ADAMA SCIENCE AND TECHNOLOGY UNVERSITY

School of Mechanical, Chemical and Materials Engineering

COMPUTER SIMULATION OF SPARK IGNITION ENGINE CYCLE PROCESS AND PERFORMANCE ANALYSIS

A thesis submitted to Adama Science and Technology University in partial fulfillment of the requirements for the award of the degree of

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by

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APPROVED BY BOARD OF EXAMINERS

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled “**computer simulation of spark ignition engine cycle process and performance analysis** ” in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from November 2017 to September 2018 under the supervision of Melesse Haile(Asst. Professor),Department Mechanical systems and Vehicle Engineering department, Adama Science and Technolog University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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Student

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name of advisor	Signature	Date
Melesse Haile (Asst. Professor)	-------------------------	-----------------

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ACRONYMS ABBREVIATIONS AND SYMBOLS

IMEP	Indicated mean effective pressure
BMEP	Brake mean effective pressure
BDC	Bottom dead center
IC	Internal combustion
TDC	Top dead center
SI	Spark ignition
C	Compression ignition
BSFC	Brake specific fuel consumption
P_b	Brake power
T_b	Brake torque
R	Radius
Rc	Compression ratio
R_{sd}	Ratio of stroke to bore
R_{rl}	Ratio of crank radius to con-rod length
S	Stroke
T	Temperature
U	Internal energy
V	Velocity or Speed or Cylinder volume
V_c	Clearance volume
V_d	Displacement volume
V_t	Total volume
W	Work transfer
X	Mass fraction
X_r	Residual mass fraction
Θ	Crank angle
ρ	Density
M	Mass
M_r	Residual mass
N	Crankshaft rotational speed
P	Pressure or Power
η_m(ETA_m)	Mechanical efficiency

η_v(ETA_v)	Volumetric efficiency
η_{th}(ETA_th)	Thermal efficiency
η_c (ETA_c)	Combustion efficiency
Z_c	Number of cylinders
RHO_G	Density of Gasoline
QLHV_G	Lower Heating Value of Gasoline
M_m	Molar mass
M_a	Mass of air
a	Number of Carbon atoms in Gasoline
b	Number of Hydrogen atoms in Gasoline
m_f	Mass of fuel
A_p	Area of piston
X_p	Piston displacement
IVOBTDC	Intake valve open before tdc
IVOATDC	Intake valve open after tdc
SCBTDC	Start of combustion before tdc
DC	Duration of combustion
EVOBTDC	Exhaust valve open before tdc
EVCATDC	Exhaust valve closed after tdc
Q_{in}	Heat added to the cylinder

ABSTRACT

The main objectives of this paper is to do computer simulation of spark ignition engines cycle process, performance analysis and introduces the preliminary simulation regarding four stroke spark ignition engine. Improving the performance about inside combustion apparatus is certain of the principal worries concerning researchers. Experimental studies are more expensive than computational techniques these allows us to obtain all the required data for the cylinder, which could not be measured.An arbitrary heat release formula was used to predict the cylinder pressure, which was used to find the indicated work done. The heat transfer of the cylinder, friction and pumping losses also were taken into account to predict the brake mean effective pressure, brake thermal efficiency and brake specific fuel consumption. Most on the parameters as executing have an effect on the overall performance over four stroke spark ignition engines, such as pressure, temperature and volume variation with crank angle theta. In addition to these the effect of engine brake power (Pb), engine torque (Tb), specific fuel consumption (bsfc) and engine kinematics to these engine performance is also studied. The use of a real combustion curves has a profound influence of the similarity in the pressure–volume profile to that sees for the real engine. To complete the research different methodology was used for collecting data from literature review and other document, C++ programing is developed, thermodynamics and performance analysis is done for these RE Bajaj engine model and finally simulation is done by the help of programing and Microsoft excel. In this computer program was tried to determine engine performance, engine capacity and engine kinematics of the selected engine. From the results were tried to study and demonstrate real PV diagrams and variation of different thermodynamic properties as much as possible. And finally comparisons of these results to experimental test outcomes were done. Generally it can conclude that computer simulation of the above variables leads to the good results than theoretical ones.

Keywords: *simulation, spark ignition, thermal efficiency, fuel consumption.*

CHAPTER ONE

INTRODUCTION

1.1 Background

Power plant or power unit of an automobile is that component or part which produces power to drive the automobile. It is generally in the form of an internal combustion engine running on petrol or diesel. In some cases, it can be a gas turbine or steam engines. These are called external combustion engines. However, steam engines are now obsolete and therefore not used for driving any vehicle. In case of an internal combustion engine (IC engines) combustion (burning) of fuel to air takes place inside the engine cylinder [1].

The operating cycle of an I.C. engine may be completed either by the two strokes or four strokes of the piston. Thus, an engine which requires two strokes of the piston or one complete revolution of the crankshaft to complete the cycle is known as two stroke engines. An engine which requires four strokes of the piston or two complete revolutions of the crankshaft to complete the cycle is known as four stroke engines. The two stroke petrol engines are generally employed in very light vehicles such as scooters, motor cycles and three wheelers. The two stroke diesel engines are generally employed in marine propulsion [1].

The four stroke petrol engines are generally employed in light vehicles such as cars, jeeps and also in aero planes. The four stroke diesel engines are generally employed in heavy duty vehicles such as buses, trucks, tractors, diesel locomotive and in the earth moving machinery[1].

Therefore, for design and development stage, an engineer would design an engine with certain aims in his mind. The aims may include the variables like indicated power, brake power, brake specific fuel consumption, exhaust emissions, cool of engine, maintenance free operation etc. The other task of the development engineer is to reduce the cost and improve power output and reliability of an engine [1].

Understanding the nature of the flows and combustion in internal combustion engines is important to improving engine performance. The flows in IC engines can be characterized by a swirl, tumble and compression in the cylinder. This flow motion has a strong influence on the engine combustion process and hence on the engine emission of pollutants. Recently simulation results by Computational Fluid Dynamics codes are used in the development and optimization of new engines by car manufacturers (automotive industry). The in-cylinder fluid motion in internal combustion engines is one of the most important factors of controlling the combustion process. Swirl and tumble are well known approaches from in-cylinder flow enhancement. Swirl and tumble are generated in the intake stroke as a result of the inlet port shape and orientations [6].

This thesis presents the Thermodynamics theory describing the main physical phenomena occurring inside a spark ignition four stroke (4S) internal combustion engines (ICE) while it is running at steady speed (constant revolutions per minute, rpm). The mathematical form of the Thermodynamic theory is developed and implemented numerically by way of a “Scilab” computer program. The result is an ICE computer simulation. This computer simulation may be used to obtain some fairly good estimates of engine performance in which the main effects of compression ratio, sparks timing, some aspects of valve timing, valve sizing, and fuel types, over a range of engine speeds[8].

Of course not every detail of ICE performance can be accounted for, but depending on the physical details incorporated and their relative importance, many of the most important performance characteristics can be determined to a reasonable degree of accuracy. This report does not deal with any structural or mechanical aspects of an ICE beyond those of the basic geometric features relevant to the containment and external manifestations of the Thermodynamics processes occurring in the engine. These thermodynamic processes are idealized to a certain degree in order to reduce the complexity at this stage of development of the engine simulation [8].

Computer simulations can be a powerful engineering tool that can help to understand the thermo physical and chemical processes that takes place in an IC engine without being forced to use possibly complicated and expensive measurement techniques [9].

Computer simulations research has unfortunately not yet reached a state where it completely describes all the processes that takes place in an IC engine. This is mainly due to the fact that it is a highly complex mechanical device which incorporates many, simultaneously interacting, thermo fluid and chemical processes [9].

1.2 Statement of the problem

An appropriate economic policy should concentrate on strengthening these processes of the country and easing the flow of information and technology between the main players- innovators, companies, state agencies, and financial institutions. Innovation and technology transfer are the key drivers of economic growth in today world economy [25].

Improving the performance of internal combustion engines is one of the major concerns of researchers. Experimental studies are more expensive than computational techniques these allows us to obtain all the required data for the cylinder, which could not be measured. In addition to that mostly there is no clear insight into complex systems. Knowing the nature of the flows and combustion in internal combustion engines is important to improve engine performance [6].

The flows in IC engines can be characterized by swirl, tumble and compression in the cylinder. By using computer simulation many of the most important performance characteristics can be determined to a reasonable degree of accuracy than calculating performance analysis of the engine without using computer simulation. For example without using computer simulation getting real engines cycle process of P-V diagram is very difficult, due to the performance analysis of the engine varies with respect to crank angle values varies. Especially from start of combustion (some amount of degree before TDC) to end of combustion (some amount of degree after TDC), the performance of the engine varies with each crank angle value varies. So that using computer simulation makes us to get more precise and accurate data. Generally to improve the above problems simulating an IC engine is necessary [6].

1.3 Objective of the study

1.3.1 **General objective**

The general objective of this thesis is computer simulation of four stroke spark ignition engine cycle process and performance analysis for RE Bajaj (three wheel) engine.

1.3.2 **Specific objectives**

- To do thermodynamics analysis of the SI Engine cycle process
- To do computer simulation of spark ignition engine cycle process
- To do performance analysis of four stroke spark ignition engine

- To do experimental tests
- To use Microsoft excel to state the data's on the form of graphs and tables

1.4 Significance of the study

This thesis or making simulation and performance analysis will help as an important method of analysis which is easily verified, communicated, understood. A simulation study has a vital role in technology transfer and innovation; furthermore it helps in understanding how the system operates. Across industries and discipline, simulation modeling provides valuable solutions by giving clear insights into complex systems. Furthermore to get more accurate or real engine cycle process in P-V diagram starting from intake valve opens to exhaust valve closed while crank angles varies using computer simulation is necessary, especially to get more accurate data from start of combustion to end of combustion using computer simulation is very useful. It can also be a valuable tool to run numerous tests and investigations of an engine without having to perform them in a test bench which can reduce development costs.

Computer simulations can also serve as a fast and cheap way to perform studies of future engine designs and concepts before a prototype is manufactured, reducing development costs further. Generally making simulation saves money and time, visualization these helps to understand concepts and ideas to be more easily verified, communicated, it also can increase accuracy because a simulation model can capture money more detail than an analytical model and simulation modeling solves real world problems safely and efficiently. These help us to understanding and know the flows and each processes that occur to the cylinder. This study will also act as a base of future researchers[6].

1.5 Beneficiary

Automotive industry and company, society, Researcher in the field, and country as a whole get benefitted.

1.6 Scope of the study

This study is focusing on computer simulation of spark ignition engine cycle process for three wheels vehicles. It includes mathematical and thermodynamic analysis and modeling, developing computer programing, performance analysis and experimental test.

1.7 Limitation

The researcher aware that it would have been interest if the research includes computer simulation and performance analysis of numerous engine type and models. But because of time and other resource constraints, the work is limited only three wheels internal combustion naturally aspirated single cylinder four stroke spark ignition engines.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introductions

A Heat Engine is a ‘work developing’ machine that can convert the thermal (heat) energy into mechanical energy (power). The mechanical energy (power) is used to propel a ‘motor vehicle’. Internal Combustion (IC) Engine is one kind of Heat Engine, where combustion is taking place inside the engine. (Example:- a Reciprocating IC Engine).There are two main types of internal combustion engines: spark ignition (SI) engines (petrol or gasoline engine) and Compression ignition (CI) engines (diesel engine). Internal combustion engines are, more popularly, known as ICE because the combustion of fuel takes place inside the engine block itself. After combustion of fuel, much heat energy is generated. This is converted into mechanical energy. The general classification of heat engine can be seen from below figure 2.1 [5].

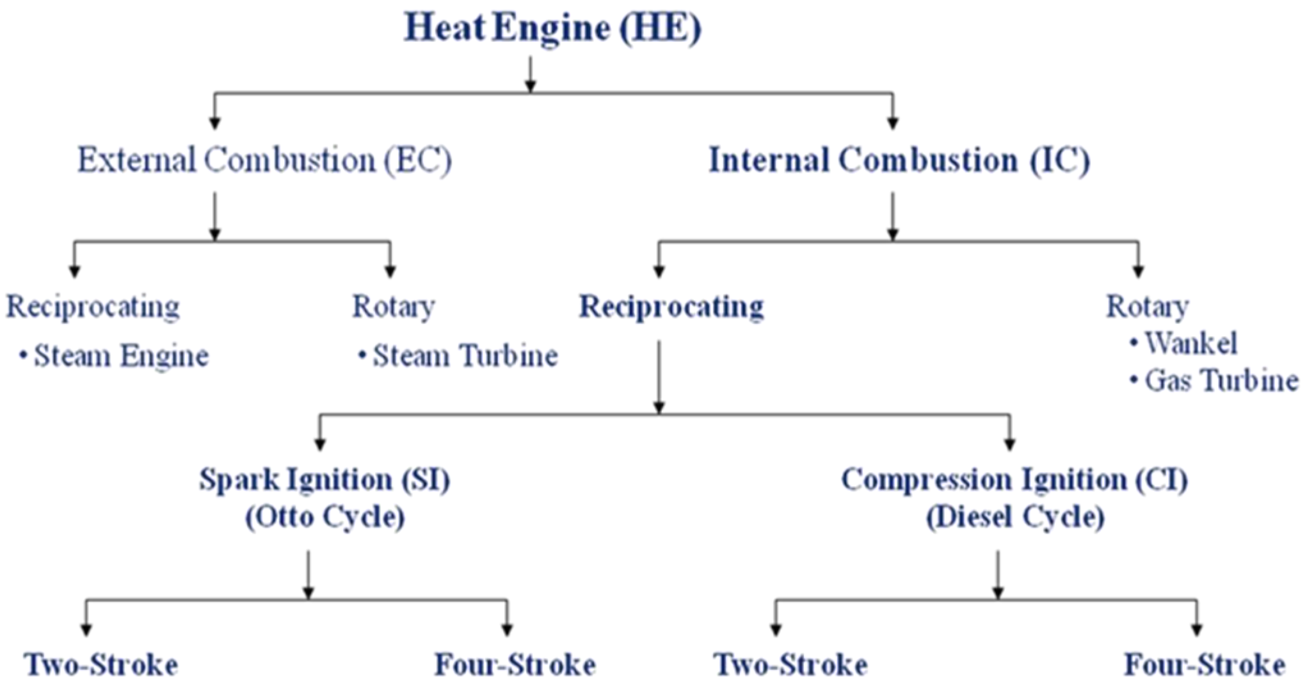


Fig 2.1 General classification of heat engine.[5]

2.2 Important Engine Parameters [9]

Bore (d): Bored refers to the diameter of the cylinder. The cross-sectional area is designated A.

