INTEGRATION OF EC & IC ENGINE'S WORKING

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Abstract:

It is known that when any kind of fossil fuel is burnt two phenomenons take place (i) Explosion and (ii) Heat generation. In the concept that is stated it is desired to merge the functioning of External Combustion (EC) and Internal Combustion (IC) engines on the basis of their working principle. In an EC engine the motive power is obtained by utilizing the factor of heat alone, which results in vaporization of a fluid that is used to move the piston inside the cylinder piston arrangement. Whereas in an IC engine the motive power is derived form the explosion factor, which takes place inside a control volume, thereby providing the necessary power to push the piston for obtaining the desired working motion. It is important to note that neither EC nor IC engines have efficiency greater than 40%. This is due to the fact that neither of the system utilizes both the factors mentioned above, for producing useful work. But if we can utilize the heat produced due to combustion of fuel in an IC engine, based on the working principle of EC engine, to supply motive power, then we can assure that maximum output would be derived. This paper aims at justifiable use of energy by the combination of the working principles of EC engines used in locomotives and IC engines powered by gasoline (petrol).

Keywords: External Combustion (EC) engine, Otto cycle, Electronic water pump, Hybrid vehicle, Water jacket, Liner.

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1. Introduction

1.1 Types of Engine

Engines can be basically classified according to the manner in which the fuel is burnt.

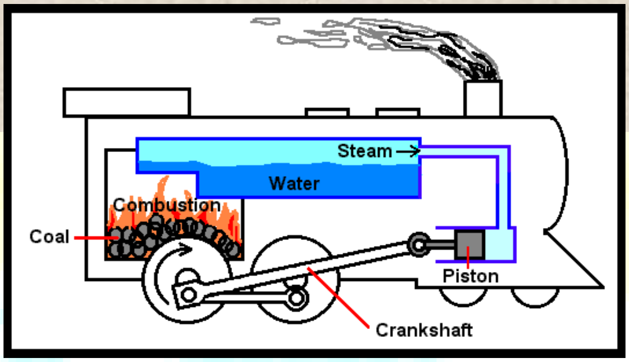

Fig. 1.1 Concept of EC engine

If fuel is burnt outside the cylinder-piston arrangement then such an engine is called "External Combustion Engine".

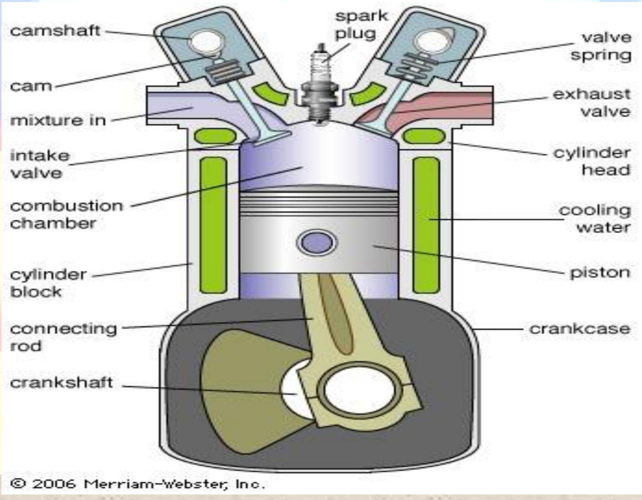

Fig. 1.2 Concept of IC engine

If the fuel is burnt inside the cylinder-piston arrangement then such an engine is called "Internal Combustion Engine".

1.2 Working of External Combustion Engine

External Combustion engine operates by converting heat energy into mechanical energy. This requires a heat source, a boiler to generate steam and cylinders converting the thermal energy contained in steam to mechanical energy, which can be used to perform work. Steam is technically defined as being elastic aeriform fluid in which water is converted when heated to its boiling point. The steam is condensed upon contact with cool air and brought back to its liquid state. The cycle of external combustion consists of 2-strokes of piston or one revolution of flywheel.

