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# Experimental Simulation and Optimization of Performance of Four Stroke Spark Ignition Injector Engine

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**Abstract**— An engine test experiment was carried out using engine test bed. The test was performed within a speed range of 1500 – 4500 rpm. The performance of an engine whose basic design parameters are known can be predicted with the assistance of simulation program into the less time, cost and near value of actual. The essence of this work is to develop a computer simulation programs for the analysis of engine performance parameters of four stroke spark ignition engine before embarking on full scale construction. They will ensure that only optimal parameters are in the design and development of an engine and also allow checking and developing the design of the engine and its operation alternatives in an inexpensive way and less time, instead of using experimental method which requires costly research test beds. The optimal values obtained for engine test experiment are; sfc is 0.2902kg/kwh, efficiency is 28.80% and a/f is 16.50. For the designed window simulator, optimal values are; sfc is 0.2838kg/kwh, efficiency is 28.69% and a/f is 15.53. From the results obtained, it could be seen that the simulator results show good agreement with experimental results, the models are therefore said to be verified.

**Index Terms**— Engine performance, Engine test, Injector engine, Optimization, Performance parameter, Simulation, Spark ignition

## 1 Introduction

THe design of an internal combustion (IC) engine is a complex compromise between performance, fuel economy and emissions. These three factors are interrelated and they cannot be simultaneously optimized. By making an engine more efficient, one or more of these factors could be increased without significantly compromising the others. Thus, studies related to internal combustion engine have been vigorously investigated in spacious areas such as fuel injection development, exhaust emission treatment and especially the engine operation can have low emissions and high efficiency [1], [2] to achieve the targeted values. Many researchers have been taken to improve fuel injection characteristics by examining available problems and developing new systems. Understanding the nature of the flows and combustion in internal combustion engines are important for improving engine performance [3].

This research focuses on simulation and optimization of performance of four stroke spark ignition engine. Performance evaluation of automotive engines is of great importance for their economic operation. The method or criteria for assessing the engine performance include the determination of engine power, engine efficiency, fuel consumption, considering the engine stroke, engine speed, mean effective pressure and bore-all of these affect the horse-power, engine efficiency and its performance.


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Simulation and optimization are important domains which attract many researchers from several fields and disciplines [4]. In recent years, extensive research has been conducted in the area of simulation to model large complex systems and understand their structures and behaviors. At the same time, a variety of design principles and approaches for computer based simulation has evolved.

Engine tests experiment require costly research engine test beds and skilful technicians to run them. In order to reduce the cost and time of engine design and development, it, therefore, becomes necessary to develop a computer simulation program that will describe and quantify engine performance process. This process is enhanced by using a computer to simulate and optimize engine performance before embarking on full scale construction. It will ensure that only optimal parameters are in the design and development of an engine. This would reduce the cost and time of engine design and development to a minimum.

This research work developed a computer simulation program for simulating and optimizing engine performance before embarking on full scale construction. The developed window simulator and experimental results were validated and engine performance parameters using the developed window simulator were equally computed. This research work is narrowed down to four stroke spark ignition injector engine. MATLAB toolbox library equation was used in the development of the simulation models. Optimization was carried out on each of air-fuel ratio, SFC and thermal efficiency.

## 2 Engine Performance Test Experiment Method

### 2.1 Engine Test Rig for the Study

An engine rig [5] consisting of an engine, dynamometer, control unit, cooling system and fuel meters was used for the experimental study. The engine specifications are as follows:

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Number of cylinder = 4, Number of strokes = 4, Bore diameter =80.98mm = 0.081m, Length of stroke =62.99mm = 0.063m, Compression = 9:1, Calorific value of fuel = 44,000kj/kg, Specific gravity of petrol =0.74, Universal engine rig: petrol.

Engine performance test rig was used for the study of torque, specific fuel consumption, power, brake mean effective pressure, air fuel ratio and efficiency. A diagram of the test rig is shown in Fig.1.