Piston Area (A): As we seen from below figure 2.2**,** the area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A and is usually expressed in square centimeter(mm^2).

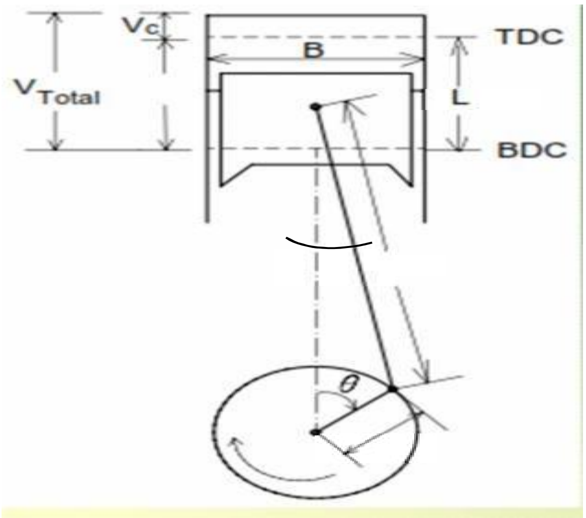


Figure 2.2: parameters in reciprocating IC Engine [9]

Stroke (L): The stroke is the distance travelled by the piston from it stop dead center (TDC) to its bottom dead center (BDC).

Square engine an engine with bore diameter (d) = stroke length (L).

Under square engine (d<L): If stroke length (L) is greater than the bore diameter (d).

- Smaller diameter cylinder with shorter flame travel distance; Combustion Chamber surface area will be smaller resulting less heat loss per cycle.
- ***Over square engine (***d>L): The picture below shows if stroke length (L) is less than the bore diameter (d). In an over square engines, the shorter stroke length gives lower average piston speed and hence lower frictional losses.

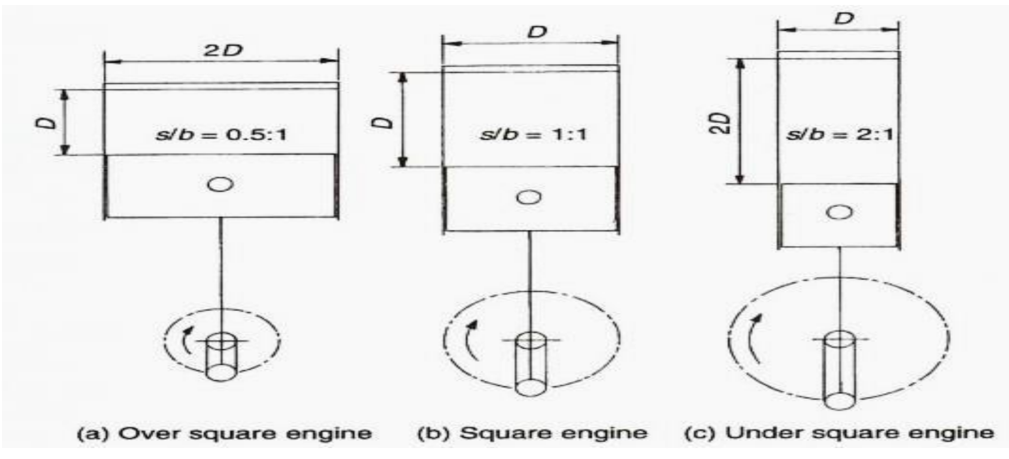


Figure 2. 3: Type of Reciprocating IC Engine [9]

- Top Dead Center (TDC): it is the dead center when the piston is farthest from the crankshaft. It is designated at TDC for vertical engines and Inner Dead Centre (IDC) for horizontal engines.
- Bottom Dead Centre (BDC)*:* It is the dead Center when the piston is nearest to the crankshaft. It is designated as BDC for vertical engines and Outer Dead Centre (ODC) for horizontal engines.

Swept volume (Vs): the swept volume refers to the volume or the capacity of the cylinder between the TDC and BDC of the piston surface. It is expressed in terms of cubic centimeter (cc or liter).

$$Vs = \frac{\pi d^2}{4}\, s \quad \text{...} 2.1$$

Engine displacement or Capacity: The displacement volume of a cylinder multiplied by number of cylinders in an engine will give the engine capacity. For example, if there are Z cylinders in an engine, then:-

Cubic capacity= V_Sx Z 2.2

Clearance volume (Vc): The space remaining above the piston crown when the piston is at the top dead center is referred to as the clearance volume (Vc). It is delimited by the piston at the moment of ignition and is also referred to as the combustion chamber.

It is designated as V_C and expressed in cubic centimeter (cc).

Compression ratio: The compression ratio indicates to what degree the fuel/air mixture is compressed in the cylinder. It describes the relationship between the volume of the cylinder and the compression space. The volume of the cylinder is the sum of the displacement and compression space. The compression ratio is always larger on diesel engines than on spark-Ignition engines.

2.3 Main Parts of IC Engines (Mechanisms and Systems): The next figure shows main parts of IC engine and its mechanism and systems. [9]

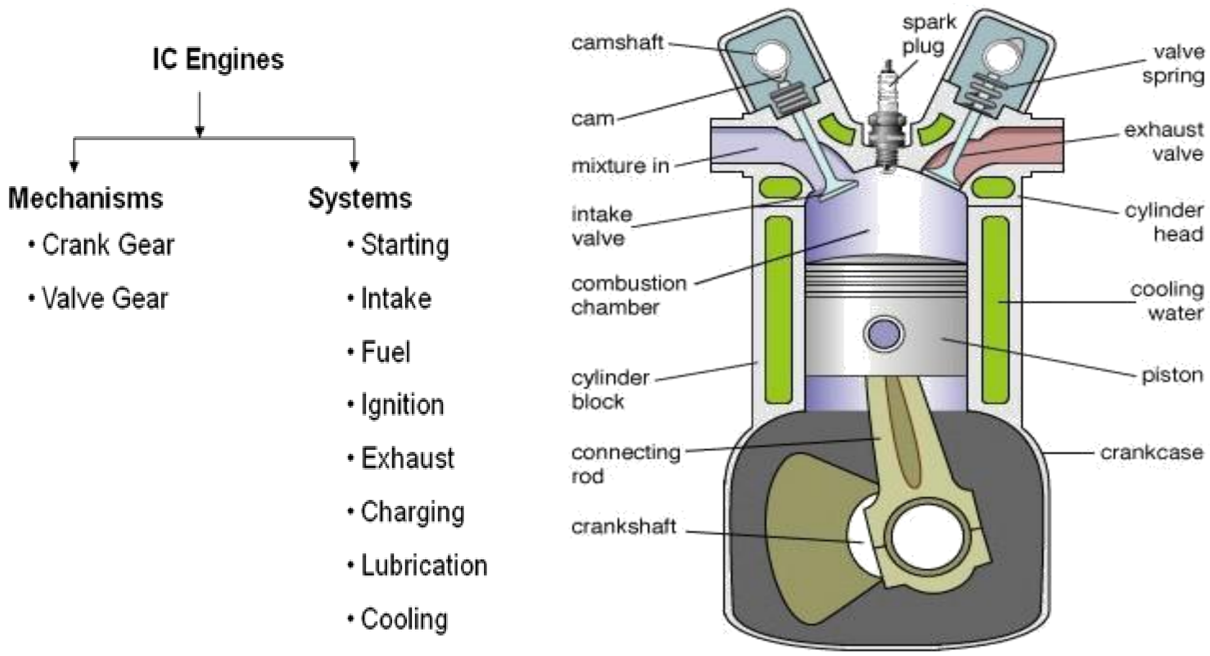


Figure 2. 4: Main parts of a Reciprocating IC [9].

2.3.1 IC Engine Mechanisms.[2]

The mechanisms of an IC engine are: **Crank Gear** and **Valve Gear**

2.3.1.1 The Crank Gear Mechanism

The main function of the 'Crank Gear Mechanism' of a reciprocating IC Engine is, to convert the Indicated Power (P_i) available on the piston head (a portion of Thermal or Heat Energy) into Brake Power (P_b) at the flywheel (Mechanical Energy).

2.3.1.2 The Valve Gear Mechanism

The main function of the 'Valve Gear Mechanism' of a reciprocating IC Engine is, to actuate (open and close) the inlet and exhaust valves at the required time with respect to the position of the crankshaft (θ), as illustrated in figure 2.4.

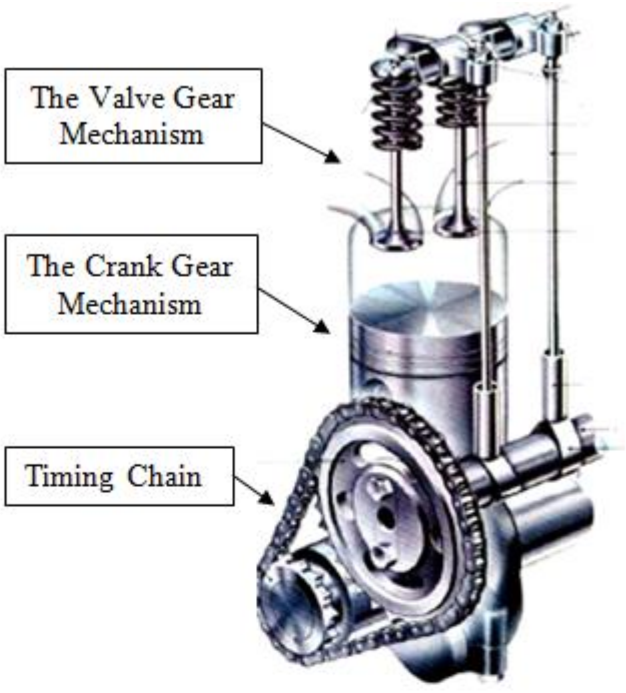


Figure 2. 5:The Crank and Valve Gear Mechanisms[2]

2.4 Internal Combustion Engines: The internal combustion (IC) engine is today the most widely used energy source in the automotive and naval industry. It has therefore become increasingly important to improve the efficiency of the engines to reduce fuel consumption, emission levels and noise pollution to decrease the negative effect it has on the health of the human being as well as its environment. Since the introduction of the IC engine in the late 19th century its development has resulted in a constant reduction of fuel consumption and emission levels, while the power output per cylinder volume has continued to increase [9].

The IC engine comes in many different types and sizes but can be divided in the category of the two stroke cycle or the four stroke cycle which can either be run by the Otto or the Diesel principle. For Otto engines the pre-mixed air-fuel mixture is ignited by a spark from a sparkplug while for the Diesel principle the air is compressed beforehand in the cylinder and the incoming fuel spray is ignited by the high pressure and temperature. In this chapter a brief explanation of the four stroke, spark-ignited (SI/Otto) engine will be presented, since this is the type of engine that the work of the thesis is performed on [9].

The four stroke cycle starts with the piston positioned in TDC (Top Dead Center) and as the piston travels down towards BDC (Bottom Dead Center) the intake valve opens, letting the fresh charge of air-fuel mixture to enter the cylinder during the intake stroke with the piston at BDC the intake valve closes and as the piston travels towards TDC again the fresh charge is compressed during the compression stroke. As the piston reaches TDC the compressed air-fuel mixture is ignited by the spark plug and the chemical energy of the fuel is converted to heat during combustion. This increases the cylinder gas temperature and pressure therefore adding work to the crankshaft during the power stroke or expansion stroke. When the piston reaches BDC again the exhaust valve opens and as the piston travels towards TDC the exhaust gas is pushed out from the cylinder during the exhaust stroke. When the piston has reached TDC the cycle is restarted again. In one power cycle the crankshaft has done two full revolutions (720 crank angle degrees or CAD) and the piston has traveled up and down the cylinder four times, therefore the name four stroke cycle [9].

2.5 Type of internal combustion engine

2.5.1 Spark Ignition Engines

In SI engines, the burning of fuel occurs by a spark generated by the spark plug located in the cylinder head of the engine. Due to this fact, they are called spark ignition engines. In these engines, the fuel used is petrol or gasoline, hence SI engines are also known as petrol or gasoline engines. The (SI) and (CI) engines are either 2-stroke or 4-stroke engines. The stroke is the distance travelled by the piston inside the cylinder in one direction. In 4-stroke engines, the crankshaft rotates two rotations to be the fuel is burnt. This means the injected fuel is burnt for every four strokes of the piston inside the cylinder and the power is produced every two rotations of the crankshaft. In 2-stroke engines, the crankshaft rotates one rotation to be the fuel is burnt. This means the injected fuel is burnt for every two strokes of piston inside the cylinder and the power is produced every one rotation of the crankshaft, so ideally the power of 2-stroke engines should be double the power of 4-stroke engines for the same volume of engine [9]

2.5.2 Compression ignition engine (CI engine)

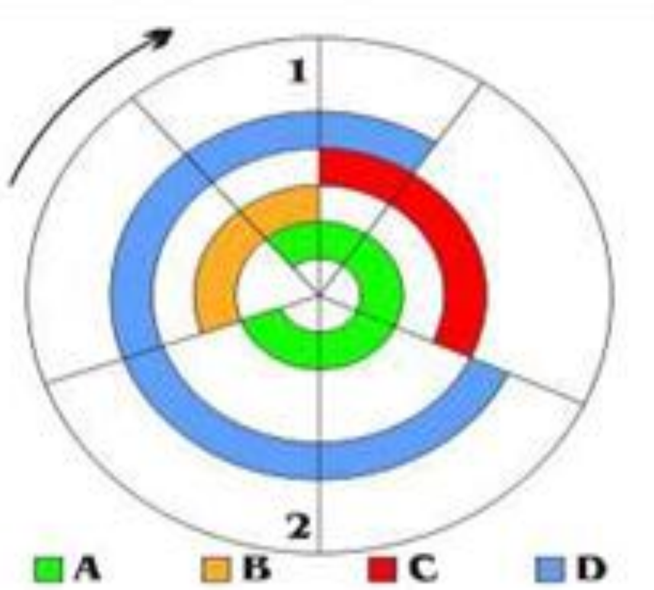
An engine in which the combustion process starts when the air-fuel mixture self -ignites due to high temperature in the combustion chamber caused by high compression [9].