- During 1st stroke pressurized steam is diverted towards the top of cylinder through a slide valve, which pushes the piston backward
- In the 2nd stroke steam is diverted towards the bottom of the piston which pushes it forward

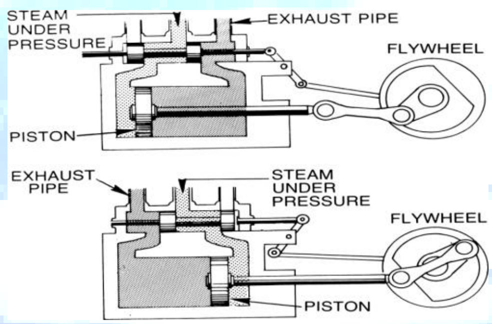

Fig. 1.3 Working of EC engine

1.3 Working of Internal Combustion Engine

Internal Combustion engine operates by converting explosion of a mixture of air and fuel into mechanical energy. This requires a technique of mixing specific quantity of fuel with air, method of igniting the mixture and a process of removing the product of combustion.

In any IC engine the combustion of mixture takes place in a space known as ‘combustion chamber’ which is the empty volume between the head of a cylinder and the top of a piston that reciprocates inside that cylinder.

The cycle of internal combustion consists of 4-strokes of piston or two revolution of crankshaft.

- In 1st stroke air-fuel mixture is sucked inside the cylinder piston arrangement through inlet valve
- In 2nd stroke the piston compresses this mixture
- In 3rd stroke spark plug produces a spark which explodes the compressed air-fuel mixture
- In 4th stroke the piston removes the gases produced due to combustion by pushing them out through the exhaust valve

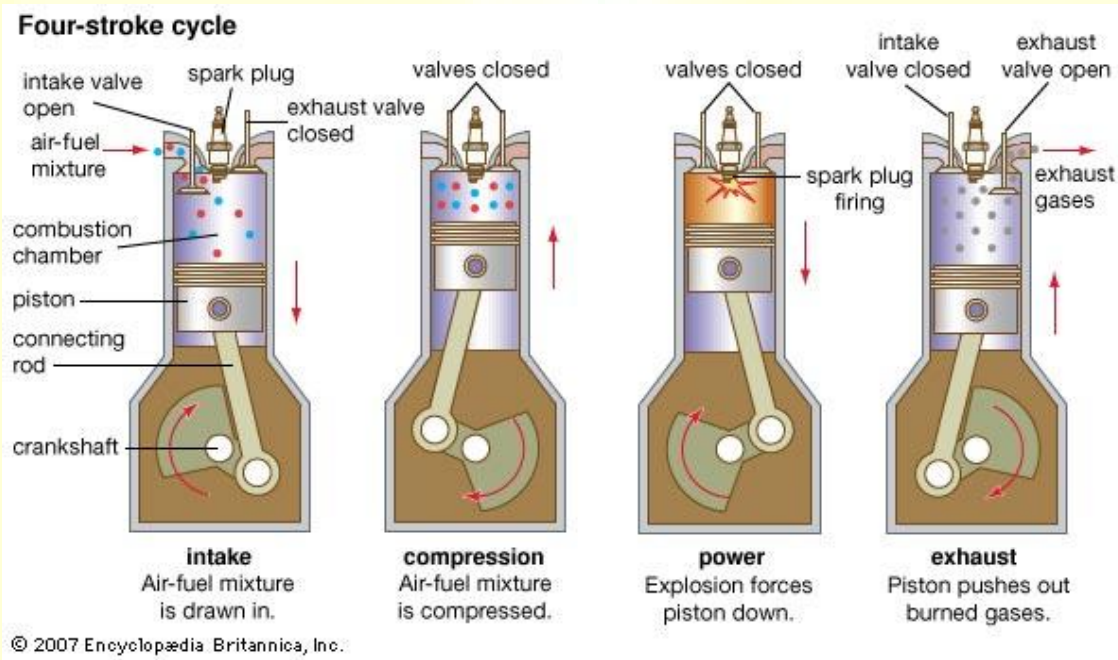

Fig. 1.4 Working of IC engine

1.4 Challenges in present day Engines

At the moment the engine technology is faced with challenges such as:

1. Low efficiency: The efficiency of IC engines is up to 37% in spite of aiding them with turbo charger, supercharger or stock efficiency aids, but it is better than that of an EC engine used in auto vehicles which is around 15%.

2. High fuel consumption: The mileage given by different category of vehicles such as 2-wheelers, 3-wheelers, 4-wheelers varies in a descending order by a large magnitude. The mileage of 2-wheelers is mostly around 70 kilometers per liter of fuel; whereas that for 3-wheelers is less than 50 kilometers per liter of fuel and that for 4-wheelers it lies between 18 to 20 kilometers per liter.

Fig. 1.5 Two-wheeler, Three-wheeler & Four-wheeler

3. Under utilization of energy: None of the working principles; neither of external combustion nor of internal combustion concentrates on benefiting from the entire energy that is available from the specific quantity of fuel that is burned. The EC engines utilize only the heat available from the combustion process while the IC engines derive the necessary power from the factor of explosion only.

4. Significant air pollution: The auto-vehicles emit a large portion of unwanted and harmful gases as the product of burning of fuel. The gases so produced are a mixture of carbon dioxide, carbon monoxide, Nitrogen oxide and suspended particulate material that contribute to the green house effect making average surrounding temperature to increase above normal value.

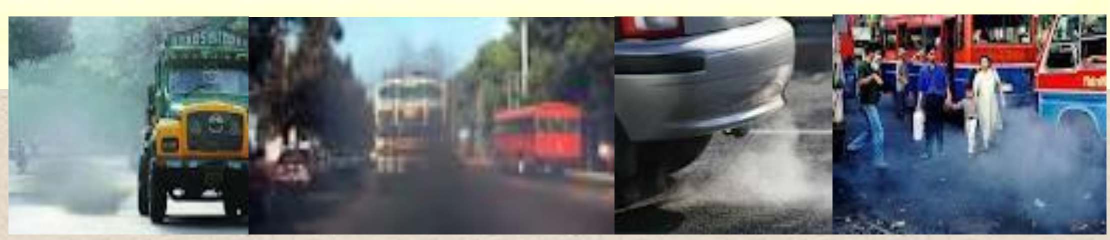

Fig. 1.6 Contribution to air pollution

1.5 Mandatory Improvements

It is essential to carry out certain improvements such as:

1. Maximization of output: This highlights that whatever quantity of fuel is poured into the engine, must be utilized to maximum possible extent without any kind of wastage.

2. Utilization of waste energy: In order to make engines more effective a mechanism must be developed to tap that portion of energy which has been lost without being effectively utilized.

3. Technique to improve efficiency: It is suggested that other than making complete alteration in the design of engines for making them more efficient, those aspects which compromise efficiency must be addressed.

4. Reducing Green House Effect: We must create such a system that decreases the toxicity of tail pipe emissions, reduces the temperature of the exhausted by- products and contributes in preserving the environment.

1.6 Outcome of Integration of EC & IC Engines

The following advantages are achieved if the two principles of working are combined

1. *Maximum utilization of generated energy:*

   By clubbing the two arrangements together we can ensure that energy loss of IC cylinder piston arrangement can be used as a source of power for driving the EC cylinder piston arrangement that would supplement the function of IC engine.

2. *Decrease in overall fuel consumption:*

   As a combination of both the arrangements would be used to produce the necessary power for doing useful work, such an arrangement would seal off any wastage of energy occurring otherwise.