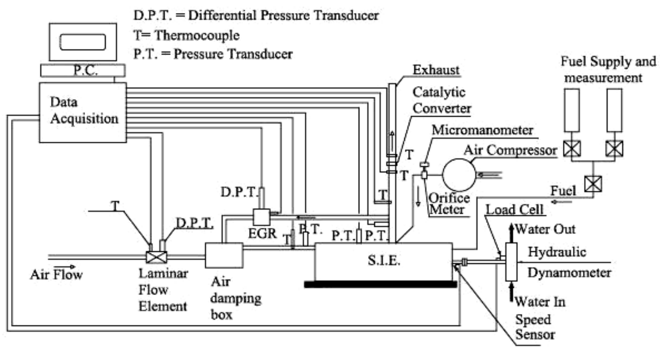


Fig. 1. Engine Performance Test Rig.

## 2.2 Test Procedure

The engine load was gradually reduced by turning the dynamometer hand wheel anticlockwise, having released the locking peg. The engine speed was allowed to rise to 4500rpm.The load on the engine at this speed was measured by adjusting the load on the spring balance by turning the hand wheel above the torque motor. Balance is achieved by adding or removing cast iron weights and by then aligning the pointers having slackened off the clamp. [6] The details of the fuel consumption were determined by obtaining the accurate time taken to consume 100cc of fuel, a stop watch was used for the timing.

In order to consume fuel in the pipette, the main fuel supply was turned off by means of the valve. The time taken for the level of fuel in the pipette to fall from the graduation lines above and below the 100cc vessel was recorded. After completion of the test, the main fuel line was reconnected by turning the valve, this will result in the pipette refilling for further tests. If the main fuel line is not reconnected, air will enter the fuel system necessitating bleeding before further successful running.

The speed was reduced in steps of 500rpm, by increasing the dynamometer load, by means of the dynamometer hand wheel. The dynamometer was relieved by adjusting of the torque meter hand wheel. The total torque was calculated by adding the torque meter reading to the effective torque due to the weights. The test was performed within a speed range of 1500-4500 rpm. Graphs of engine speed versus sfc, thermal efficiency, MEP and A/F ratio was plotted.

## 2.3 Experimental Calculation

### 2.3.1 Measurement of Torque (Nm),T

The engine torque is measured by the hydraulic dynamometer by a combination of spring balance and added weights. The total effective load on the torque arm is the sum of the added weights plus the spring balance reading. Generally, the value of torque, T is the total weight applied multiplied by the torque arm length, L: $Torque, T = [(W+S)/1000]L$ **(1)**

Where T = Torque (Nm),(W+S) = total weight applied, Newton, L = torque arm Length or radius arm (m). For test number one, torque, $T_1$ = (w+s) = 70.5Nm

### 2.3.2 Measurement of Power (kW)

The power or rate of doing work is measured in watts (Nm/sec) or kilowatts and is defined as the torque multiplied by the angular velocity; Power (p) = Tω (2)

Where T = torque, ω = Angular speed = (2πN)/60, N = speed in rpm. For test number one, $P_1 = 33.2kw$.

### 2.3.3 Fuel Consumption (kg/h)

Having timed the consumption of a control volume of fuel, the fuel consumption in kg/h may be calculated as follows; for a control volume of 100cc the consumption per second is given by $100/t$. Where; t is the measured time.

$$\text{Fuel consumption} = V/T \quad (3)$$

Fuel consumption may then be converted to g/s by multiplying by the specific gravity, which is 0.74 for 95 octane petrol. Weight of fuel per second = (100x0.74)/t and weight of fuel in kg per hour = (100x0.74x3600)/(tx1000). For test number one, $t_1$ = 26.4, therefore fuel consumption is = 10.07kg/h.

### 2.3.4 Specific Fuel Consumption (kg/kwh)

An important characteristic of an internal combustion engine is the specific fuel consumption which relates the thermal efficiency of the engine. This is defined as the weight of fuel required to generate each kilowatts hour of energy;

$$Sfc = weight\ of\ fuel/power \text{ (kg/kwh)} \quad \textbf{(4)}$$

For test number one, $Sfc_1 = 10.07/33.22 = 0.303kg/kwh$

### 2.3.5 Mass flow Rate of Fuel ($M_f$)

This is the quantity of fuel consumed in kg/s or weight of fuel supplied in kg per second

$$M_F = (Volume\ in\ litre\ x\ Specific\ gravity)/(time\ \ in\sec x\ 1000) \quad \textbf{(5)}$$

For test number one, $M_{F1} = (100\ x\ 0.74)/(26.4\ x\ 1000) = 0.002803kg/s$.