2.6 Four strokes of SI Engine Cycle[1]

1. Suction/Intake stroke: Intake of air fuel mixture in cylinder through intake manifold.
2. Compression stroke: When the piston reaches BDC, the intake valve closes and the piston travels back to TDC with all valves closed.
3. Expansion stroke/Power stroke: With all valves closed the high pressure created by the combustion process pushes the piston away from the TDC.
4. Exhaust Blow-down: Late in the power stroke, the exhaust valve is opened and exhaust blow-down occurs.
5. Exhaust stroke: By the time piston reaches BDC, exhaust blow down is complete, but the cylinder is still full of exhaust gases at approximately atmospheric pressure.

2.7 Valve Timing Diagram

The Valve Timing Diagram:- is a kind of diagram that shows the 'opening' and 'closing' points of the Intake (**In.**) and Exhaust (**Ex.**) valves with respect to the position of the Crankshaft (θ) during a complete cycle of engine operation. These can be seen from below picture [7].



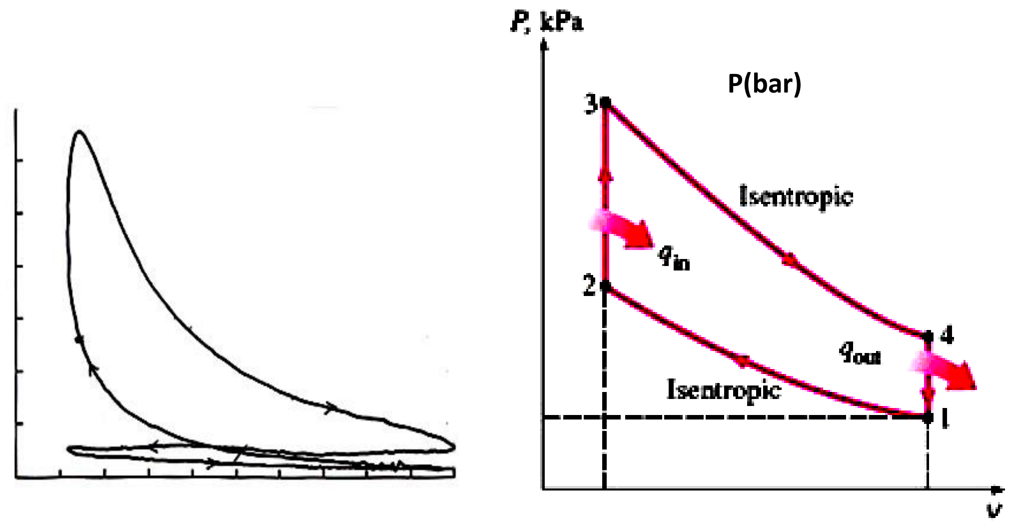
1=TDC 2=BDC

A: Intake **B: Compression** **C: Power** **D: Exhaust**

Figure 2. 6: The Valve Timing Diagram of a Four-Stroke IC Engine.[7]

2.8 Cycle Processes of IC Engines[2]

2.8.1 'Ideal' and 'Actual' Cycle Processes of IC Engines: The following picture shows actual and ideal cycle process of SI Engine.



'Actual' Cycle Processes of SI Engines ' Ideal' Cycle Processes of SI Engines.

Figure 2.7: Cycle Processes of IC Engine. [2]

2.9 Combustion in IC Engines

In SI engines, a high energy spark is discharged across the spark plug electrodes at the end of compression stroke at the right time ($\theta_{sc} \approx 10^0$ bTDC). As a result, the compressed combustible gaseous mixture in between the electrodes starts to ignite and flame is formed. From this point, the flame front moves out (propagated) smoothly and spherically (in three dimension) across the combustion chamber, until it is terminated around the quenching zone(lower tempreture zone on the combustion chamber) as illustrated in Fig. 2.8. The duration of combustion (θ_{dc}) will be about 20^0 to 40^0 of crank angle (θ). The combustion process, in general, may take place within a very short period of time ($\approx$ 0.01 to 0.001 seconds at a particular intermediate engine speed, N) [5].

The combustion processes in SI engines, therefore, can be divided into three main regions: [5].

1. Ignition and Flame Formation.
2. Flame Propagation.
3. Flame Termination.

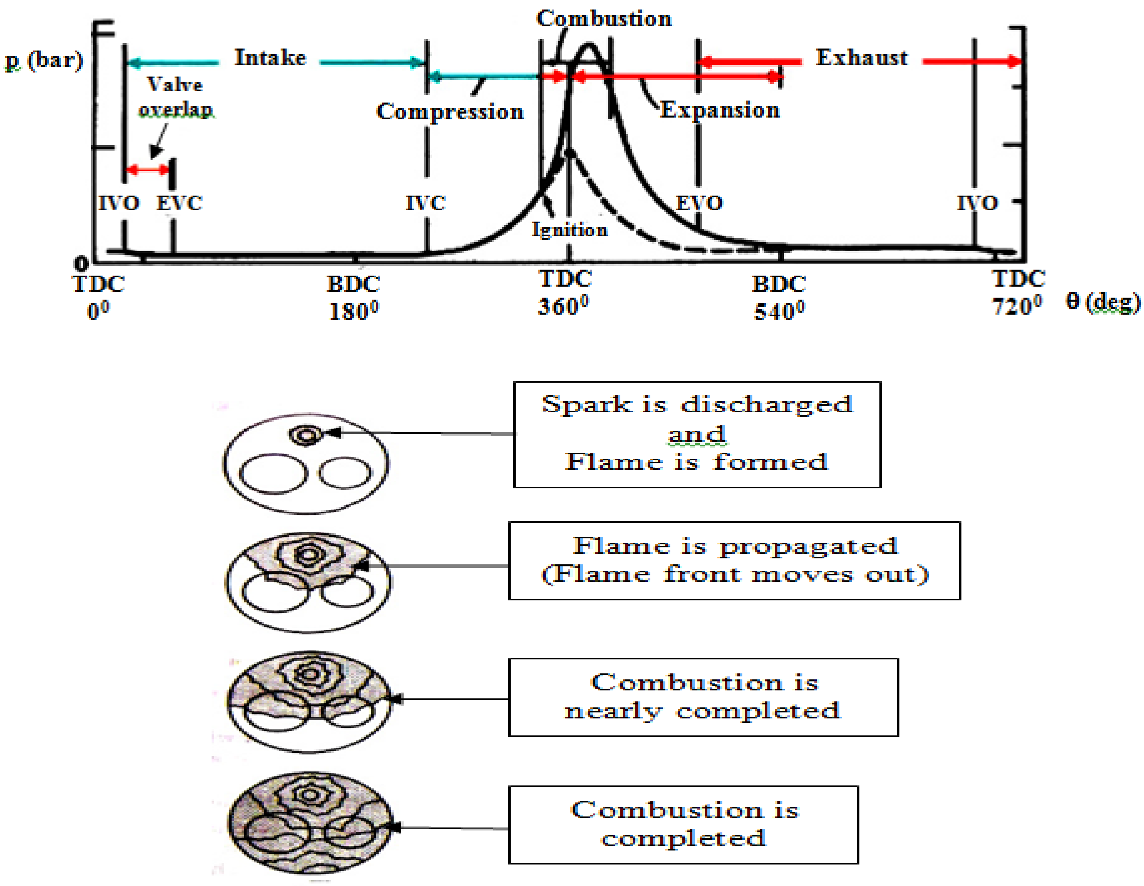


Figure 2.8: Ignition and flame propagation during normal combustion. [5]

2.10 Chemistry of Combustion

Combustion is a kind of *exothermic reaction*, where a fuel comes into contact with air (oxygen) under a particular condition. As a result, a large amount of thermal (heat) energy is released. It is this energy that is used to run internal combustion engines [5].

As illustrated in figure 2.9, the combustion process is a complex and a rapidly occurring series of reactions. Whenever combustion occurs, the energy associated with the chemical bonds in the fuel molecules are released. In doing so, the chemical energy is converted into thermal (heat) energy and is manifested by a very rapid motion and collision of molecules. This indicates that there is a high temperature and pressure within the engine cylinder (combustion chamber) and is ready to do work or push the piston [5].

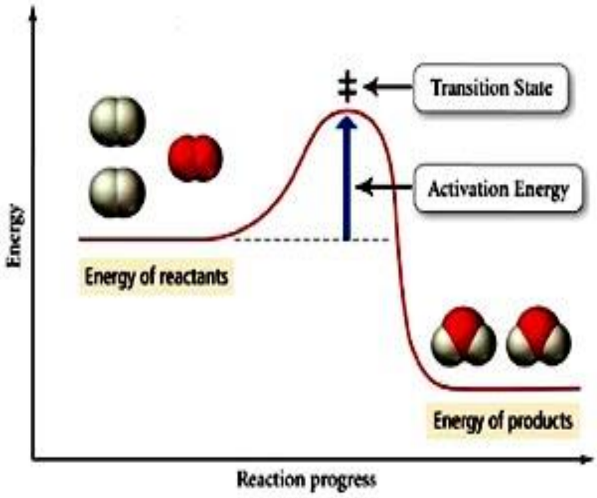


Figure 2.9: Combustion in IC engines and Activation energy. [2]

Activation energy is the amount of energy that is required to start a chemical reaction. Not all chemical reactions can take place on their own, and need a little push to overcome the energy barrier. The final combustion temperature and pressure of the products of combustion do depend on or influenced by a number of factors. The most important factors are [5].:

i) The properties of fuel and mixture composition (air-fuel ratio).

ii) The state of mixture (liquid or vapor).

iii) The pressure and temperature at the beginning of ignition (combustion).

iv) External constraints, such as: igniter (spark), combustion process (constant volume or constant pressure), etc.

In order to determine the final temperature of the combustion products, the amount of 'Thermal energy' released during the combustion process has to be known in advance. The amount of 'Thermal energy' released during a constant volume combustion process is called the 'change of internal energy (ΔU)' and during a constant pressure combustion process it is called the 'change of enthalpy (ΔH)'. The process of transferring 'Thermal energy' from the combustion chamber is called 'Heat Transfer or Heat (Q_{in})' [5].

The change in internal energy (ΔU) during a constant volume combustion is given by [5],

$$\Delta U = U_p - U_r = \sum \left[\left(N_i \bar{u}_i \right)_p - \left(N_j \bar{u}_j \right) \right] = Q_{out} \qquad \Rightarrow \qquad Q_{in} = -Q_{out} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

where, the subscripts *i* and *j* stands for the various species in the products and reactants respectively.

N represents the amount of the species in 'kilo mole (*kmol)'*.

$\bar{u}$ represents the specific internal energy in *kJ/kmol*.

Similarly, the change in enthalpy (ΔH) during a constant pressure combustion is given by,

$$\Delta H = H_p - H_r = \sum \left[\left(N_i \bar{h}_i \right)_p - \left(N_j \bar{h}_j \right) \right] = Q_{out} \quad \Rightarrow \quad Q_{in} = -Q_{out} \quad \text{...............2.4}$$

where, the subscripts *i* and *j* stands for the various species in the products and reactants respectively.

N represents the amount of the species in 'kilo mole (*kmol)'*.

$\bar{u}$ represents the specific enthalpy in *kJ/kmol*

2.11 Previous works

António Emanuel Figueiredo Costa (2008) [8], studied on Computer Simulation of an Internal Combustion Engine. The main propose of his work:

● Complete the program with the heat transfer model and insert the correct modifications to perform a simulation of a non adiabatic engine;

● Add a new combustion model, replacing the existing one used in the initial program. The new combustion model would take into account the turbulence in the cylinder and would then allow the variation of burn duration (which is fixed in the simple model used) to vary with engine speed. In addition to these he try to cover about internal combustion engine, thermodynamics and mathematical model of the engine, power cycle and gas exchange cycle.

The result of his project is a computer simulation which may be used to obtain some fairly good estimates of engine performance. These estimates are most useful for understanding basic engine performance as well as assessing modifications as regards valve sizing, spark advance and various fuels. In his result he try to see the result of temperature with crank angle, pressure with volume, work with volume, heat transfer with crank angle, turbulence with crank angle and flame speed with crank angle relations.

G.H. AbdAlla(2001) [5], studied on Computer simulation of a four stroke spark ignition engine. This paper introduces the preliminary simulation of a four stroke spark ignition engine. In addition to these he try to show variation of indicated and brake thermal efficiency with the compression ratio, variation of P-V diagram for different value of compression ratio, variation of cylinder pressure with crank position for different value of compression ratio, variation of cumulative work done with crank position for different value of compression ratio, variation of indicated and brake mean effective pressure with the equivalent ratio and variation of indicated and brake specific fuel consumption with equilibrium ratio. He also try to discuss effects of spark timing, effects of combustion duration and effects of compression index (n).

Kota Sridhar, R.B.V.Murali, Sk.MohammadYounus, K.MohanLakshmiBeside (2013) [6], studied on Computerised Simulation of Spark Ignition Internal Combustion Engine.
In the Present work Turbulence flow conditions are considered. Standard k-€ turbulence model for fluid flow and eddy break-up model for turbulent combustion were utilized. CFD analysis has been used extensively to improve each of these processes. In this paper discuss simulates the Intake, Compression, Expansion and Exhaust process with hexane fuel combustion.

