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EVALUATION OF THE PERFORMANCE OF A SPARK-IGNITION FOUR CYCLE ENGINE, IN A TROPICAL ENVIRONMENT

Kingsley Ejikeme Madu

Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra, Nigeria
Mobile Phone Number: +234(0)8033910640, E-mail: kingsleyblack2@gmail.com.

ABSTRACT
When an I. C. engine is designed and manufactured, then it is tested in the laboratory. The purposes of testing include: to determine the information which cannot be obtained by calculation; to confirm the data used in design, the validity of which may be doubtful; and to satisfy the customer regarding the performance of the engine. By performance, we mean the operation of all variables relating to the working of the engine. These variables are power, fuel consumption, etc. An internal combustion engine is put to the thermodynamic tests, so as to determine the following quantities: indicated mean effective pressure, indicated power, speed of the engine, brake torque, brake power, mechanical losses, mechanical efficiency, fuel consumption, thermal efficiency, air consumption, volumetric efficiency, various temperatures, and heat balance sheet. It may be noted that these quantities (analytically determined) are measured after the engine has reached the steady conditions.

KEYWORDS: Internal Combustion Engine, Four-Stroke Cycle, Fuel Combustion, Spark Ignition, Performance Analysis, Tropical Environment.

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INTRODUCTION

Energy is the basic necessity for the economic development of any country. Many indispensable functions for present-day living grind to halt when the supply of energy stops. As such, it is practically impossible to estimate the actual magnitude of the part that energy has played in the building up of the 21st century civilization. The availability of huge amount of energy – whether in the crude and unprocessed form or in the form consumable by people – in developed economies has resulted in shorter working day and hour, higher agricultural and industrial production, a healthier and more balanced life-style (Mehta and Mehta, 2013). In fact, there is a close relationship between the energy used per person and his standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of her citizens.

The high rate of increase in the population and fast changing life style has made a significant and progressive change in the industrial and transport sector. The consumption of the petroleum derivatives has been therefore increased to a soaring level that it is being depleted at a much higher rate than expected (Victor, Mohhammed and Baskar, 2015). This over growing demand has forced engineers in the field of energy study, to look into an efficient utilization of petroleum products until a stable and suitable alternative is found.

In recent times, some fuels are required but these fuels are not available in abundance. Basically these fuels play a very important role in the modern development and rapid industrialization. The important fossil fuels are Coal, Petroleum and Natural Gas. The automobiles are the most important sector for the social development; it has enhanced the life standards of the human beings. But these are causing a lot of pollution. Decreasing emissions from automobiles and increasing engine efficiency are necessary steps towards improving air quality and reducing greenhouse effect. Transportation vehicles are the largest consumer of fuels and a major source of pollution that affects the air quality. It is well known that alcohol addition to SI Engines can reduce the exhaust emissions and increase its efficiency (Krishna and Mayank, 2015).

With the addition of alcohol to the gasoline, SI Engines can run on lean air fuel ratios and this lean operation of SI Engines can reduce NOx emissions by a significant amount relative to NOx emissions at stoichiometric conditions. The significant progress made in the material research in the recent times enables the application of the thermoelectric modules in the automobiles. The vaporization of petrol in the carburetor is affected by the humidity in the atmosphere (Bharadwaj, 2012).

Preheating the intake air eases the vaporization of fuel thereby achieving a fast combustion. The reduction of the water vapour content in the intake air reduces the steam formation, pitting of the engine cylinder, piston and exhaust pipe (Xi, Chen and Zhao, 2014; Fu, Liu and Ren, 2012; Heywood, 1998; Ganesan, 2012). Similarly, Zhang et al., (2011) studied the impact of increasing the intake temperature on the pressure in the cylinder. The experiment was carried out in a CT2100Q engine which is a double cylinder, four strokes, compulsory water cooling, naturally aspirated and direct injection. The primary analysis revealed that with the increase in intake temperature, the carbon monoxide and hydrocarbon emissions decrease. The emission of oxides of nitrogen increases with the increase in intake temperature. Kumar and Raj (2013) discussed the effects of the intake temperature on the CO and HC emissions. Better vaporization of fuel and in-cylinder combustion potentially reduces the CO and smoke emissions. The engine parameters were experimentally investigated on a single cylinder, four stroke and air cooled compression-ignition engine with a bore of 78 mm, stroke of 68 mm and total displacement of 325 cm^3. The performance parameters include brake thermal efficiency, volumetric efficiency, brake specific fuel consumption, equivalence air fuel ratio and brake power. The intake preheating performs a better economy, which is contributed by the decreased loss and faster combustion.