### 2.3.6 Efficiency (η)

This is the ratio of brake power to energy supplied by the fuel;

$$\eta = BP/(M_f\ x\ Calorific\ value) \quad \textbf{(6)}$$

For test number one, $\boldsymbol{\eta}_1 = (33.22)/(0.00280\ x\ 44200) = 26.8\%$

### 2.3.7 Brake Mean Effective Pressure

Mean effective pressure is defined as hypothetical pressure which bis thought to be acting on the piston throughout the power stroke. If it is based on brake power it is called brake mean effective pressure.

$$B.M.E.P = bp/LAn = (60000\ x\ BP)/LAnk \quad \textbf{(7)}$$

For test number one, B.M.E.$P_1$ =

$$\frac{60000\times 2\times 33.2}{0.063\times 3.14\times 0.006561\times 4500\times 100000} = 6.82bar$$

## 3 Results and Analysis

TABLE 1
RESULTS OBTAINED FOR ENGINE TEST EXPERIMENT

| Test S/N | Speed (Rev/Min) | Weight, W (Nm) | Spring balance,S, (Nm) | Torque (W+S) (Nm) | Brake power (kw) | Time for 100cc (sec) | Air/Fuel Ratio | S.F.C kg/kwh | Thermal efficiency (%) | M.E.P Bar |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4500 | 30 | 40.5 | 70.5 | 33.22 | 26.4 | 13.8 | 0.304 | 26.8 | 27.30 |
| 2 | 4000 | 30 | 46 | 76 | 31.83 | 29.1 | 14.55 | 0.288 | 28.3 | 29.43 |
| 3 | 3500 | 30 | 50 | 80 | 29.32 | 32.1 | 15.2 | 0.283 | 28.8 | 30.98 |
| 4 | 3000 | 30 | 53 | 83 | 26.08 | 36.1 | 15.89 | 0.283 | 28.8 | 32.15 |
| 5 | 2500 | 30 | 56 | 86 | 22.5 | 40.2 | 15.08 | 0.295 | 27.7 | 33.28 |
| 6 | 2000 | 30 | 56.5 | 86.5 | 18.11 | 46.2 | 14.78 | 0.318 | 25.6 | 33.49 |
| 7 | 1500 | 30 | 52.5 | 82.5 | 12.96 | 62.4 | 15.95 | 0.329 | 24.7 | 31.95 |

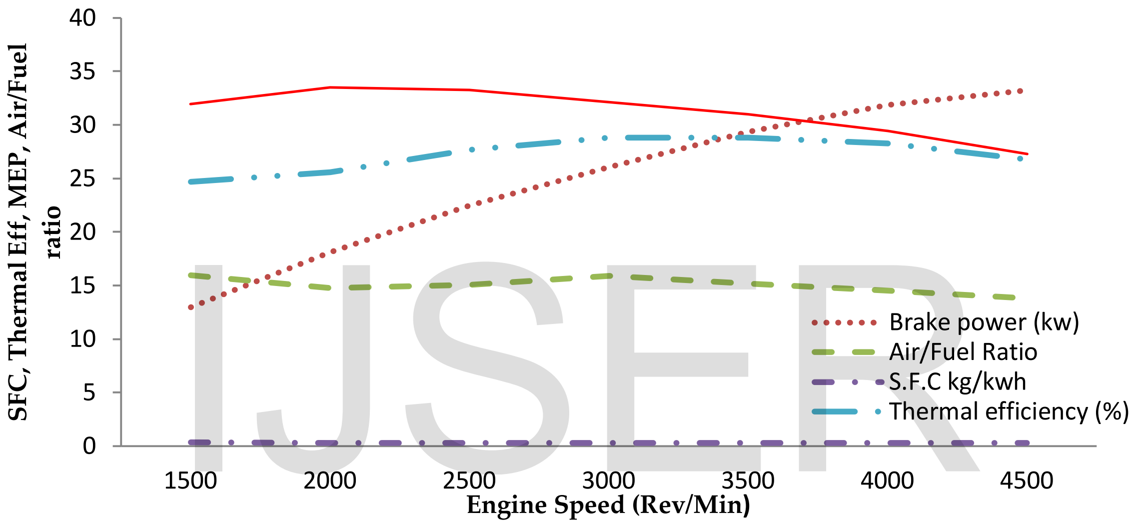


Fig. 2. A plot of engine speed in rpm against sfc, thermal efficiency, mep and air/fuel ratio for experimental results

Fig.2 is the plot of engine speed in rpm against sfc, thermal efficiency, mep and A/F ratio for experimental results. It could be seen from the engine performance curves that there is no need for optimizing brake power and mean effective pressure since linear approximation could give accurate result. The performance parameters that are eligible for optimization are a/f, sfc and efficiency.