The researchers try to cover about internal combustion engine, operation of internal spark ignition engine, P-V diagram of 4-stroke spark ignition engine, valve timing diagram of spark ignition engine and hexane fuel. In the present work a four-stroke internal combustion spark ignition engine is simulation model. All, suction, compression, expansion and exhaust strokes are simulated. The Discrete Phase Model is used for simulating fuel injection, evaporation, and droplet boiling. The simulation model developed successfully captures the single cylinder spark ignition engine operating with Hexane as fuel. Result were noted with different crank angles at different flow time. It is found Maximum and Minimum Volume-Average static pressures, Mass-Average static Temperatures at different flow time, Predicted $C_6 H_{14}$ Mass fraction Distribution and Predicted Static Temperature Distribution of Hexane Fuel.

The operational range of the model is wide and computational run time is short, thus making the simulation model suitable for use with thermodynamically based cycle simulations in spark ignition engines running with ignition improver with Hexane fuel.

Due to its simplicity, the model can be used for wide range of different fuels to optimize the design.

STEFAN GUNDMALM (2009): [9], studied and develop on title of CFD (Computational Fluid Dynamics) modeling of a four stroke S.I. engine for motorcycle application, this thesis deals with the numerical 3D simulation of a four stroke, spark-ignited, internal combustion engine, which is mounted on a high performance motorcycle. The work, focuses on the simulation of the intake, compression and expansion stroke, including combustion simulation, using an open source CFD code. The main purpose of the research done by this group is to develop advanced 1D and 3D fluid dynamic models for the calculation of the in-cylinder gas exchange, combustion process and pollutant formation.
The thesis concerns the CFD modeling of a four stroke, four cylinder, spark-ignited engine which is mounted on the motorcycle models based on the F4 series. The CFD simulations were done on one of the cylinders during the intake, compression and expansion phases, including combustion simulation, taking into account the valve and piston motion. The simulations were carried out from the start of the intake stroke (IVO) until around the end of the combustion process, thus covering the intake, compression and part of the expansion phases.

These thesis also try to discuss about internal combustion engine, SI engine cycle process, the combustion process in the SI engine, Computational Fluid Dynamics Modeling, flame propagation, Abnormal Combustion Phenomena and soon. Result was noted with different crank angles at different flow time. It is found pressure, temperature, volume, turbulence, distribution at different crank angle positions [9].

Radoslav Plamenov Georgiev: [11], studied on Design a four-cylinder Internal Combustion Engine. The aim of this Thesis is to introduce to the interesting world of internal combustion engines and to describe what actually Internal Combustion Engine is. What are its main components and structure. How the engine indeed operates. Also to design a real engine, having into account all necessary calculations concerning with kinematics, dynamics and strength calculation of basic details. Another purpose of the project is to define the proper materials for each part. He also try to see history and development of the engine, type of engine, main components of engine, kinematic calculation of a supercharge engine, dynamic calculation of an engine with supercharging.

And the researcher lastly concludes that it has to be taking into consideration all necessary calculations concerning its basic components. In addition the most proper materials which have to be used have been determined. It has been taken into consideration that the chosen materials must resist on the maximum forces, moments and stresses that occur when the engine is operating.

CHAPTER THREE

MATERIALS AND METHODS

The major step followed in the execution of this work is as given below

- Literature review
- Data collection
- Mathematical and thermodynamic analysis is done
- Develop computer programing
- Experimental test done

3.1 Literature review

Literature review is the first and foremost activity to be performed in any research work. Various sources like journal, books, article, others and previous research works on computer simulation of spark ignition engine process and performance analysis were referred in order to have comprehensive understanding of the subject under research.

3.2 Data collection

After related research review was done, different vehicle of three wheel, two wheel and four wheel spark ignition four stroke single cylinder engines data was collected from TVS companies, Dilla university and Adama science and technology university library and workshops. In addition to these few related data are collected from internets.

3.3 Material required

The main required material to do this research is:-

- CT 110 Test Stand for Small Combustion Engines up to 7.5kW.
- Three wheel vehicle engine
- Computer

3.4 Flow chart diagram

From the following figure we can understand how the researcher follows various steps to prepare this thesis.

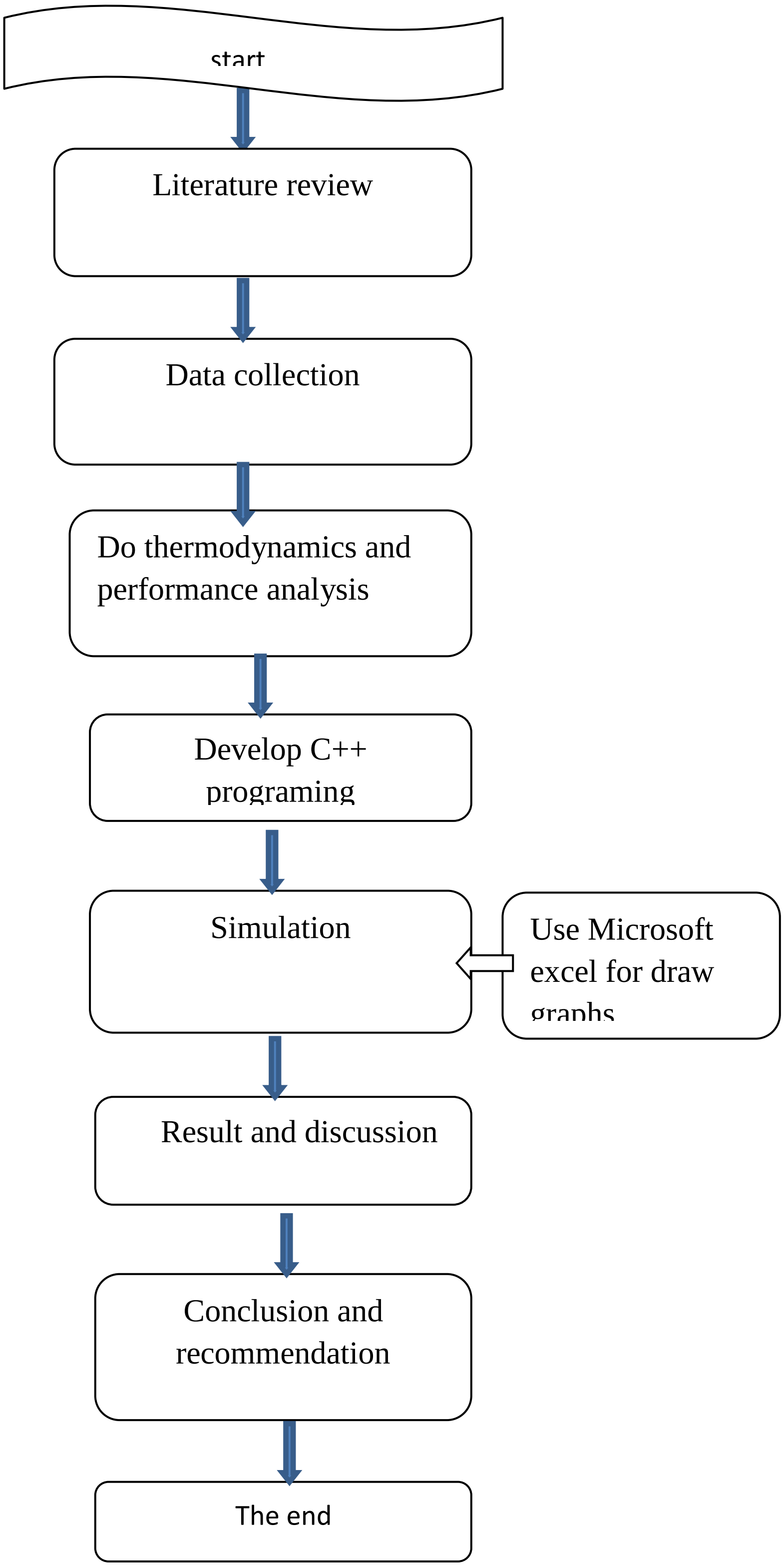


Figure 3.1 Flow chart diagram

3.5 Engine specification

Table 3.1: RE Bajaj Engine specification

No	Engine Parts	Dimensions
1	Cylinder Bore original	89 mm
2	Stroke – original	63 mm
3	Crank length	31.5 mm
4	Conn. Rod length	110 mm
5	Displacement	391.7cc
6	Compression ratio	8.5:1
7	Max. Engine Torque	24.6 Nm at 2200 rpm
8	Max. H.P	
9	No of Cylinder	1
10	Dwell Angle	46^0
11	Idle Speed	500rpm
12	Ignition Timing	8^0 BTDC@600rpm
13	Valve overlap	32^0
14	angle Intake Valve opened Btdc	16^0
15	Intake Valve closed Abdc	50^0
16	Qsc	16^0
17	Qdc	50^0
18	Exhaust Valve opened Bbdc	50^0
19	Exhaust Valve closed aTDC	16^0
20	Vehicle Wheel No	3
21	Pb max	8.2 Kw
22	Bsfc pa	0.1044kg/kwh
23	Reciprocating mass(M R)	
24	Maximum speed	**3600 rpm**
25	Qout	44.5 MJ/kg(C8H15)
26	Density of fuel(ῥf)	0.75kg/lit
27	Engine Load	0.9 bar

28	Spark Ignition T^0 (k)	650k
29	Air /Fuel Ratio	12.5:1
30	Engine Type	RR
31	Fuel Type	Gasoline
32	Position of Cylinder	Single cylinder
33	Two/Four Stroke:	4 Stroke
34	Cooling method:	Water
35	No. of valves/cylinder	2 (1 inlet, 1exhoust)
36	No. of camshafts:	1
37	No. of ports total:	2(inlet,1 exhoust,1)
38	Drive:	Chain

3.6 Calculation of basic Geometrical Properties of the Engine [2].

Bore (*d*), Stroke (*s*), Crank radius (r_{cr}) and Connecting rod length (*l*)

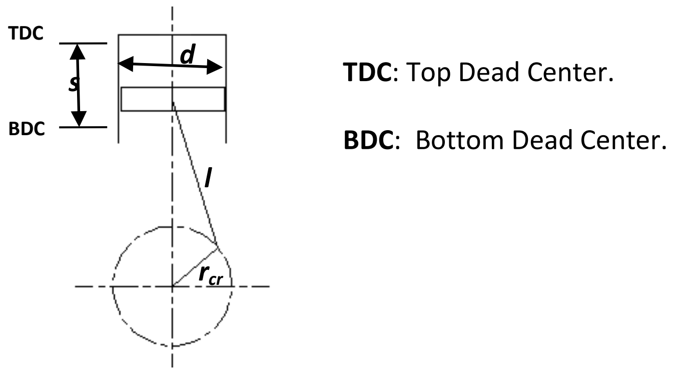


Figure 3. 2: Geometrical Properties of IC Engines.[9]

- **Swept Volume (V_s),**

$$E_c = V_s \times z \quad \Rightarrow \quad V_s = \frac{E_c}{z} \qquad \rightarrow \qquad V_s \text{ in 'm}^3\text{', 'cm}^3 \text{ or cc' and 'liter'}$$

E_c = 391.7cc*1=391.7cc ……………………………………………………3.1

Where E_c = Engine capacity

V_s = Swept volume

Z = No of cylinder

- **Bore *(d)* and Stroke *(s)***

$$V_s = \frac{\pi d^2}{4} \times s \quad \Rightarrow \quad d = \left(\frac{4 \times V_s}{\pi \times ratio_{sd}}\right)^{1/3} \quad \text{and,} \quad s = ratio_{sd} \times d \rightarrow d \text{ and } s \text{ in 'mm'}$$

$$V_S = 3.14 * 0.089 * \frac{0.089}{4} * 0.063 = 0.0003917 m^3 \text{ ....3.2}$$

Where V_S = swept volume

d = bore diameter

s = stroke

- **Crank radius *(r_{cr})*,**

$$r_{cr} = \frac{s}{2} \quad \rightarrow \quad r_{cr} \text{ in 'mm' ....……..3.3}$$

r_{cr} =63/2

r_{cr} =31.5mm

- $\lambda = \frac{r_{cr}}{l}$ 3.4

= 31.5mm/110mm

= 0.28

Where λ = ratio of crank radius to con rod length

r_{cr} = crank radius

l = con rod length

s = stroke

- **Stroke to bore ratio**

$= \frac{S}{B}$ ……………………………………………………………………….3.5

= 63mm/89mm

= 0.70

Where S = stroke

B = bore

3.7 Mathematical Thermodynamic Analysis of Selected Engine [5]

For one cylinder:

Displacement volume (V_D):

V_D = 391.7cm3/1 = 391.7cm3 = $V_D = 0.0003917\ m^3$

Clearance volume:

$R_C = \frac{V_1}{V_2} = V_D + V_C\ /\ V_C$ ……………………………………………………….3.6

8.5= 0.0003917m3 + V_C / V_C

$Vc = 0.0000522\ m^3$

Where V_D = Displacement volume,

V_C = Clearance volume and

R_C= compression ratio

3.7.1 State-1 (from 0 to 180 degree)

The intake stroke of the Otto cycle starts with the piston at TDC and is a constant pressure process at an inlet pressure of one atmosphere. The temperature of the air during the inlet stroke is increased as the air passes through the hot intake manifold.

The temperature at point TDC will generally be on the order of 25°to 35°C hotter than the surrounding air temperature.

T_1 = 60°c = 333k

P_1 = 100kpa

V_1 = V_D + V_C = 0.0003917m3 + 0.0000522 m3 = 0.0004439 m3

Mass of gas mixture in cylinder can be calculated at state 1.the mass with in the cylinder will then remain the same for the entire cycle.

In air-standard cycles, air is considered an ideal gas such that the following ideal gas relationships can be used:

PV = mRT…………………………………………………………………3.7

$P_1\ V_1 = m_m \mathrm{R} T_1$

$$m_m = \frac{P_1\ V_1}{\mathrm{R}T_1} = \frac{(100\text{kpa})(\ 0.0004439\ \text{m3})}{(0.287\text{KJ/Kg}-\text{k})(333\text{k})} = 0.0004644\text{Kg}$$

Where P_1= pressure at state one

V_1 = Volume at state one

$T_{1=}$Temprature at state one

R= Gas constant for air = 0.287KJ

3.7.2 State-2 (from 180 to 360 degree)

The compression stroke is isentropic. The following ideal gas relationships can be used to find pressure and temperature.