3. *Improvement in performance:*

The duration of operation of an engine working on such an arrangement would be increased due to the combined effect. Thus the period of effectiveness of the machinery is increased which would be beneficial in the long run.

4. *Reduction in temperature of exhaust gases:*

In conventional IC engines the high temperature of exhaust gases is a major contributor of rising the surrounding atmospheric temperature. In case we are able to utilize this heat for providing the necessary energy to an associated EC engine then it would contribute in lowering the exhaust gas temperature hence reducing their share in increasing the green house effect.

2. Stimulus for Exploration

2.1 Motivation

(1) *Studied the working principles of EC & IC engines:*

While studying the principles on how EC and IC engines work, the demerits of both the approaches surfaced, which provided the basis of research

(2) *Identified myopic efficiency:*

Otto cycle is typically used for car's internal combustion engine that works using gasoline as a fuel. IC engines that are based on 4 strokes of the 'Otto cycle' have one power stroke for every four strokes, which is a significant reason behind the reduced efficiency.

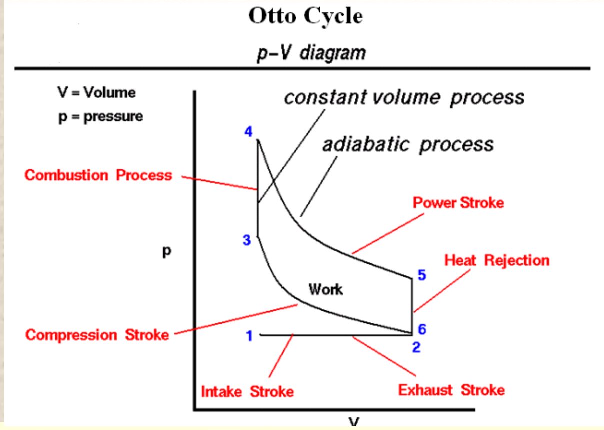

Fig. 1.7 Cycle of IC engines

(3) Realized the limited usage of energy:

Neither of the two working approaches of EC or IC makes efficient use of the entire energy which is available after the burning of fuel.

(4) Decided to obtain combined result:

In order to wok-out a suitable mechanism to reutilize the waste heat exhausted from an IC arrangement and to channelize this energy for supporting its working the decision to integrate the two concepts was taken.

2.2 Objectives

The shortlisted objectives of the research work to be achieved are as follows:

a) To increase overall efficiency of an IC engine

b) To achieve maximum possible output from a given input, in an engine

c) To minimize the consumption of fuel

d) To decrease the wastage of energy available from fuel, in existing engines

e) To re-utilize the wasted energy

3. Work done so far

3.1 Cooling System Components

A conventional cooling system consists of four major components:

i) Radiator

ii) Water Pump

iii) Thermostat valve

iv) Water Jacket

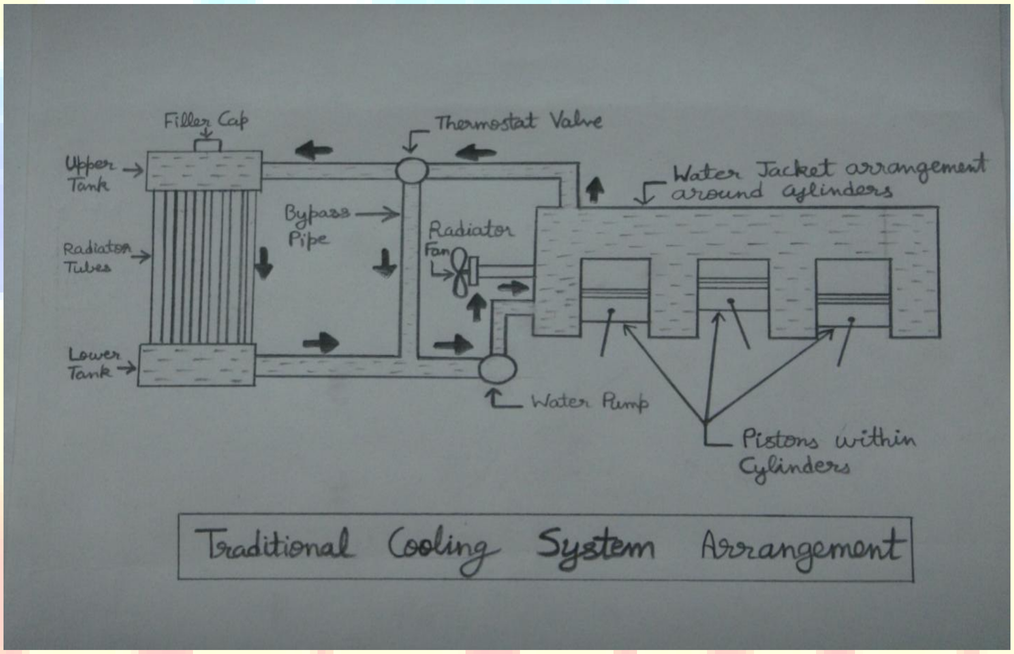

Fig. 3.1 Cooling System of IC engine

3.2 Working

The water is pumped by water pump from the water tank into the engine's water jacket but until the temperature of engine reaches a value of 93°C the Thermostat valves does not allow water to enter the radiator and by-passes it through the by-pass valve for recirculation

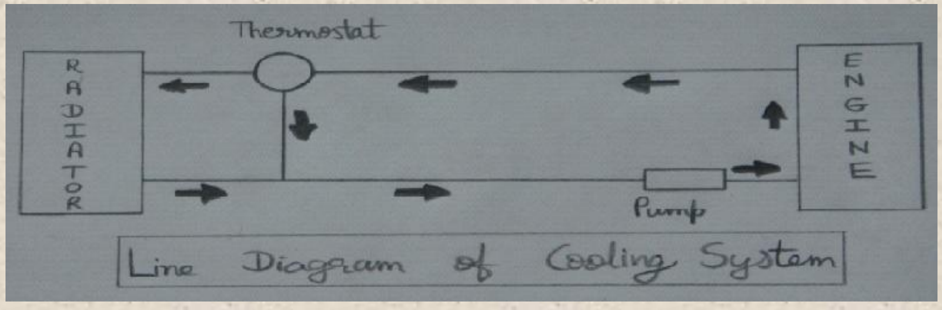

Fig. 3.2 Working of IC engine cooling system

3.3 New Arrangement

In the new arrangement the flow rate of water is very low compared to conventional cooling systems, which is regulated by the water pump. The slow flow rate of water ensures the more time is available between the flowing water and the outer wall of liner for obtaining maximum heat transfer to take place thereby ensuring phase change. The steam so generated is diverted to the EC cylinder piston arrangements where it is used for obtaining useful work.