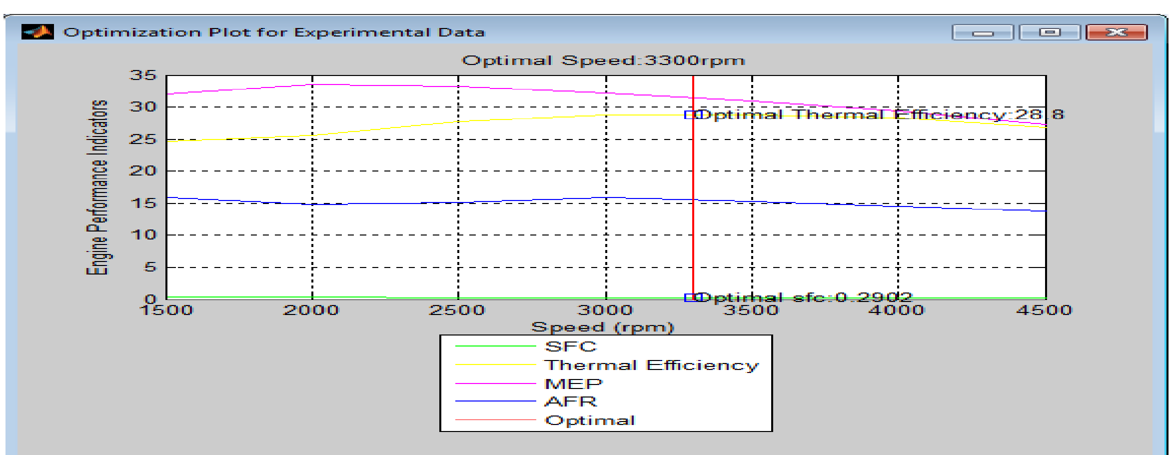


Fig. 3. Plot of engine speed in rpm against sfc, thermal efficiency, mep and a/f ratio for experimental results

Fig.3 is the plot of engine speed in rpm against sfc, thermal efficiency, mep and A/F ratio for experimental results. From the plot it could be seen that sfc has an optimal value of 0.2902kg/kwh, thermal efficiency has an optimal value of 28.8% and a/f ratio is 16.5

### 3.1 Software Package

This section presents a computer software package developed for simulation and optimization of engine performance. This entailed programming the fundamental equations developed to describe and evaluate engine performance and optimization into one model [7]. MATLAB curve fitting toolbox library equations were used in the development of sfc, thermal efficiency, mep and a/f ratio simulation models. Interaction is provided in this package which is user friendly and lends itself quite readily to change in the design and operation process.

The program was written in MATLAB and will run on any computer that has MATLAB software. The MATLAB language was chosen because it is widely available, and most engineers/students are already familiar with the language. The software package is designed such that it can be used as a teaching and research tool. The design of the package involved a number of different steps as shown in the window simulator.

The steps are: Select task then click on simulation to run. The tasks are engine performance mathematical models, compare developed models and experimental results, engine performance optimization and calculate engine performance parameters. The tasks are performed one at a time, select task then click on simulation to run. After the simulation you should click on reset before selecting any other task to be performed. At the end of the tasks, you should click on close in order to close the window simulator. The program is relatively short; therefore execution time is a minor concern. The window simulator screen display for simulation and optimization of engine performance showing the instruction to be followed, tasks to be performed, input parameter, output parameters and the control units is shown in fig.4.