$P_2 = P_1 * \text{rc}^{\text{k}}$= 100kpa$*$ $(8.5)^{1.35}$ =1797.69 kpa ……………………….…3.8

$T_2 = T_1 * \text{rc}^{\text{k}-1}$ = 333k $*$ $(8.5)^{1.35-1}$=704.27 k …………………………...3.9

$V_2 = \frac{\text{mmR}T_2}{P_2} = \frac{(0.0004644\text{Kg})\ (0.287\text{KJ/Kg}-\text{k})\ (704.27\ \text{k})}{(1797.69\ \text{kpa})}$ = 0.0000522m3 = V_C………………………………………………………………………..…3.10

Where P_1= pressure at state two

V_1 = Volume at state two

$T_{1=}$Temprature at state two

R= Gas constant for air = 0.287KJ

The type of fuel used in this work is gasoline.

The mass of gas mixture mm in the cylinder made up of air ma, fuel mf (mass of gasoline).

Mass of air

$m_a = \frac{12.5}{13.5}$ (0.0004644Kg) = 0.00043 kg …………………………………3.11

Mass of fuel

$m_f = \frac{1}{13.5}$ (0.0004644Kg) = 0.0000344 kg ………………………………3.12

3.7.3 State-3 (from 360 to 540 degree)

Heat addition from hydrocarbon fuel is:-

$Q_{in} = m_f Q_{LHV} \eta_c$ ………………………………………………………….…3.13

where, m_f= 0.00002541kg

Q_{LHV}= lower heating value of gasoline

η_c = combustion efficiency

Q_{in}= heat addition

η_c = 100%

Q_{in} = $m_f Q_{LHV}$ ηc

= (0.0000344 kg) (44.5MJ/kg) (1)

= (0.0000344 kg) (44,500MJ/kg) (1)

= 1.53kJ

Q_{in} = m_m C_V (T_3-T_2) …………………………………………………..3.14

= 1.53kJ = (0.0004644 Kg) (0.821KJ/kg-k) (T3 -704.27 k)

T_3= 4718.04K = Tmax

V_3 = V_2 = 0.0000522m3 from these we can understand that PV=MRT, so that V= MRT/P

Because V_3=V_2, MRT_3/P_3=MRT_2/P_2, but M and R are constant due to these

$\frac{T_3}{P_3} = \frac{T_2}{P_2}$ from these we get

P_3 = P_2 $(\frac{T_3}{T_2})$ …..………………………………………………………… 3.15

= 1797.69 kpa $* \frac{4718.04\text{K}}{704.27\text{ k}}$

= 12043.07 kpa = Pmax

Where P_2= pressure at state two

P_3 = Pressure at state three

$T_{2=}$Temprature at state two

$T_{3=}$Temprature at state three

$Q_{in=}$ Heat addition during one cycle

$m_{m=}$ Mass of gas mixture

$C_{V=}$ Specific heat

3.7.4 State 4 (from 540 to 720 degree)

Power stroke.

The following ideal gas relationships can be used to find pressure and temperature.

P_4 = P_3 $(\frac{1}{rc})^k =$ 12043.07kpa $(\frac{1}{8.5})^{1.35}$ = 664.94Kpa …………………....3.16

T_4 = T_3 $(\frac{1}{rc})^{k-1}$ = 4718.04K $(\frac{1}{8.5})^{1.35-1}$ = 2226.52k …………………..3.17

V_4 = V_1 = 0.0004439 m3

Work produced in isentropic power stroke for one cylinder during one cycle:

$$\text{W power} = \frac{[\ \text{mR}\ (T_4 - T_3)]}{1-\text{k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.18$$

$$= \frac{[\ 0.0004644\text{Kg}*0.287\text{KJ/Kg}-\text{k}\ (2226.52\text{k}-4718.04\text{K})]}{1-1.35}$$

= 0.9489KJ Work absorbed during isentropic compression stroke for one cylinder during one cycle.

$$\text{W compression} = \frac{[\ \text{mR}\ (T_2 - T_1)]}{1-\text{k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.19$$

$$= \frac{[\ 0.0004644\text{Kg}*0.287\text{KJ/Kg}-\text{k}\ (704.27\ \text{k} - 333\text{K})]}{1-1.35}$$

= - 0.1413KJ Work of the intake stroke is canceled by work of the exhaust stroke.

Net indicated work for one cylinder during one cycle is:

$$W_{Net} = W_{Power} + W_{Compression} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.20$$

= 0.9489KJ - 0.1413KJ

= 0.8076KJ

Where P_3= pressure at state three

P_4 = Pressure at state four

$T_{3=}$Temprature at state three

$T_{4=}$Temprature at state four

V_4= volume at state four

rc =compression ratio

m = mass of gas mixture

R = Gas constant for air = 0.287KJ

K = $\frac{C^P}{C^V}$

Thermal efficiency (ηt)**:**

$$\eta_t = \frac{W_{net}}{Q_{in}} = 0.8076\text{KJ}/1.53\text{kJ} = 0.5278 \quad = 52.78\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.21$$

Where $W_{net=}$ net work

Q_{in}= Heat addition during one cycle

η_t = thermal efficiency

Indicated mean effective pressure (imep):

Imep = $\frac{W_{net}}{V_1 - V_2}$ ……………………………………………………………3.22

= 0.8076KJ / (0.0004439 m3 - 0.0000522m3)

= 0.8076KJ /0.0003917m3

= 2061.78 KJ/ m3

= 2061.78 kpa

Where W_{net} = net work

V_1 = Volume at state one

V_2 =Volume at state two

Indicated power(pi):

P_i = $\frac{\mathrm{WN}}{\mathrm{n}}$ = [0.8076KJ /cylinder-cycle (3600/60 rev/sec)/ (2rev/cycle)] 1cylinder ……………………………………………………………………………………….3.23

= 24.22 kw

Where P_i= Indicated power

w = Net indicated work

N = Engine speed

n = No of revolution per second

Brake power (P_b)

P_b = η_m P_i = 0.86 *24.22 kw ……………………………………………..3.24

= 20.83 kw

Where, η_m = Mechanical efficiency is 86%

P_b= Brake power

P_i= Indicated power

Brake torque (T_b)

= $\frac{60\ x\ P_b}{2*\pi*N}$ … ……………………………………………………….…….3.25

= $\frac{60\ x\ 20.83\ kw}{2*3.14*3600}$

= 0.055KN-m

= 55N-m

Where P_b= Brake power

N= Engine speed

Brake specific fuel consumption (bsfc)

bsfc= $\frac{m_f}{P_b}$ ……………………………………………………………..3.26

= [(0.0000344kg/cylin-cycle) *(50 rev/sec)*(0.5 cycle /rev)*1cyli]/20.83 kw

= 0.000041kg/sec/kw

= 0.147kg/kwh

Where bsfc= brake specific fuel consumption

m_f =Mass of fuel

P_b = Brake power

Volumetric efficiency (η_t)**:**

η_v = $\frac{\text{Ma}}{P_a * V_d}$ …………………………………………………………...3.27

= 0.00043kg/1.181kg/m3*0.0003917m3

= 0.934

= 93.4%

Where Ma = mass of air

P_a= density of air

V_d =Displacement volume

brake mean effective pressure (bmep)

bmep = Imep* η_m ……………………………………………………..3.28

$\text{bmep} = 0.86 \times 2061.78\text{kpa}$

= 17.52 bar

Where, η_m = mechanical efficiency is 86%

bmep= Brake mean effective pressure

Imep= Indicated mean effective pressure

3.8 Mathematical Engine Performance analysis [2]

Using the values of $P_{b\text{-max}}$ and <u>N@Pb-max</u> , the curves of: brake Power (P_b) , brake Torque (T_b), brake mean effective pressure (bmep) and brake specific fuel consumption (bsfc) as a function of engine speed (N) can be determined and plotted.

3.8.1 Empirical Relations for spark ignition engine

- Brake Power (P_b),
- Brake Torque (T_b),
- Brake mean effective pressure (bmep) and

Brake specific fuel consumption (bsfc) as a function of engine speed (N) can be determined and plotted.

Brake power (Pb)

Brake Power (P_b):- is an engine performance parameter which mainly determines the maximum rate of work done or the maximum vehicle velocity (v_{max}) [2].

$$P_b = P_{b-max} \times \frac{N}{N_{@P_b-max}}\left[1+\left(\frac{N}{N_{@P_b-max}}\right)-\left(\frac{N}{N_{@P_b-max}}\right)^2\right] \Rightarrow \text{N in 'rpm'; } P_b \text{ in 'kW'..3.29}$$

$$P_b = 8.2 \times \frac{500}{3600}\left[1+\left(\frac{500}{3600}\right)-\left(\frac{500}{3600}\right)^2\right]$$

$$P_b = 8.2 \times 0.14\left[1+(0.14)-(0.14)^2\right]$$

$$P_b = 1.28\,\textbf{kw}$$

Where N@Pb - max is engine speed at maximum Pb and let N=500

$P_{b\text{-max}}$ = maximum brake power

Brake Torque (T_b)

Brake Torque (T_b):- is an engine performance parameter which mainly determines the 'effort' or the 'traction', 'acceleration' and 'uphill drive' ability of the vehicle [2].

$$T_b = \frac{60 \times P_b \times 1000}{2\pi \times N} \Rightarrow P_b \text{ in 'kW'}; \quad N \text{ in 'rpm'}; \quad \text{and} \quad T_b \text{ in 'Nm'} \ldots\ldots 3.30$$

$$T_b = \frac{60 \times 1.28 \times 1000}{2\pi \times 500}$$

$$T_b = 24.45\text{Nm}$$

Where P_b = brake power

N= Engine speed in rpm

Brake mean effective pressure (bmep)

$$\text{bmep} = \frac{4\pi \times T_b}{E_c \times 10^5} \Rightarrow T_b \text{ in 'Nm'}; \quad E_c \text{ in 'm}^3\text{'}; \quad \text{and} \quad \text{bmep in 'bar'} \ldots\ldots 3.31$$

$$\text{bmep} = \frac{4\pi \times 24.45}{0.0003917 \times 10^5}$$

$$\text{bmep} = 7.84\,\text{bar}$$

Where T_b = Engine brake torque

E_c = Engine displacement

Brake specific fuel consumption (bsfc)

brake specific fuel consumption (bsfc):- is an engine performance parameter which mainly determines the amount of fuel consumed by the engine in 'gram per hour (g/h)' to develop a unit brake power (P_b) in 'kW' while running at a constant engine speed (N) in 'rpm'[2].

$$\text{bscf} = \text{bscf}_{@P_b - max} \times \left[1.2 - \left(1.2 \times \frac{N}{N_{@P_b - max}} \right) + \left(\frac{N}{N_{@P_b - max}} \right)^2 \right] \Rightarrow N \text{ in 'rpm'; bsfc in 'kg/kWh'} \ldots\ldots 3.32$$

$$\text{bscf} = 0.27 \times \left[1.2 - \left(1.2 \times \frac{500}{3600} \right) + \left(\frac{500}{3600} \right)^2 \right]$$

$$bscf = 0.27 kg/kwh$$

Where $bscf_{@Pbmax}$ = brake specific fuel consumption at maximum brake power

$N_{@Pbmax}$ = Engine speed at maximum brake power

Frictions mean effective pressure (fmep)

- For $\frac{s}{d} > 1$ where, 's' is the stroke and 'd' is the bore.

$$fmep = \lfloor 0.049 + (0.0152 \times v_{pm}) \rfloor \times 10 \; ; \Rightarrow v_{pm} = \frac{2 \times s \times N}{60} \text{ in 'm/s'; ....3.33}$$

- For $\frac{s}{d} \leq 1$

$$fmep = \lfloor 0.034 + (0.0113 \times v_{pm}) \rfloor \times 10 \; ; \Rightarrow v_{pm} \text{ in 'm/s'; and fmep in 'bar'}$$

But for these engine stroke to bore ratio is 0.70, which is less than one. So that we use the second equation:-

$$fmep = \lfloor 0.034 + (0.0113 \times v_{pm}) \rfloor \times 10 \; ; \Rightarrow v_{pm} \text{ in 'm/s'; and fmep in 'bar'}$$

But $v_{pm-\max} = \frac{2 \times s \times N_{\max}}{60} \approx \frac{v_{p\max}}{1.6}$

$N_{@Pb-max} \approx$ (0.85 to 0.95) x N_{max}

From the above relations we can get 3600= 0.90* N_{max}

N_{max} = 4000 rpm

$$v_{pm-max} = \frac{2 \times 0.063 \times 4000}{60}$$

$$v_{pm-max} = 8.4 m/s2$$

$$fmep = [0.034 + (0.0113 \times 8.4)] \times 10$$

$fmep$ = 1.28 bar

Where $N_{@Pb-max}$ = Engine speed at maximum brake power

N_{max} = maximum engine speed in rpm

V_{pm} = mean piston velocity

s = Stroke in meter

Indicated mean effective pressure (imep)

$\text{imep} = \text{bmep} + \text{fmep}$ ⇒ bmep in bar; and imep in 'bar' 3.34

$\text{imep} = 7.84 + 1.28$

$\text{imep} = 9.11\text{bar}$

Where bmep= brake mean effective pressure

fmep= friction mean effective presure

Mechanical Efficiency (η_m)

$\eta_m = \frac{\text{bmep}}{\text{imep}} \times 100$ ⇒ bmep in 'bar'; imep in 'bar' and η_m in '%' ...3.35

$$\eta_m = \frac{7.84}{9.11} \times 100$$

$$\eta_m = 86.05\%$$

Where bmep= brake mean effective pressure

Imep= indicated mean effective presure

Indicated Power (P_i)

$P_i = \frac{P_b}{\eta_m}$ ⇒ P_b in 'kW' and P_i in 'kW' 3.36

$$P_i = \frac{1.28}{86.05}$$

$$P_i = 1.48kw$$

Where P_b = brake power

η_m = Mechanical efficiency

Friction Power (P_f)

$P_f = P_i - P_b$ ⇒ P_b in 'kW'; P_i in 'kW' and P_f in 'kW'.........3.37

$$P_f = 1.48 - 1.28$$

$$P_f = 0.2kw$$

Where P_b = brake power

P_i = indicated power

3.9 Kinematic analysis of IC Engines [2]

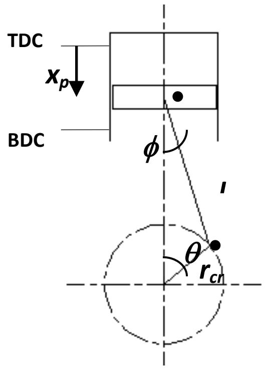


Figure 3. 3: Engine Kinematics

where, ϕ is the angle between the center line of the cylinder and con-rod.

