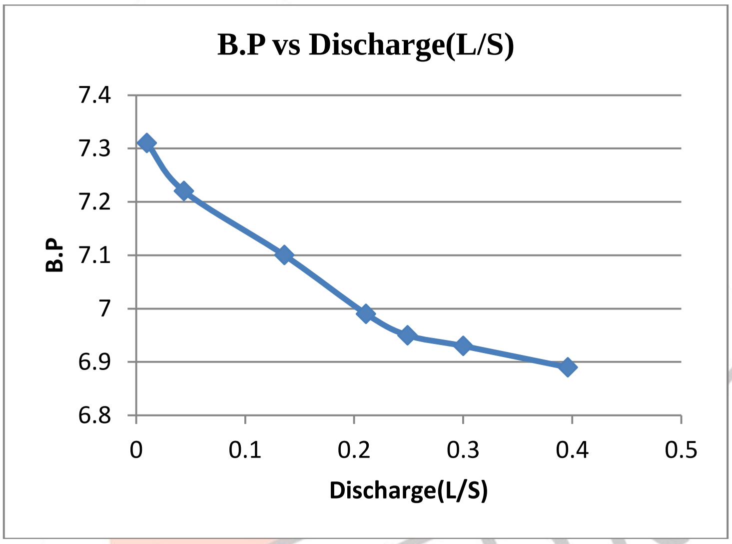


Fig 14: Brake power VS Discharge(L/S)

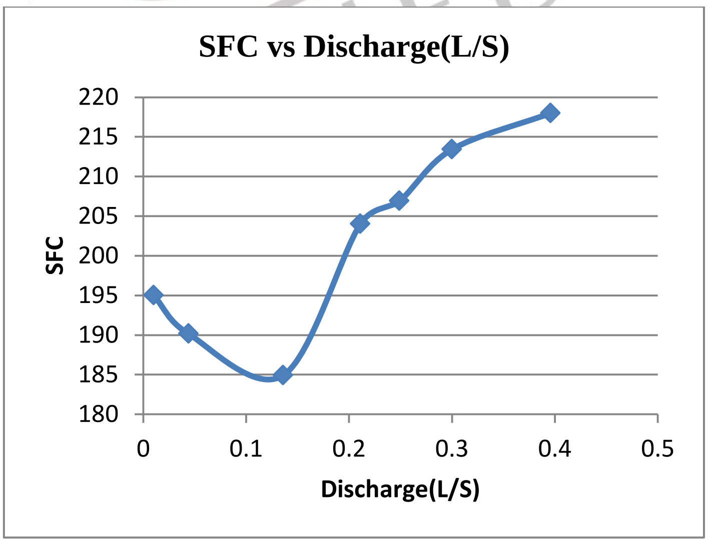


Fig 15: Specific fuel consumption VS Discharge(L/S)