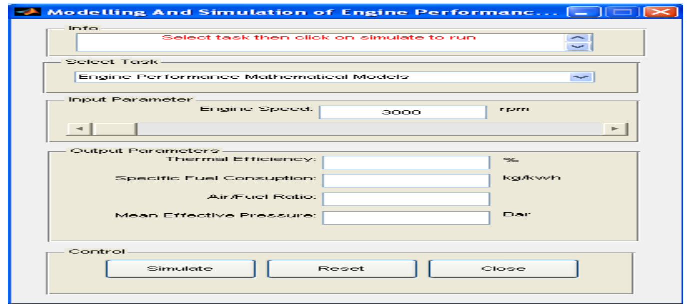


Fig. 4. Sample window of engine performance simulator

Fig.4 is the engine performance simulator designed for this work using MATLAB. It is interactive, graphic and user friendly window which was designed for use in analyzing engine performance. The designed simulator will be used in optimization and calculation of engine performance parameters.

TABLE 2
Results Obtained for Modeling and Simulation of Engine Performance

| Engine speed rpm | SFC kg/kwh | Thermal Efficiency(%) | MEP (bar) | Air/fuel ratio |
|---|---|---|---|---|
| 4500 | 0.302 | 26.99 | 27.11 | 13.81 |
| 4000 | 0.290 | 28.16 | 29.49 | 14.49 |
| 3500 | 0.264 | 28.67 | 31.25 | 15.36 |
| 3000 | 0.286 | 28.54 | 32.42 | 15.68 |
| 2500 | 0.295 | 27.76 | 32.99 | 15.24 |
| 2000 | 0.311 | 26.33 | 32.97 | 14.72 |
| 1500 | 0.334 | 24.25 | 32.34 | 15.96 |

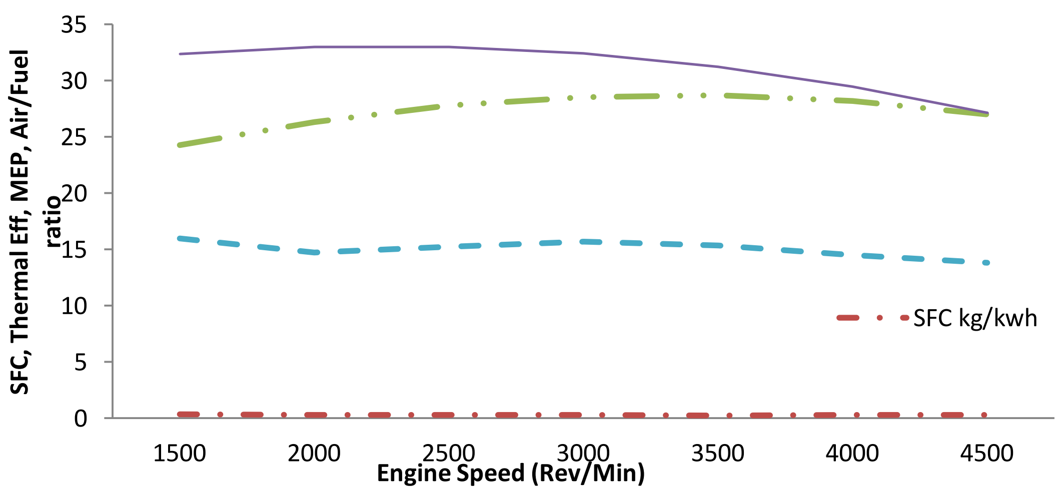


Fig.5.A plot of engine speed in rpm against sfc, thermal efficiency, mep and air/fuel ratio for simulator results.