θ is the Crank angle.

Piston displacement (x_p)

$$x_p = (\ell + r_{cr}) - (r_{cr}\cos\theta + l\cos\phi)$$
$$= r_{cr}(1-\cos\theta) + l(1-\cos\phi)$$

and, $\ell \sin\phi = r_{cr}\sin\theta \Rightarrow \sin\phi = \frac{r_{cr}}{\ell}\sin\theta$

$$= \lambda \sin\theta$$

From 'Trigonometry',

$$\sin^2\phi + \cos^2\phi = 1 \Rightarrow \cos\phi = (1-\sin^2\phi)^{1/2}$$
$$\Rightarrow \cos\phi = (1-\lambda^2\sin^2\theta)^{1/2}$$

Expanding by 'Binomial Theorem' and neglecting higher powers of λ,

$$\Rightarrow \cos\phi = \left(1 - \frac{\lambda^2\sin^2\theta}{2}\right)$$

Hence, $(1-\cos\phi) = \frac{\lambda^2\sin^2\theta}{2}$

$$x_p = r_{cr}\left(1-\cos\theta\right) + l\left(\frac{\lambda^2 \sin^2\theta}{2}\right) \quad \ldots\ldots\ldots\ldots\ldots \quad x_p,\ r_{cr} \text{ and } l \text{ are in 'm'.}$$

$$\therefore \quad x_p = r_{cr}\left((1-\cos\theta) + \frac{\lambda \sin^2\theta}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.38$$

Piston velocity (v_p)

$$v_p = \frac{dx_p}{dt} = \frac{dx_p}{d\theta} \times \frac{d\theta}{dt} \quad \Rightarrow \quad \frac{dx_p}{d\theta} = r_{cr}\left(\sin\theta + \frac{\lambda \sin 2\theta}{2}\right) \quad \text{and,}$$

$$\frac{d\theta}{dt} = \varpi = \frac{2\pi N}{60}$$

$$\therefore \quad v_p = \varpi\, r_{cr}\left(\sin\theta + \frac{\lambda \sin 2\theta}{2}\right) \quad \ldots\ldots\ldots\ldots\ldots \quad v_p \text{ in 'm/s'. } \ldots\ldots\ldots;\ldots 3.39$$

The design (maximum) mean piston velocity (v_{pm-max}) can be calculated as,

$$v_{pm-\max} = \frac{2 \times s \times N_{\max}}{60} \approx \frac{v_{p\max}}{1.6}$$

where, s is the Stroke in 'm' and N_{max} in 'rpm'.

From this relation the design (maximum) mean piston velocity (v_{pm-max}) can be determined.

Piston acceleration (a_p)

$$a_p = \frac{dv_p}{dt} = \frac{dv_p}{d\theta} \times \frac{d\theta}{dt} \qquad \frac{dv_p}{d\theta} = \varpi\, r_{cr}\left(\cos\theta + \lambda \cos 2\theta\right) \text{ and,} \qquad \frac{d\theta}{dt} = \varpi = \frac{2\pi N}{60}$$

$$= \varpi^2\, r_{cr}\left(\cos\theta + \lambda \cos 2\theta\right) \quad \ldots\ldots\ldots\ldots\ldots \quad a_p \text{ in 'm/s}^2\text{'. } \ldots\ldots\ldots\ldots\ldots\ldots 3.38$$

Generally we can understand from the above that at different crank angle we can get different piston displacement, velocity and acceleration.

3.10 Experimental test

<u>Experiments</u>

Plotting a power curve and the torque curve at full load

Setting up

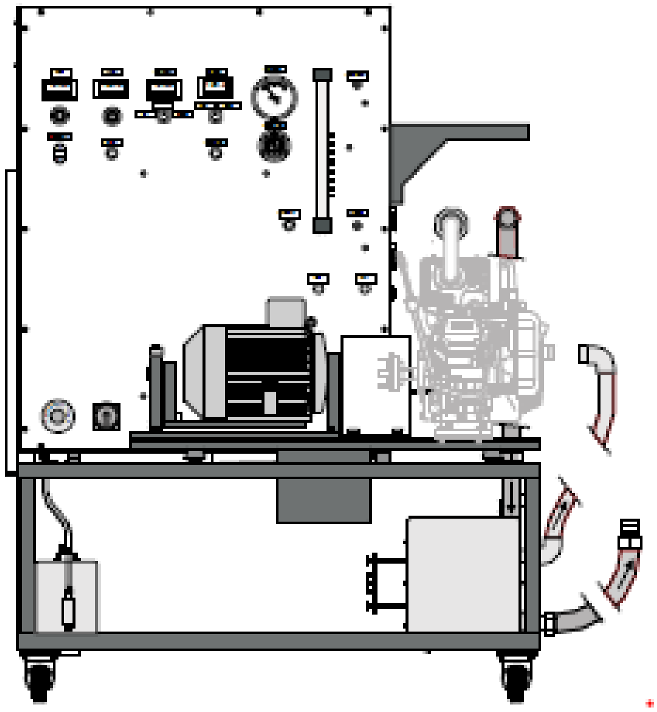


Figure 3.4:Test stand for single cylinder air cooled engine 7.5 kW

Installing and connecting the engine

- The engine and base plate are installed in the CT 110 Test Stand for Small Combustion Engines up to 7.5kW.
- The engine is aligned with to the braking device such that after inserting the center piece of the coupling, the inserts for the two halves of the coupling are aligned (see also the instructions for the CT 110)
- After alignment the fixing bolts for the engine are tightened.
- The safety cover for the coupling is fitted.
- The fuel line to the engine is connected to the supply connection on the CT 110 test stand.
- The other lines on the engine (ignition, vacuum hose and temperature sensor) should be connected to the connections on the test stand as shown below figure.
- The air hose and the exhaust gas hose from the test stand are connected to the engine.

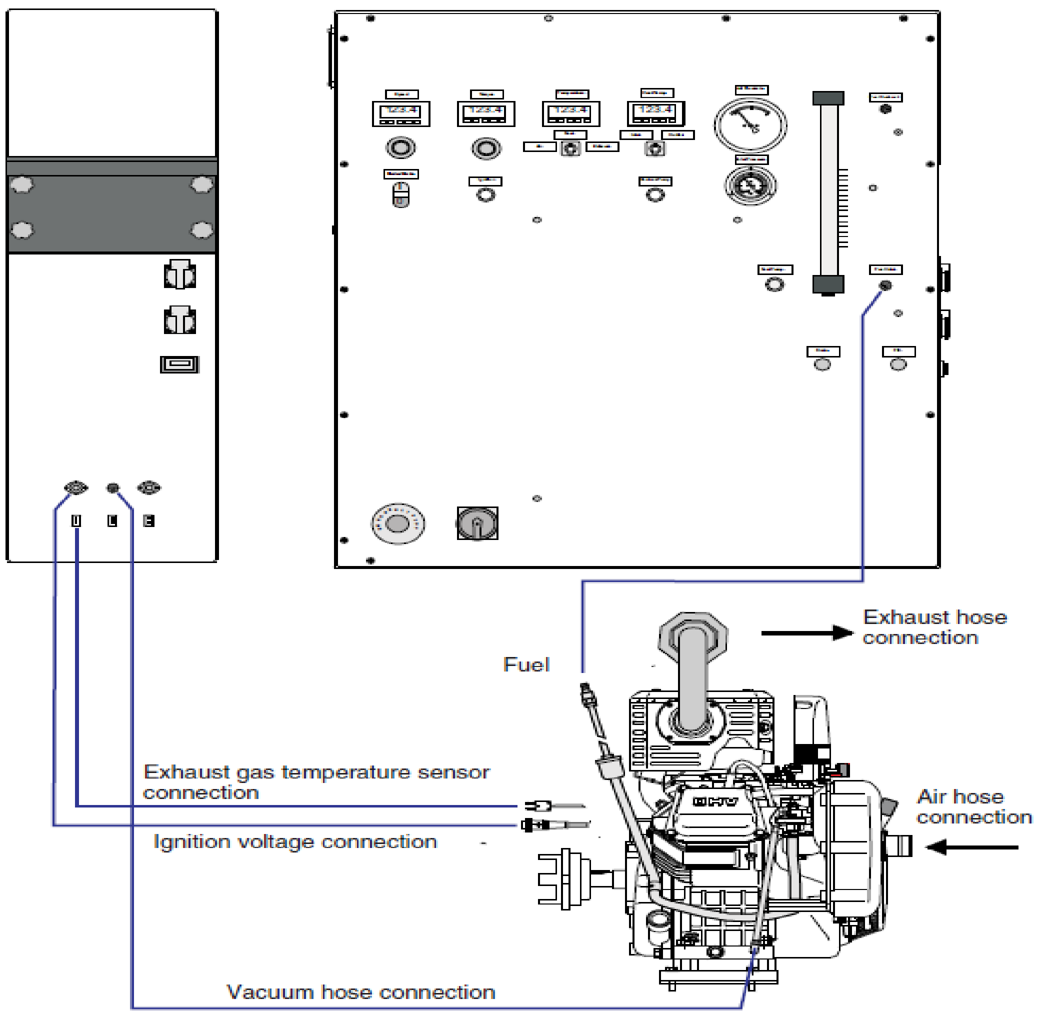


Figure 3.5: connection between CT110 test stand and CT 100.20 engine.

Performing the experiment

- Once the engine has warmed up, operate it at full throttle.
- Apply a load to the engine:
- To do this, set the torque adjusting knob on the CT 110 to a maximum value of "10".
- Set the speed adjusting knob so that the maximum speed in the engine's speed range is reached.
- Operate the "Starter/Brake" button.
- Record the measured values (speed, torque and consumption), i.e. read off the speed and torque on the displays.
- Calculate the fuel consumption using the scale on the measuring tube and a stopwatch.
- To move to the next measuring point, reduce the speed with the adjusting know on the CT 110.
- Record the measured values.
- Repeat the procedure until a speed of around 2200 rpm is reached or the engine comes to a stop.

Determination of specific fuel consumption at 80% partial load

- Performing the experiment
- Once the engine has warmed up, operate it at 80% of full throttle.
- Apply a load to the engine.
- Set the speed adjusting knob on the CT 110 to “0".
- Set the torque adjusting knob on the CT 110 to “0".
- Operate the “Starter/Brake” button.
- Keep the speed constant, i.e. if necessary adjust the speed on the engine with the throttle control lever.
- Record the measured values.
- Read off and note the speed.
- Read and note the torque.
- Determine the consumption using the measuring tube and a stopwatch.
- To move to the next measuring point, increase the torque while keeping the speed of the C engine constant with the throttle control lever.
- Record measured values and repeat the procedure up to the maximum torque.

From below pictures we can understand how performing experiment, measuring result from bench test and installing and connecting to the engine.

Figure 3.6:performing experimental test

Figure 3.7: Measuring results from the bench test

Figure 3.8: Installing and connecting to the engine

CHAPTER FOUR

RESULT AND DISCUSTION

This 'Computer Program (in C++)' is used to determine:
Vehicle Performance, Engine Performance and Engine capacity (Ec) of: a Two-Wheel, a Three-Wheel and a Four-Wheel Motor Vehicles.

4.1 Output of computer C++ program

4.1.1 Engine performance

Engine Size

Engine capacity (Ec) =391.7 cc

swept Volume (Vs) = 391.7 cc

bore (d) = 89.12 mm

stroke (s) = 62.38 mm

maximum piston velocity (V mp_max) = 8.61 m/s

Table 4. 1 Engine performance

Pb	Tb	Bmep	Bsfc	N
(kW)	(Nm)	(bar)	(kg/kWh) (%)	(rpm)
2.43	8.61	1.73	1.41	900
3.95	8.97	1.8	1.3	1400
5.41	9.06	1.82	1.24	1900
6.68	8.86	1.78	1.24	2400
7.64	8.39	1.68	1.3	2900
8.15	7.63	1.53	1.41	3400
8.08	6.6	1.32	1.58	3900

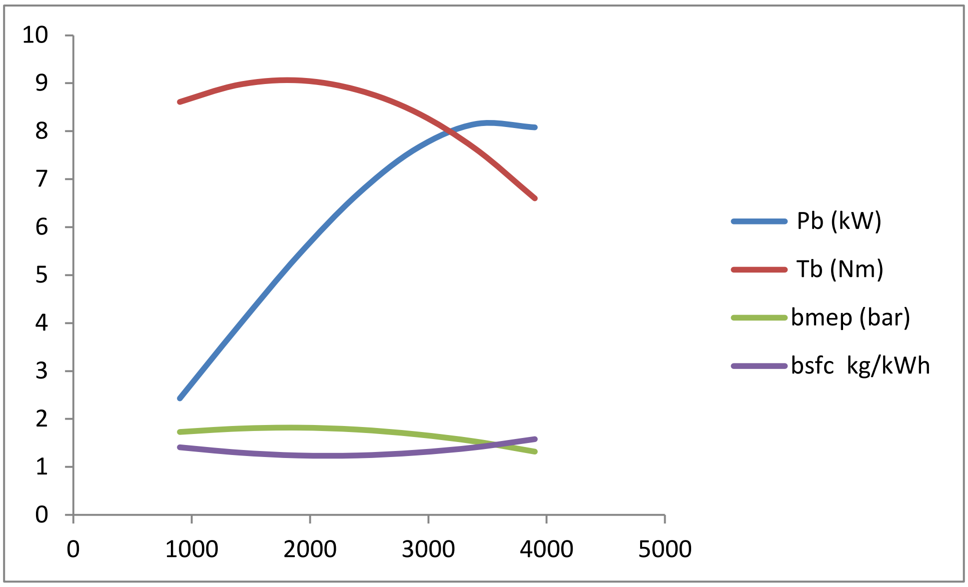


Figure 4.1 Variation of Pb,Tb,bsfc and bmep with engine speed

4.1.1.1 Brake power

Brake power is the function of brake mean effective pressure, engine capacity, and engine revolution per minute and mechanical efficiency. As illustrated from below picture a result of theoretical and experimental maximum brake power is 8.15 kW at 3400 and 7.2 kw at 2984 rpm respectively. This peak pressure mostly depends on the type of fuel used and ignition timing.