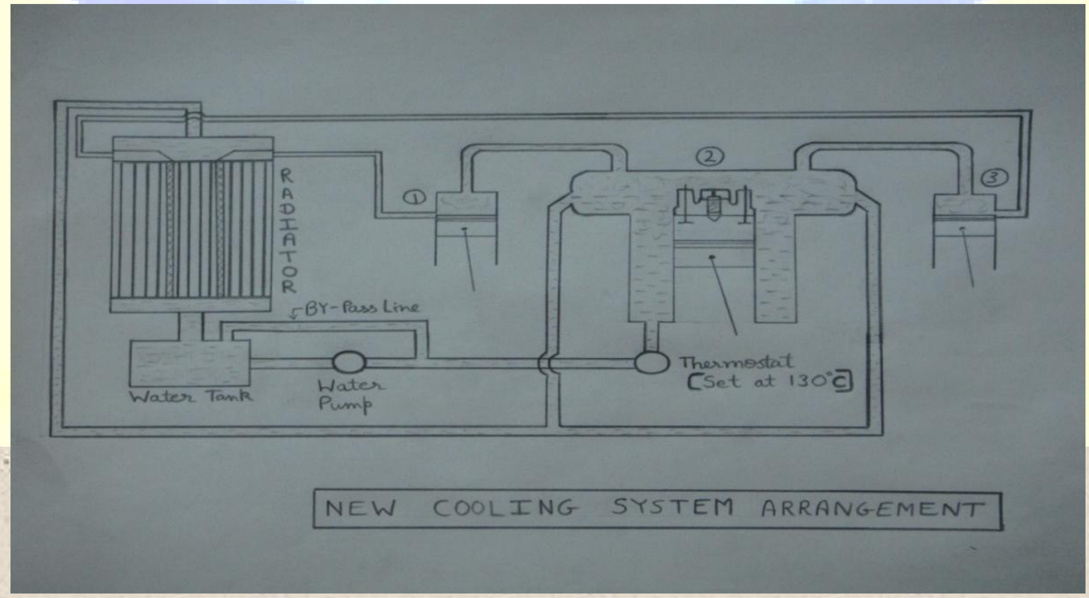

Fig. 3.3 New Concept for Cooling System

3.4 Calculations

- Flow rate of coolant or water varies with engine's speed
- Diameter of crankshaft pulley, Dc = 12cm
- Diameter of water pump pulley, Dw = 11cm

Table 1: Water flow rate corresponding to engine speed

Crankshaft pulley's rpm	Water pump pulley's rpm	Flow rate, liter/s
900	983	2.77
1000	1092	3.08
2500	2730	7.70
5000	5459	15.41

3.5 Typical Data

- Temperature inside combustion chamber during power-stroke is nearly = 1400^{o}C
- Maximum possible heat transferred to the liner is nearly = 40%
- Preferable temperature of liner = 250^{o}C
- Actual temperature of liner is nearly = 602^{o}C
- Pressure within the cooling system = 103.42 KPa
- Boiling point of water under this pressure = 125^{o}C

For ensuring that the flowing water converts into steam, the required flow rate will be as under:

Heat lost by liner = Heat gained by flowing water (from 'energy balance equation')

- Q = mw.Cp-w.(T1-T2)
- h.A.(Ts- Tf) = mw.Cp-w.(T1-T2)

i) For h = 1600 W/m²-K; mw = 129 milliliters/s (Lower Limit)

ii) For h = 2000 W/m²-K; mw = 180 milliliters/s (Upper Limit)

Remark: This flow rate can be achieved by using either an 'electronic water' pump or by 'changing' the 'diameter of pulley' of the mechanically operated water pump.

3.6 Integrated Engine

As compared to a conventional IC engine, the engine that would be able to generate power for propulsion, by the combustion of fuel, according to Otto cycle and makes use of the energy escaping through the cooling system in the form of heat to do useful work will be referred as 'Integrated engine', as shown in Fig. 3.3. For the concerned research work the selected configuration of cylinder-piston arrangements for the integrated engine will the '*3 cylinder Inline'*. In which the second cylinder would function as IC cylinder while the first and third cylinders would work in a fashion similar to EC engine's cylinders.

It is proposed that for a brief initial period, when the engine is started, the sole IC cylinder would support the movement of the two EC cylinders till steam generation takes place due to boiling and resulting phase change of the circulating cooling water in the water jacket. So it is imperative for the sole IC cylinder to generate sufficient power for sustaining the load of the two EC cylinder-piston arrangements. So taking into consideration the smallest bore size available for engines used in a four wheeler, the most favorable bore diameter for the IC cylinder of the integrated engine was identified as under.