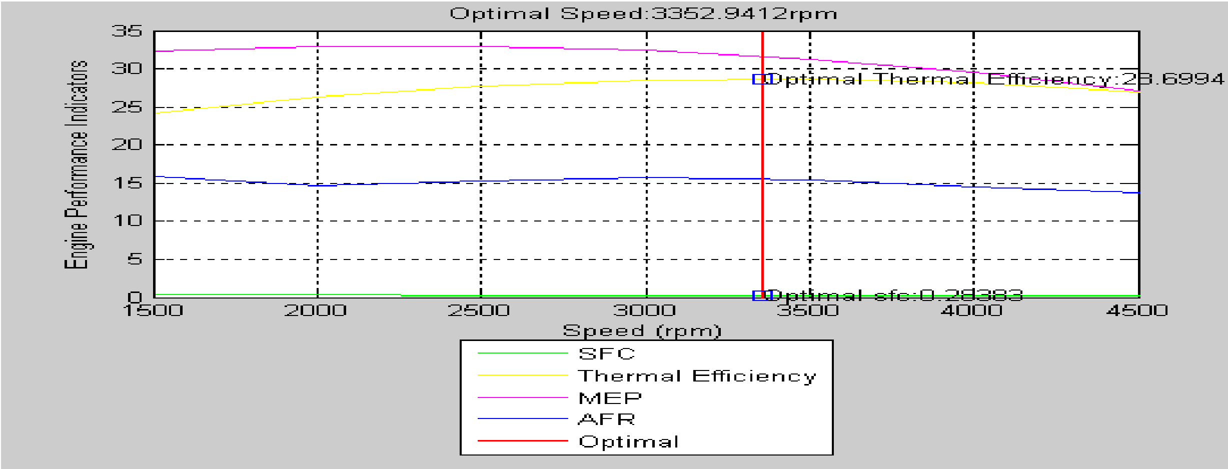


Fig.6. An optimization plot of engine speed in rpm against sfc, thermal efficiency, mep and A/F ratio for designed simulator.

The fig.6 is the optimization plot of engine speed in rpm against sfc, thermal efficiency, mep and A/F ratio for the designed simulator. From the plot it could be seen that sfc has an optimal value of 0.2838kg/kwh, thermal efficiency has an optimal value of 28.69%, and air/fuel ratio is 15.53

TABLE 3

Comparison of optimum values obtained for experimental and window simulator and mathematical model results

| | Sfc. (kg/kwh) | Thermal efficiency (%) | A/F ratio |
|---|---|---|---|
| Experimental results | 0.2902 | 28.8 | 16.50 |
| Window simulator results | 0.2838 | 28.69 | 15.53 |
| Mathematical models results[8] | 0.2833 | 28.77 | 20.75 |

From table 3, it could be seen that the optimum values obtained for the engine test experiment, the developed window simulator and mathematical model results[8] are in close agreement, and such the model is said to be verified.

### 3.2. Verification of the engine performance simulation models developed

Experimental data obtained from the engine performance test experiment (table 1) were used to validate or compare the developed models. A plot of engine speed in rpm against sfc, thermal efficiency, mep and A/F ratio is shown in fig.7 for experimental results and developed models.

TABLE 4

**Experimental and simulated results obtained**

| **Experimental data** | | | | | **Simulated data** | | | |
|---|---|---|---|---|---|---|---|---|
| Speed | SFC | Efficiency | MEP | A/F ratio | SFC | Efficiency | MEP | A/F ratio |
| 4500 | 0.304 | 26.8 | 27.30 | 13.8 | 0.302 | 26.99 | 27.11 | 13.81 |
| 4000 | 0.288 | 28.3 | 29.43 | 14.55 | 0.290 | 28.16 | 29.49 | 14.49 |
| 3500 | 0.283 | 28.8 | 30.98 | 15.2 | 0.284 | 28.67 | 31.25 | 15.36 |
| 3000 | 0.283 | 28.8 | 32.15 | 15.89 | 0.286 | 28.54 | 32.42 | 15.68 |
| 2500 | 0.295 | 27.7 | 33.28 | 15.08 | 0.295 | 27.76 | 32.99 | 15.24 |
| 2000 | 0.318 | 25.6 | 33.49 | 14.78 | 0.311 | 26.33 | 32.97 | 14.72 |
| 1500 | 0.329 | 24.7 | 31.95 | 15.95 | 0.334 | 24.25 | 32.34 | 15.96 |