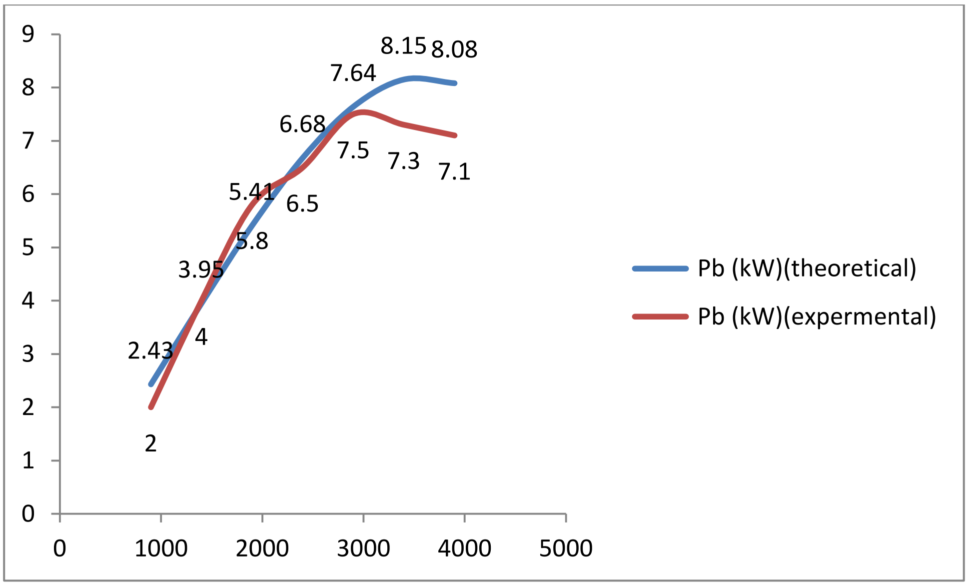


Figure 4.2 Variation of Pb with engine speed

4.1.1.2 Engine brake torque

Brake torque is the function of brake power, engine capacity, and engine rpm. As illustrated from below figure the theoretical and experimental maximum brake torque is 9.06 NM at 1900 rpm and 25.32 at 2426 rpm respectively.

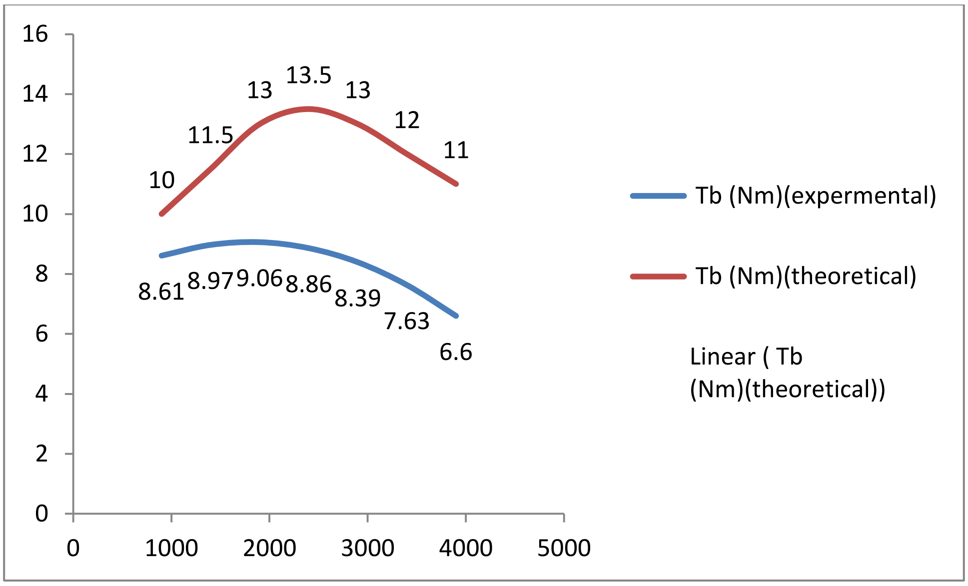


Figure 4.3 Variation of Tb with engine speed

4.1.1.3 Brake specific fuel consumption

Brake specific fuel consumption is high at lower speed and decreasing as speed increase and become optimum at the medium and decrease as speed increase. As that of brake power and torque brake specific fuel consumption diagram is drawn by using empirical method. As shown from below picture the theoretical and experimental maximum fuel consumption result is 1.58 kg/kwh at 3900 rpm and 1.3023 at 3438rpm.

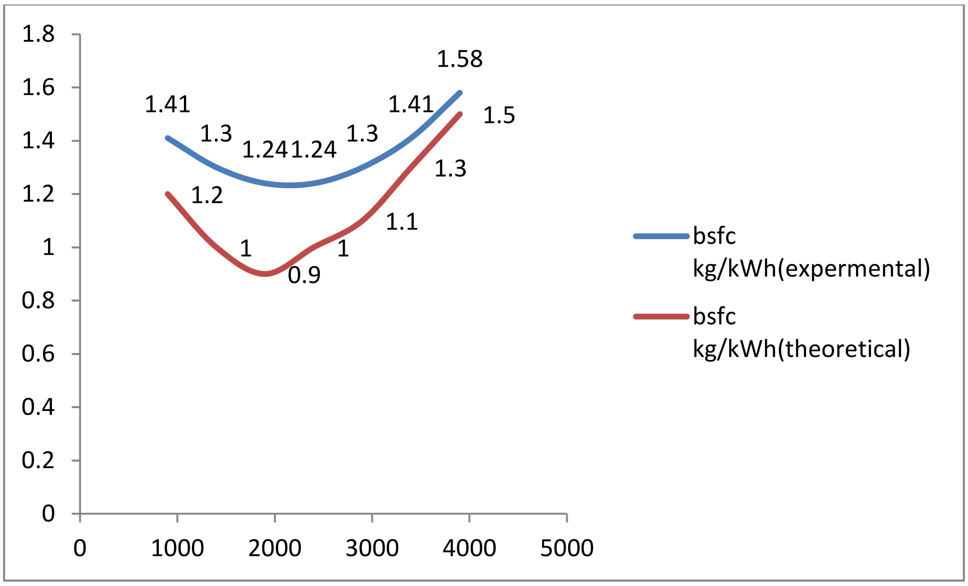


Figure 4.4 Variation of bsfc with engine speed

4.1.2 Kinematic analysis

Table 4.2:'Xp', 'Vp' and 'ap' as a function of 'theta'

theta (deg.)	xp (m)	vp (m/s)	ap (m/s*s)	theta (deg.)	xp (m)	vp (m/s)	ap (m/s*s)
0	0	0	28.623	100	8.24	11.125	-9.751
10	0.12	2.628	27.906	110	9.23	10.092	-12.432
20	0.48	5.125	25.812	120	10.11	8.848	-14.302
30	1.06	7.37	22.502	130	10.86	7.465	-15.455
40	1.84	9.262	18.227	140	11.49	6.003	-16.04
50	2.77	10.726	13.3	150	11.97	4.507	-16.235
60	3.81	11.716	8.066	160	12.32	3.004	-16.217
70	4.92	12.221	2.87	170	12.53	1.506	-16.139
80	6.06	12.258	-1.982	180	12.6	0.014	-16.1
90	7.18	11.872	-6.243				

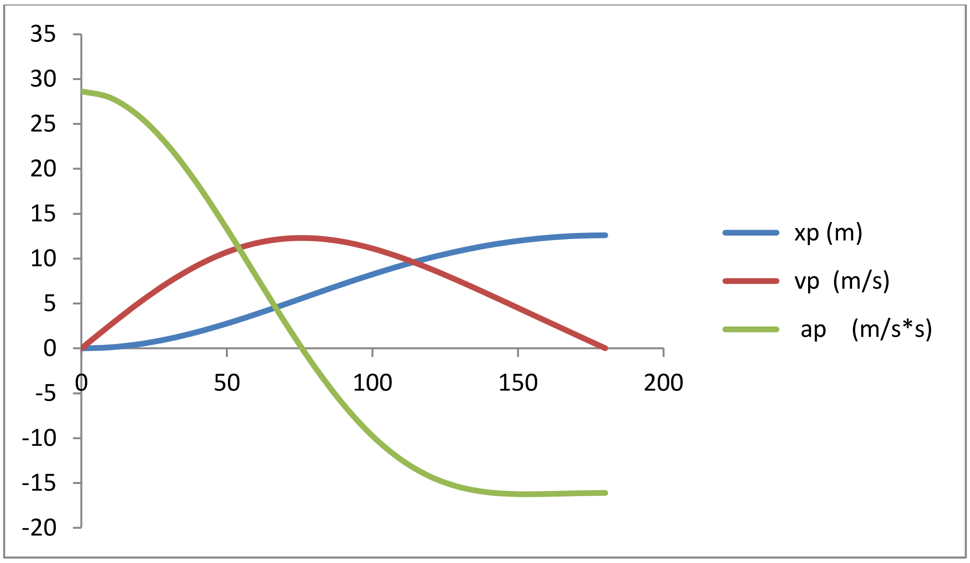


Fig 4.5: Variation of **'Xp', 'Vp' and 'ap'** with **'theta'(crank angle)**

4.1.2.1 Variation of crank angle with piston displacement

Piston displacement (Xp): As we see from the diagram as the crank angle raises the piston displacement also increase proportionally. Due to these 12.6m is the maximum Xp at 180 degree of crank angle.

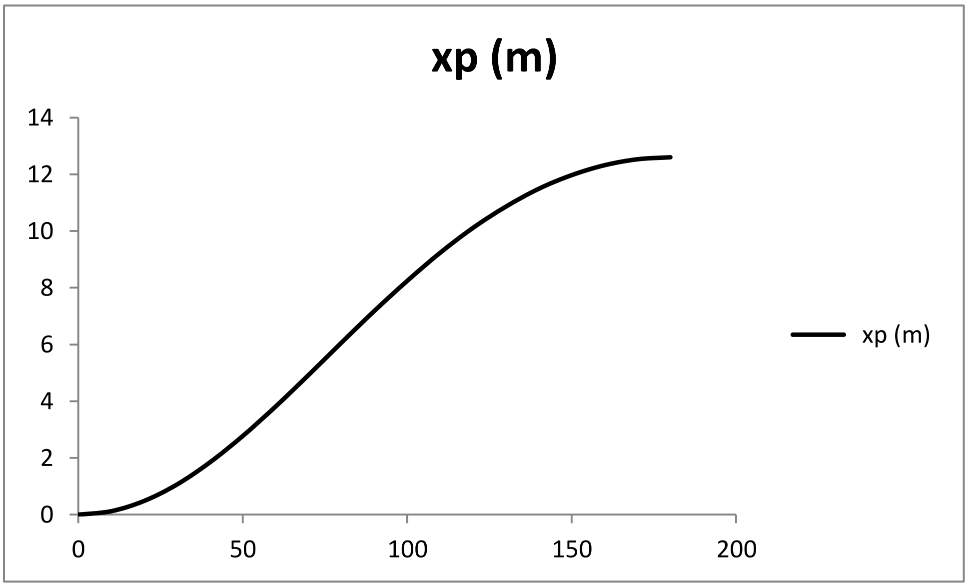


Figure 4.6 Variation of 'Xp' with 'theta'(crank angle

4.1.2.2 Variation of crank angle with piston velocity

Piston velocity (Vp): As we see from below diagram crank angle rises the piston velocity also increases up to some amount and finally reduced. So that 12.258m/s2 is the maximum Vp at 80 degree of crank angle.

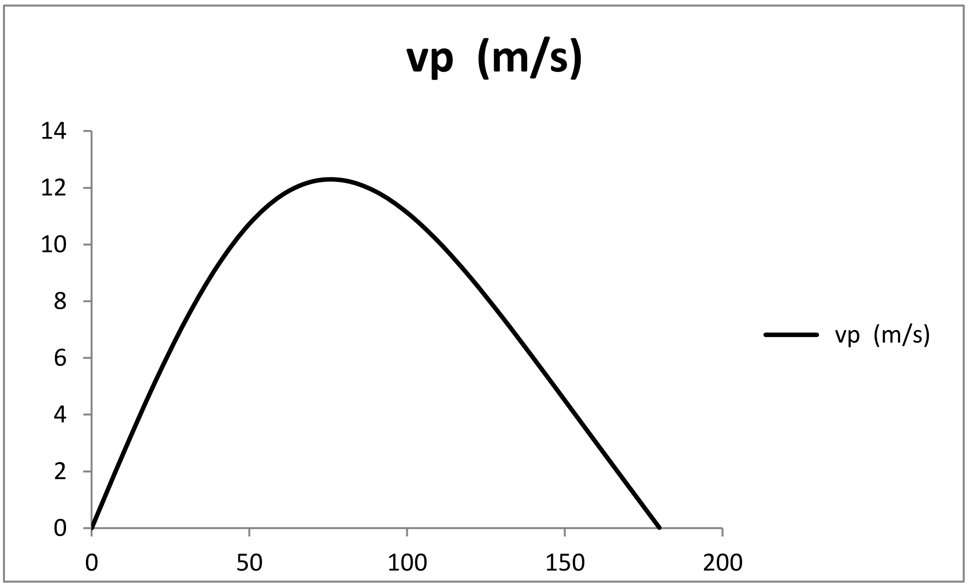


Figure 4.7:Variation of 'Vp' with 'theta'(crank angle)

4.1.2.3 Variation of crank angle with piston acceleration

Piston acceleration (ap): As we illustrated from below diagram crank angle rises the piston acceleration reduced proportionally, and the maximum piston acceleration is at 0 degree of crank angle.