Table 2: Bore diameter versus Power developed

Bore diameter, cm	Increase in diameter, cm	Power developed, KW	Power enhances by, %
6.85	-----	2.941	-----
7.85	1.0	3.862	31.31
8.05	1.2	4.061	38.08
8.85	2.0	4.909	66.91

From the above tabulated data it can be commented that increasing bore diameter by 2.0 cm gives most optimized results for the power developed, by the engine. Hence for the sole IC cylinder of the integrated engine the bore diameter of 8.85 cm is selected.

Corresponding to this value of bore diameter the other related parameters obtained by considering the total engine volume to be equal to 0.8 liters, are as follows:

1) *Swept volume of the sole IC cylinder = 442.67cm³*

2) *Mass of fuel injected in sole IC cylinder = 0.00648 Kg/s*

3) *Swept volume of each EC cylinder = 178.665cm³*

4) *Bore diameter of each EC cylinder = 5.62cm*

The contribution of the generated steam in the form of EC cylinders in doing useful work is as under:

i) *Pressure of steam inside the system = 103.420 KPa*

ii) *Surface area of piston on which steam would act = 24.791cm²*

iii) *Force developed by steam pressure = 256.409 N*

iv) *Force available at crankshaft = 238.461 N*

v) *Combined effort of two EC cylinders = 476.922 N*

vi) *Power produced by two EC cylinders = 28.616 Watt*

Hence the features of the integrated engine are:

(1) *Maximum power output, bhp = 4.937 KW*

(2) *Mechanical efficiency, ηm = 80%*

(3) *Thermal efficiency, ηbt = 34.35%*

(4) *Specific fuel consumption, bsfc = 0.2381 Kg/KW-h*

3.7 Case Study

In order to determine the practical applicability of the concept of combining together working principles of EC and IC engines, a case study of a vehicle, from the Indian auto market is taken up. The vehicle is *Maruti 800 car* which is appreciated for its superior fuel economy.

Two tests were conducted on the engine of this vehicle whose results are as under:

(1) Result of *Morse Test* for Maruti 800 engine

(i) *Indicated power available= 11.028 KW*

(ii) *Indicated power per cylinder = 3.676 KW*

(iii) *Brake power available = 8.823 KW*

(iv) *Brake power per cylinder = 2.941 KW*

(v) *Mechanical efficiency = 80%*

(2) Result of *Performance Test* for Maruti 800 engine:

(i) *Mass of fuel consumed in all 3 cylinders = 0.00097984 Kg/s*

(ii) *Mass of fuel consumed in each cylinder = 0.0003266 Kg/s*

(iii) *Thermal efficiency = 20.46%*

(iv) *Specific fuel consumption = 0.39979 Kg/KW-hour*

It can be noticed that as a result of integrating the working principles of EC and IC engines, the following benefits are achieved:

(a) *Maximum utilization of generated energy*

(b) *Decrease in overall fuel consumption*

(c) *Improvement in performance*

The above mentioned benefits are supported by the following table of comparison:

Table 3: Comparative Conclusion

Parameters	**Engine Under Study (Maruti 800, 796cc, 3 cylinder inline)**	**Integrated Engine (1 IC + 2 EC cylinders, Inline, 800 cc)**
Bore diameter	6.85cm for all cylinders	IC cylinder = 8.85cm EC cylinders = 5.62cm (each)
Stroke length	7.2cm	7.2cm
Mechanical efficiency	80%	80%
Brake Power	8.823 KW at 2000 rpm	4.937 KW at 2000 rpm

Mechanical efficiency	80%	80%
Brake thermal efficiency	20.46%	34.35%
Brake specific fuel consumption	0.399789 Kg/KW-h	0.2381 Kg/KW-h

4. Further Scope of Research

This concept of integration of the IC and EC approaches can be extended to different applications such as

1) Improving efficiency of vehicular Diesel engines
2) Development of a compound Locomotive engine
3) Introducing the concept of integration in Marine Engines
4) Focusing on low manufacturing cost of integrated Engines
5) Extending the concept to other engine configurations
6) Upgrading Hybrid vehicles through this concept

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