Internal combustion engine is a heat engine in which the chemical energy of combustion is released inside the engine cylinder, while in the other group of heat engines, the energy developed during combustion of fuel is transmitted first to steam, and only through steam does its work in the engine. There are no standard ways or methods of classifying internal combustion engines. Most times, they are classified based on the working cycle employed, fuel used, speed, nature of thermodynamic cycle, method of cooling, field of application, method of fuel ignition, cylinder arrangement, etc. (Ballaney, 2011).

In this paper, the author is concerned about the performance analysis of a spark ignition, four stroke cycle, internal combustion engine, in a tropical country like Nigeria. A brief review of the operation and purpose of the principal parts is necessary for complete understanding of the whole engine. The main working parts of a spark ignition, four stroke cycle engine are described;

Cylinder. The heart of the engine is the cylinder where the fuel is burnt and the power developed. The inside of the cylinder is formed by the liner or sleeve. The inside diameter of the cylinder is called the bore. In most engines, the pistons bear directly on the walls forming part of the cylinder block, but in some, and particularly in engine with larger cylinder, removable liners are used.

Cylinder Head. It closes one end of the cylinder and often contains the valves through which air and fuel are admitted and exhaust gas discharged.

Working Cycle Employed	Four-stroke cycle engine	Two-stroke cycle engine
Fuel Used	Petrol engine Gas engine	Diesel engine Bi-fuel engine
Nature of Thermodynamic Cycle	Otto cycle (Otto engine) Dual combustion cycle (Dual combustion engine)	Diesel cycle (Diesel engine)
Speed	Low speed engine (up to 500 rpm) Medium speed engine (up to 1000 rpm) High speed engine (above 1000 rpm)	
Method of Cooling	Air-cooled engine	Water-cooled engine
Field of Specialization	Stationary engine Automobile engine Aero engine	Marine engine Motor cycle engine Locomotive engine
Method of Ignition	Spark ignition engine	Compression ignition engine
Arrangement of Engine Cylinder	Horizontal engine V-engine Opposed cylinder engine Radial engine	Vertical engine Inline engine Opposed piston engine

Piston. The other end of the working space of the cylinder is closed by the piston that transmits to the crankshaft, the power developed by the burning of the fuel. The distance that the piston travels from one end of the cylinder to the other is called the stroke.

Connecting Rod. One end, called the small end of the connecting rod, is attached to the wrist pin located in the piston. The other end, or the big end has a bearing for the crank pin. The connecting rod changes and transmits the reciprocating motion of the piston to the continuously rotating crank pin during the working stroke, and vice versa during the other strokes.

Crankshaft. The crankshaft runs under the action of the piston through the connecting rod and crank pin located between crank webs or cheeks, and transmits work from the piston to the driven shaft. The parts of the crankshafts supported by and rotating in the main bearing, are called the journals.

Piston Rings. The piston rings lubricated with engine oil produce gas-tight/fuel-tight seal between the piston and the cylinder liners. They conduct heat away from the piston head to the cylinder block.

Intake Valves. Fresh air enters through this valve operated by a cam.

Exhaust Valve. The products of combustion of fuel after doing work on the piston are removed via this valve. These valves (*intake valves and exhaust valves*) are mounted either in the cylinder block or the cylinder block.

Fly Wheel. It takes care of the fluctuations or the cyclic variations in speed. It stores energy during the power stroke, and releases during the other strokes; thus giving a fairly constant output torque.

Spark Plugs. This is a device used for delivering electrical current from an ignition system to the combustion chamber of a spark-ignition engine, to ignite the compressed fuel/air mixture by an electric spark, while containing combustion pressure within the engine.

The sequence of events in a typical four-stroke internal combustion engine; whether it is spark ignition or compression ignition engine, are discussed below;

Suction Stroke. The inlet valve remains open and the fuel and air are drawn in an Otto engine.

Compression Stroke. Both the inlet valve and the exhaust valve remain closed. The mixture of air and fuel is compressed and thus negative work is done.

Power Stroke. Both the inlet valve and the exhaust valve remain closed. Due to ignition by the spark plug, the fuel burning takes place, and energy is released. During the power stroke or the expansion stroke, positive work is done, i.e., work is done by the gases.

Exhaust Stroke. The exhaust valve remains open and the inlet valve is closed. The products of combustion, after expanding during power stroke are pushed out through the exhaust valve, during exhaust stroke. Then, the cycle repeats itself. In spark ignition petrol engine, during the suction operation, a mixture of air and fuel (petrol) is charged into the cylinder. The carburetor is a device for atomizing and vaporizing the fuel and mixing it with air in varying proportions to suit the changing operation conditions in the engine. This process of breaking up and mixing the petrol with air is called *carburetion*.