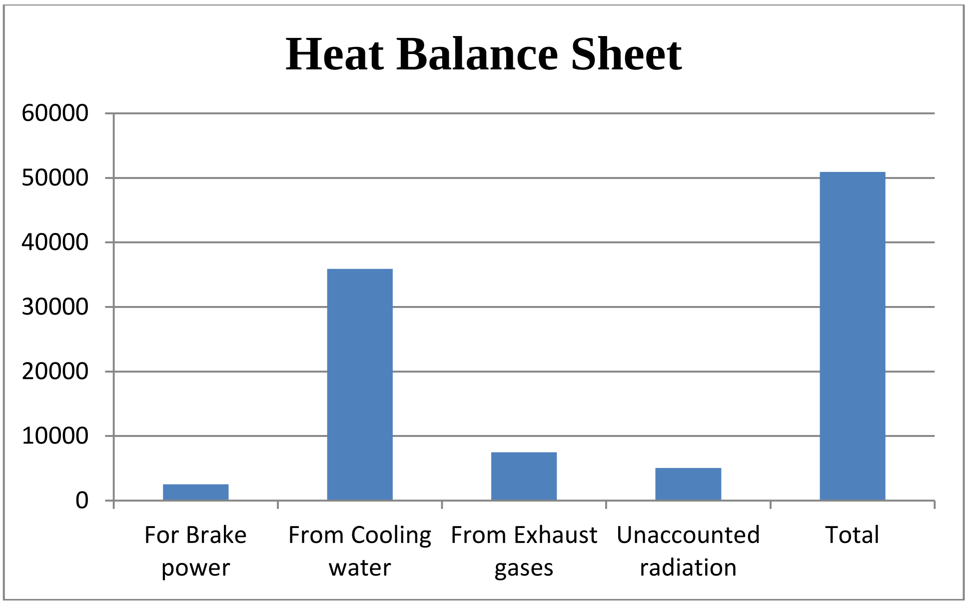


Fig 16: Heat balance sheet of water with spiral tube type heat exchanger

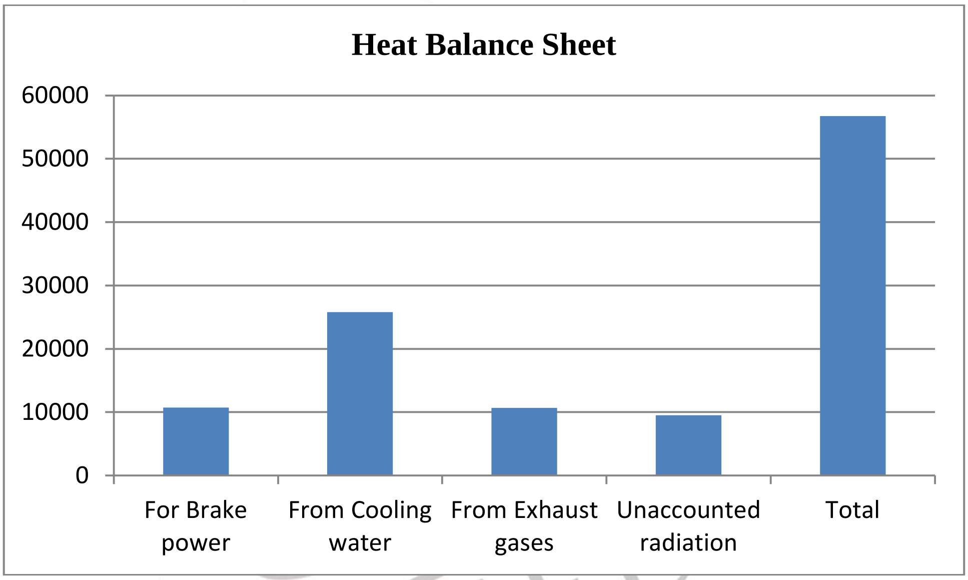


Fig 17: Heat balance sheet of water with shell and tube type heat exchanger

## V. RESULTS AND DISCUSSION

TABLE: 2 Comparison of Exhaust Gas Calorimeter

| Sr no. | Description/Practical data | Shell & Tube type modified Exhaust gas Calorimeter | Spiral Tube type Old Exhaust gas calorimeter |
|---|---|---|---|
| 1 | Overall weight | 10.2 kg | 28 kg |
| 2 | Overall volume | 0.008 $m^3$ | 0.0342 $m^3$ |
| 3 | Copper tube length | 7 m | 6.28 m |
| 4 | type of body Material- outer | G.I | G.I |
| 5 | Overall fabrication cost | RS 8013/- | RS 12012/- |
| 6 | Mass flow rate of water | 0.186 Lit./sec | 0.230 Lit./sec. |
| 7 | % of cooling Media requirement | 23 % Less coolant require | 19 % of more coolant require |
| 8 | Mass flow rate of green diesel coolant | 0.136 Lit/Sec. | 0.216 Lit/Sec. |
| 9 | % of Mass flow rate of green diesel coolant requirement | 58 % Less Mass flow rate of green diesel coolant require | 37 % more Mass flow rate of green diesel coolant |