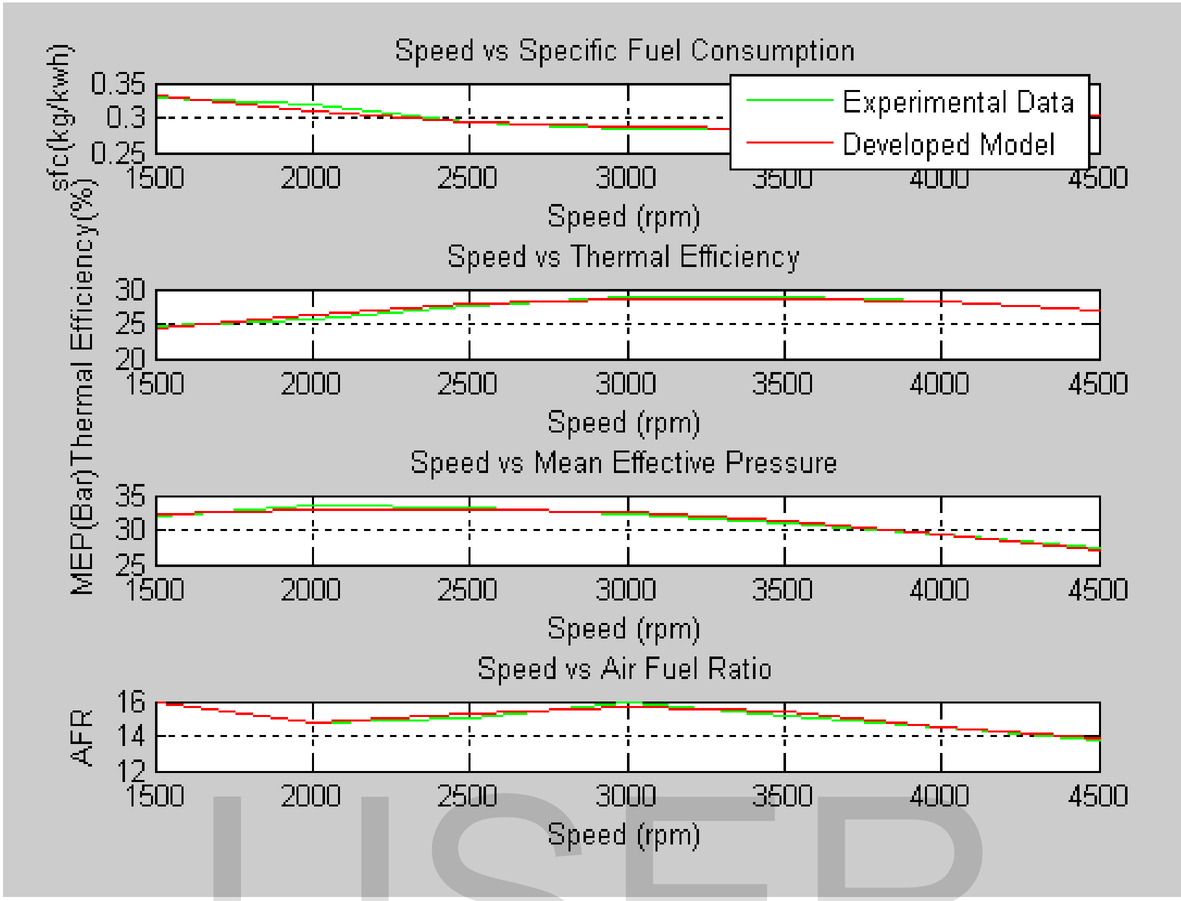


Fig.7. A plot of engine speed in rpm against sfc, thermal efficiency, mep and A/F ratio for experimental and simulator results

From fig.7 and table 4, it could be seen that simulated results are in close agreement with the experimental results for the whole models developed, (specific fuel consumption, thermal efficiency, mean effective pressure and air-fuel ratio) the models are said to be verified.

## 4. CONCLUSION

The simulated data from the simulation run have been compared with the experimental data. If simulated data are in close agreement with the experimental data, the model is said to be verified. From table 4 and fig.7, it could be seen that simulated results are in close agreement with the experimental results for the whole models developed, (sfc, therm. Eff., mep and air-fuel ratio), thus the models are said to be verified. From table 3; the optimum values obtained for the experimental result, are: sfc is 0.2902kg/kwh, thermal efficiency is 28.8% and Air/fuel ratio is 16.5. The optimum values obtained for the simulation results are: sfc is 0.2838kg/kwh, thermal efficiency 28.69% and air/fuel ratio 15.53. It could be seen that the optimum values for experimental results and simulation results are in close agreement, and validated with the mathematical results[8] and the models are said to be verified also.

A window simulator has been designed to be used in analyzing the performance of four stroke spark ignition engines. Comparison between the simulator's results and experimental results agree thus pointing to accuracy of this work. It must be pointed out that the results of the experiment for various engine performance correlate closely with the MATLAB simulation. Based on the achievements, it can be concluded that this research work has attained its set objectives.

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