Vaporization means the change of phase of the liquid fuel to vapour phase. Atomization, on the other hand, means, the reduction of the fuel to fine and tiny particles by mechanical breaking up process. It would be desirable to pass on the fuel in completely vaporized phase mixed with air, in desired proportion, to the engine cylinder, through the carburetor; but in the intake manifold, complete vaporization is, however, not obtainable. The heated intake manifolds do vaporize the finely atomized fuel to some extent. But the vaporization is normally not complete until the end of the compression stroke after the heat of compression is applied. The theoretically correct mixture of air and petrol is approximately 15 : 1. The uniform supply of such mixture would result in burning without leaving excess of air or fuel. But it is difficult to get such a mixture in actual practice. When there is too little air, some of the fuel goes unburnt or simply charred to carbon. When there is too much air in the mixture, it burns slowly and erratically, and power is lost. There is, however, a range of mixtures between which combustion will take place. The lower limit is approximately 7 : 1 to 10 : 1. This mixture is barely explosive. The upper limit is approximately 20 : 1. This mixture burns irregularly. These limits will also vary with the characteristics of the fuel, the shape of the combustion space, and the temperature and pressure of the combustion space.

MATERIAL AND METHOD

Engine performance is an indication of the degree of success with which it does its assigned job, i.e., conversion of the chemical energy contained in fuel into the useful mechanical work. In evaluation of engine performance, certain basic parameters are chosen and the effects of various operating conditions, design concepts and modifications on these parameters are studied. The basic parameters are delineated below:

- Power and Mechanical Efficiency
- Mean Effective Pressure and Torque
- Specific Output
- Volumetric Efficiency
- Fuel-Air Ratio
- Specific Fuel Consumption
- Thermal Efficiency and Heat Balance
- Exhaust Smoke and other Emissions
- Specific Weight

RESULTS AND DISCUSSION

Power and Mechanical Efficiency

Indicated Power (I. P.): The total power developed by combustion of fuel in the combustion chamber is called indicated power.

$$\text{I.P.} = \frac{nP_{mi}\,LANk\ x\ 10}{6}\ \text{kW}$$

where, n = Number of cylinders

P_{mi} = Indicated mean effective pressure, (bar)

L = Length of stroke, (m)

A = Area of piston, (m^2), and

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

Brake Power (B. P.): The power developed by an engine at the output shaft is called the brake power.

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

where, N = Speed in r.p.m., and

T = Torque in Nm

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

i.e., F.P. = I.P. – B.P.

The ratio of B.P. to I.P. is called mechanical efficiency

i.e., Mechanical efficiency, $\eta_{mech} = \frac{B.P.}{I.P.}$

Mean Effective Pressure and Torque

This is defined as hypothetical pressure which is thought to be acting on the piston throughout the power stroke. If it is based on I.P., it is called indicated mean effective pressure ($I_{m.e.p}$ or p_{mi}), and if based on B.P., is called brake mean effective pressure ($B_{m.e.p}$ or p_{mb}). Similarly, frictional mean effective pressure ($F_{m.e.p}$ or p_{mf}) can be defined as:

$F_{m.e.p} = I_{m.e.p} - B_{m.e.p}$

The torque and mean effective pressure are related by the engine size. Since the power (P) of an engine is dependent on its size and speed, therefore, it is not possible to compare engine on the basis of either power or torque. Mean effective pressure is the true indication of the relative performance of different engines.

Specific Output

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

Specific Output = $\frac{B.P.}{A \ x \ L}$

= Constant x p_{mb} x r.p.m.

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

Volumetric Efficiency

It is defined as the ratio of the actual volume (reduced to N.T.P.) of the charge drawn in during the suction stroke to the swept volume of the piston. The average value of this efficiency is from 70 to 80 per cent, but, in case of supercharged engine, it may be more than 100 per cent, if air at about atmospheric pressure is forced into the cylinder at a pressure greater than that of air surrounding the engine.

Fuel-Air Ratio

It is the ratio of mass of 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 Stoichiometric fuel-air ratio required to burn the fuel supplied.

Specific Fuel Consumption (S.F.C.)

It is the mass of fuel consumed per kW developed per hour; and it is a criterion of economical power production.

i.e., s.f.c. = $\frac{\dot{m}_f}{B.P.}$ kg/kWh

Thermal Efficiency and Heat Balance

Thermal Efficiency: It is the ratio of indicated work done to energy supplied by the fuel.

If $\dot{m}_f$ = Mass of fuel used in kg/sec., and

C = Calorific value of fuel (lower),

The indicated thermal efficiency (based on I.P.),

$\eta_{th\,(I)} = \frac{I.P.}{\dot{m}_f \ x \ C}$

and brake thermal efficiency (based on B.P.)