| | | | |
|---|---|---|---|
| | | | require |
| 10 | Mass flow of Exhaust gases ×Sp.heats of exhaust gases for water | 34.59 kJ/hr.k | 50.16 KJ/hr. k |
| 11 | Optimum Mass flow rate of water in engine jacket at rated power | 0.255 Lit./sec | 0.313 Lit./sec. |
| 12 | Overall Performance | Best | Poor |
| 13 | Engine Rated power for water | 5.51 KW | 5.39 KW |
| 14 | Engine Rated power for coolant | 7.10 KW | 6.98 KW |
| 15 | Specific fuel consumption required for engine | 0.259 Kg/KW. Hr | 0.274 Kg/KW. Hr |

In which consider that modified exhaust gas calorimeter better because,

- Overall weight of modified shell & tube exhaust gas calorimeter is less compared to old spiral tube exhaust gas calorimeter. Overall volume of modified calorimeter is less compared to old calorimeter because of this minimum space required.
- Overall weight & volume is less than old calorimeter so cost of fabrication also reduces than old spiral tube exhaust gas calorimeter.
- Mass flow rate of water for modified calorimeter is 23% less cooling media required than old calorimeter other side Mass flow rate of water for old calorimeter is 19% more cooling media required than modified calorimeter.
- Mass flow rate of green diesel coolant for modified calorimeter is 58 % less Mass flow rate of green diesel coolant require than old calorimeter other side Mass flow rate of green diesel coolant for old calorimeter is 37 % more Mass flow rate of green diesel coolant require than modified calorimeter.
- From the experiment concluded more brake power found in modified shell & tube type exhaust gas calorimeter for both water & diesel coolant than old spiral tube type exhaust gas calorimeter.
- Specific fuel consumption for modified exhaust gas calorimeter is less compared to old exhaust gas calorimeter.
- Overall performance of modified shell & tube type exhaust gas calorimeter is better than the old spiral tube type exhaust gas calorimeter.
- The results suggest that there is with increase in Brake power the fuel consumption, mechanical efficiency, Brake thermal efficiency, Indicated thermal efficiency are increases up to full load due to specific fuel consumption are decreases but over load condition Brake thermal efficiency and Indicated thermal efficiency are decreases.
- Also checked temperature distribution analysis of spiral tube exhaust gas calorimeter with computational and after compare with experimental just 2.71% error found which is nearest value of experimental data.

## VI. CONCLUSION

In case of I.C engine it is important to find heat balance sheet. How much heat goes to Brake power, how much heat goes to exhaust gas as a loss& heat loss in cooling water. Hear effort also made for using cooling media as a water and diesel engine cooling coolant media as light viscous green coolant.

In existing spiral tube type heat exchanger as exhaust gas calorimeter in difficult to find out how much exact heat goes in to the exhaust gas. Main problem is carbon deposited on spiral tube heat exchanger and inner cell of the body. Here for existing spiral tube type exhaust gas calorimeter overall volume is $0.0342m^3$ & overall weight is 28 kg.

So effort can apply fabricated new shell & tube type exhaust gas calorimeter & perform effectively with engine. It is found better mass flow of water coolant and product of mass flow of exhaust gas ×Specific heat of exhaust gas. Here 0.63% less weight & 0.76% less volume required than spiral tube type exhaust gas calorimeter. I also perform with computational &also found 1.64% error in result.

So conclude that with new shell & tube type exhaust gas calorimeter found more Brake power with minimum fuel consumption & minimum vibration and noise. It is also found that by using diesel engine coolant as a coolant media then it is less vaporized in hot condition. so diesel coolant is better as cooling media.

So shell & tube type exhaust gas calorimeter & use coolant as cooling media found better result than existing spiral tube type exhaust gas calorimeter& water.

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