$\eta_{th\,(B)} = \frac{B.P.}{\dot{m}_f \ x \ C}$

Heat Balance: The performance of an engine is generally given by heat balance sheet. To draw a heat balance sheet for I.C. engine, it is run at constant load. Indicator diagram is obtained with the help of an indicator. The quantity of fuel used in a given time and its calorific value, the amount, inlet and outlet temperatures of cooling water and the weight of the exhaust gases are recorded. After calculating I.P. and B.P., the heat in different items is found as follows:

Heat absorbed in I.P.

Heat equivalent of I.P. (per minute) = I.P. x 60 kJ

Heat taken away by cooling water

If m_w = Mass of cooling water used per minute,

t_1 = Initial temperature of cooling water, and

t_2 = Final temperature of cooling water

Then, heat taken away by water = $m_w \times c_w \times (t_2 - t_1)$

Where c_w = Specific heat of water

Heat taken away by exhaust gases

If m_e = Mass of exhaust gases (kg/min)

c_{pg} = Mean specific heat at constant pressure

t_e = Temperature of exhaust gases, and

t_r = Room (or boiler house) temperature

Then, heat carried away by exhaust gases = $m_e \times c_{pg} \times (t_e - t_r)$

It must be noted that the mass of exhaust gases can be obtained by adding together mass of fuel supplied and mass of air supplied.

The heat balance sheet from the above analysis can be drawn using the template as shown in Table 1.

Table 1: Typical Heat Balance Sheet

Item	kJ	Percent
Heat Supplied by Fuel	…	…
Heat absorption in I.P Heat taken away by cooling water Heat carried away by exhaust gases Heat unaccounted for (by difference)	… … … …	… … … …
Total	…	…

Exhaust Smoke and other Emissions

Smoke is an indication of incomplete combustion. It limits the output of an engine if air pollution control is the consideration. Exhaust emissions have, of late, become a matter of grave concern. With the enforcement of legislation on air pollution in many countries, it has become necessary to view them as performance parameters.

Specific Weight

It is defined as the weight of the engine in kg for each B.P. developed. It is an indication of the engine bulk.

Basic Measurement: To evaluate the performance of an engine, the following basic measurements are usually undertaken;

- Speed
- Fuel consumption
- Air consumption
- Smoke density
- Exhaust gas analysis
- Brake power
- Indicated power and friction power
- Heat going to cooling water
- Heat going to exhaust

Some of these considerations are discussed below.

Measurement of Speed: The speed may be measured by:

a. Revolution counters
b. Mechanical tachometer
c. Electrical tachometer

Fuel Measurement: The fuel consumed by an engine can be measured by the following methods:

a. Fuel flow method
b. Gravimetric method
c. Continuous flow meters

Measurement of Air Consumption: The air consumption can be measured by the following methods:

a. Air box method
b. Viscous-flow air meter

Measurement of Exhaust Smoke*:* The following smoke meters are used:

a. Bosch smoke meter
b. Hatridge smoke meter
c. PHS smoke meter

Measurement of Exhaust Emission*:* Substances which are emitted to the atmosphere from any opening downstream of the exhaust part of the engine are termed as exhaust emissions. Some of the more commonly used instruments for measuring exhaust components are given below:

a. Flame ionization detector
b. Spectroscopic analyzers
c. Gas chromatography

Measurement of B. P.: The B.P. of an engine can be determined by a brake of some kind applied to the brake pulley of the engine. The arrangement for determination of B.P. of the engine is known as dynamometer. The dynamometers are classified into the following two categories:

a. Absorption dynamometer
b. Transmission dynamometer

CONCLUSION

An internal combustion engine (ICE) is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine, the expansion of the high-temperature and high-pressure gases produced by combustion applies direct force to some component of the engine. The force is applied typically to piston and moves the component over a distance; thus, transforming chemical energy into useful mechanical energy. The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines; along with variants such as the six-stroke piston engine, and the *Wankel* rotary engine.

A second class of internal combustion engine use continuous combustion: gas turbines, jet engines, and most rocket engines. Each of these is internal combustion engine on the same principle as previously described. Firearms are also forms of internal combustion engine. ICEs are usually powered by energy-dense fuels such as gasoline (petrol) or diesel, liquids derived from fossil fuels. While there are many stationary applications, most ICEs are used in mobile applications, and are dominant power supply for vehicles such as cars, aircraft, and boats. Typically, an ICE is fed with fossil fuels like natural gas or petroleum products such as gasoline, diesel fuel or fuel oil. There is a growing usage of renewable fuels like biodiesel for compression ignition engines, and bioethanol or methanol for spark ignition engines. Hydrogen is, sometimes, used and can be obtained from either fossil fuels or renewable energy.

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