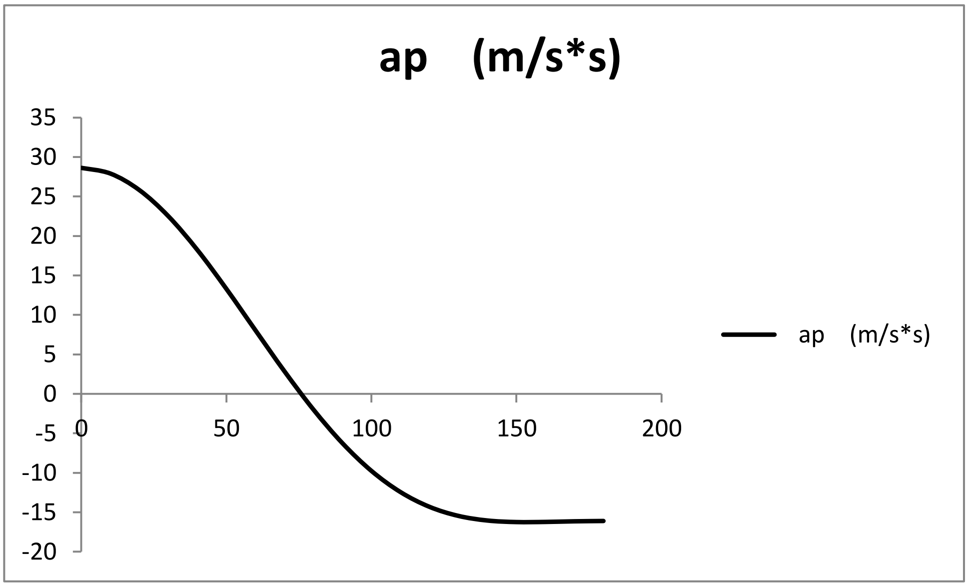


Figure 4.8:Variation of 'ap' with 'theta'(crank angle)

4.1.3 Variation of volume, pressure and temperature with crank angle

Table 4. 3:'V', 'p' and 'T' as a function of 'theta'

theta (deg.)	V (cc)	p (bar)	T (K)	theta (deg.)	V (cc)	p (bar)	T (K)
20	68.66	0.9	323	370	56.39	57.67	2.43E+03
30	88.43	0.9	323	380	68.66	62.71	3.21E+03
40	114.75	0.9	323	390	88.44	51.72	3.41E+03
50	146.37	0.9	323	400	114.75	36.39	3.12E+03
60	181.86	0.9	323	410	146.37	26.2	2.86E+03
70	219.7	0.9	323	420	181.86	19.54	2.65E+03
80	258.39	0.9	323	430	219.71	15.14	2.48E+03
90	296.5	0.9	323	440	258.39	12.16	2.35E+03
100	332.8	0.9	323	450	296.5	10.1	2.24E+03
110	366.27	0.9	323	460	332.8	8.64	2.15E+03
120	396.13	0.9	323	470	366.28	7.59	2.08E+03
130	421.83	0.9	323	480	396.14	6.83	2.02E+03
140	443.04	0.9	323	490	421.84	6.28	1.98E+03
150	459.56	0.9	323	500	443.04	5.87	1.94E+03
160	471.36	0.9	323	510	459.56	5.59	1.92E+03
170	478.42	0.9	323	520	471.36	5.4	1.90E+03
180	480.77	0.9	323	530	478.42	5.3	1.89E+03
190	478.42	0.91	323.55	540	480.77	5.26	1.89E+03
200	471.36	0.92	325.24	550	478.42	1.07	338.13
210	459.56	0.96	328.14	560	471.36	1.07	338.13
220	443.03	1.01	332.37	570	459.56	1.07	338.13
230	421.83	1.07	338.13	580	443.03	1.07	338.13

240	396.13	1.17	345.65	590	421.83	1.07	338.13
250	366.27	1.3	355.26	600	396.13	1.07	338.13
260	332.8	1.48	367.38	610	366.27	1.07	338.13
270	296.49	1.73	382.54	620	332.8	1.07	338.13
280	258.38	2.08	401.41	630	296.49	1.07	338.13
290	219.7	2.59	424.85	640	258.38	1.07	338.13
300	181.86	3.34	453.91	650	219.7	1.07	338.13
310	146.37	4.48	489.75	660	181.86	1.07	338.13
320	114.75	6.23	533.3	670	146.37	1.07	338.13
330	88.43	8.85	584.21	680	114.75	1.07	338.13
340	68.66	12.45	638.32	690	88.43	1.07	338.13
350	56.39	17.79	748.78	700	68.66	1.07	338.13
360	52.23	37.04	1.44E+03				

4.1.3.1 Pressure versus volume diagram

The peak pressure is one of the determinant factor for brake power and other engine performance parameter. This peak pressure depends on compression ratio, environmental pressure and the nature of fuel used. As illustrated from below diagram the Value of this pressure is the same with maximum pressure (62.71 bar) developed in the engine.

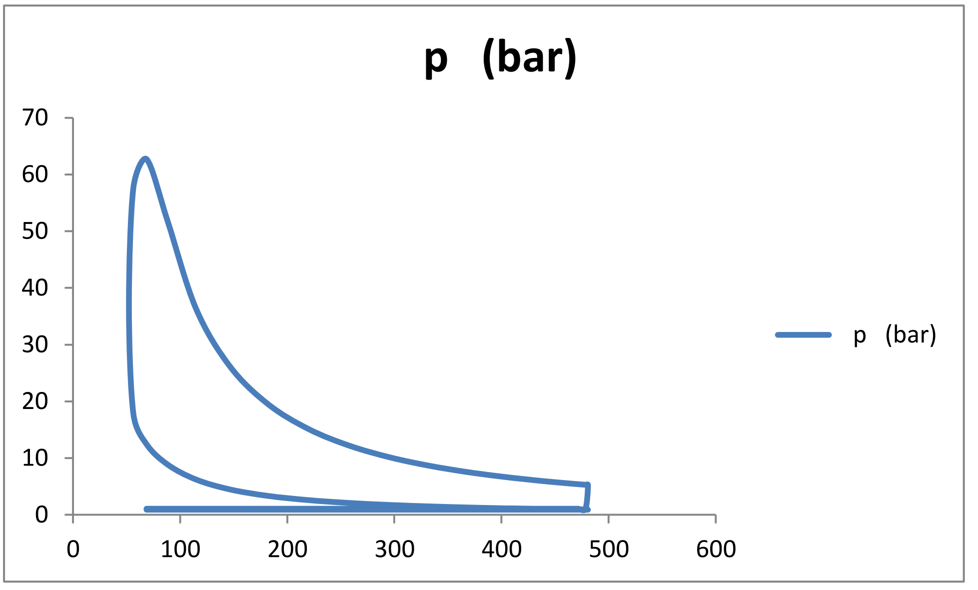


Figure 4.9: P-V diagram

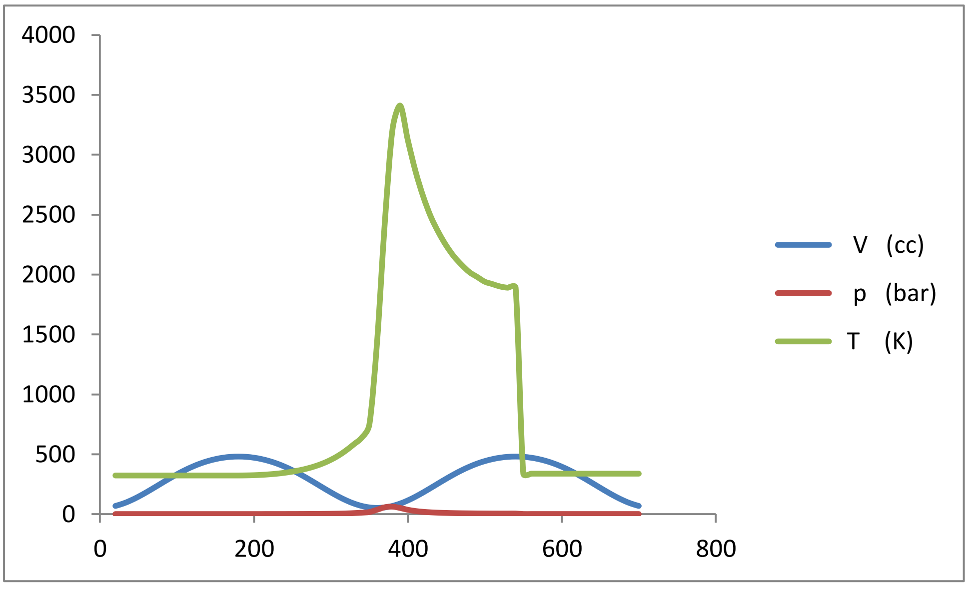


Figure 4.10: Variation of 'V', 'P' and 'T' with 'theta'

4.1.3.2 Variation of temperature with crank angle

The maximum temperature is created at 390^{o} of crank angle which can be adjusted initially on the engine. This temperature can be affected by ambient temperature of environment.so it depends on the initially on the environmental temperature. The angle at which combustion started before TDC and the duration of combustion determine the crank angle at which maximum temperature occurred.

This temperature (Tmax) could affect the work net from the engine which has direct relations with brake power and other engine performance parameter. From below diagram we can see that for this specific engine and environment the maximum temperature created in engine is 3410k.

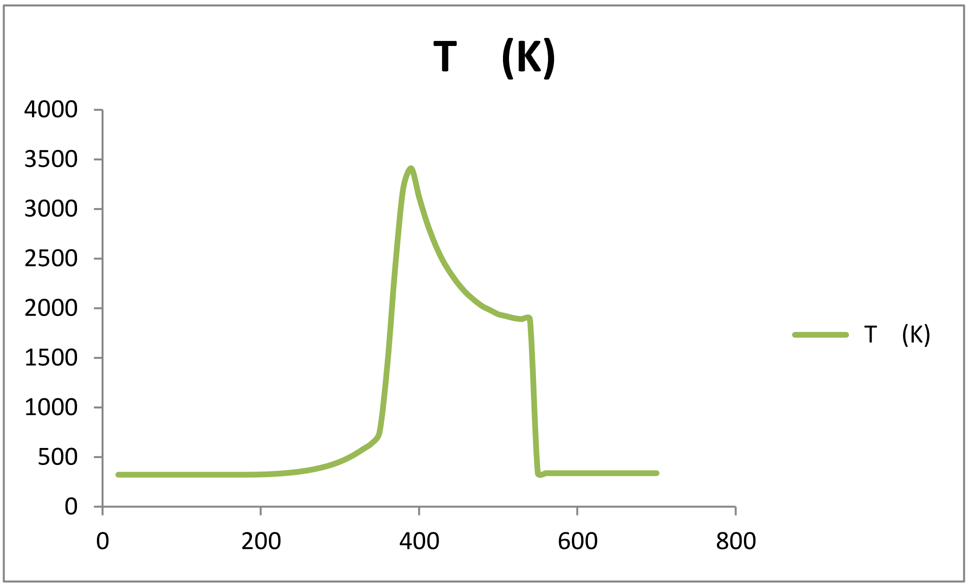


Figure 4.11: Variation of Temperature with 'theta'

4.1.3.3 Variation of volume with crank angle

The volume created in the engine depends on the like compression ratio, bore, stroke and the length of connecting rod. Due to positive and negative displacement in the cylinder the volume created was changes between total volume of cylinder and clearance volume of cylinder. As we illustrated from below figure for these specific engine the maximum volume created in the engine is 480.77cc at both 180 and 540 degree of crank angle.

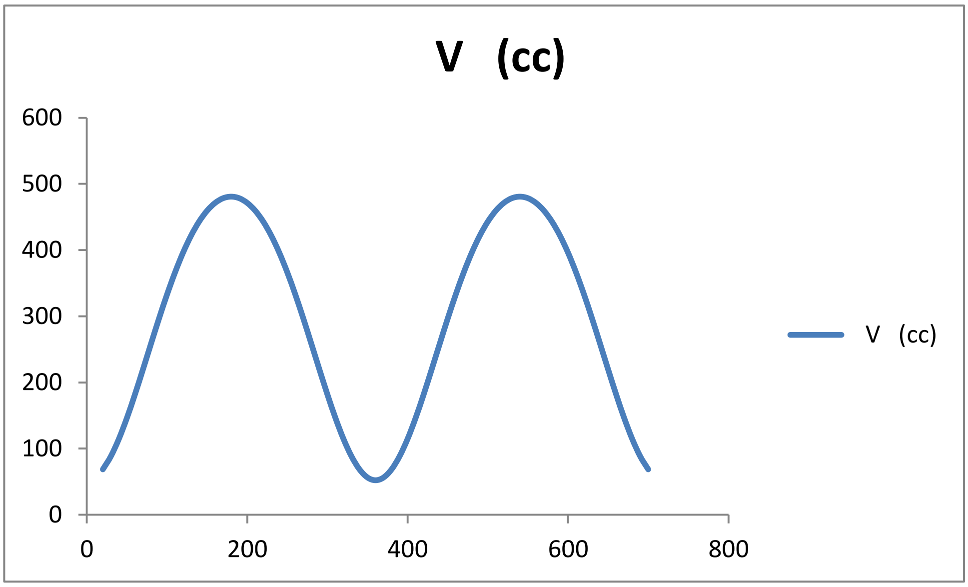


Figure 4.12: variation of volume with respect to crank angle variation

4.1.3.4 Variation of pressure with crank angle

Temperature developed in engine and pressure created in engine are interdependent. The maximum pressure is created at 360^o ,370^o ,380^o and 390^o of crank angle which can be adjusted on the engine and not constant for all engine. The angle at which combustion started before TDC and the duration of combustion determine the crank angle at which maximum pressure occurred. As we show from below diagram for these specific engine and environment the maximum pressure created in engine is 62.71 bar.

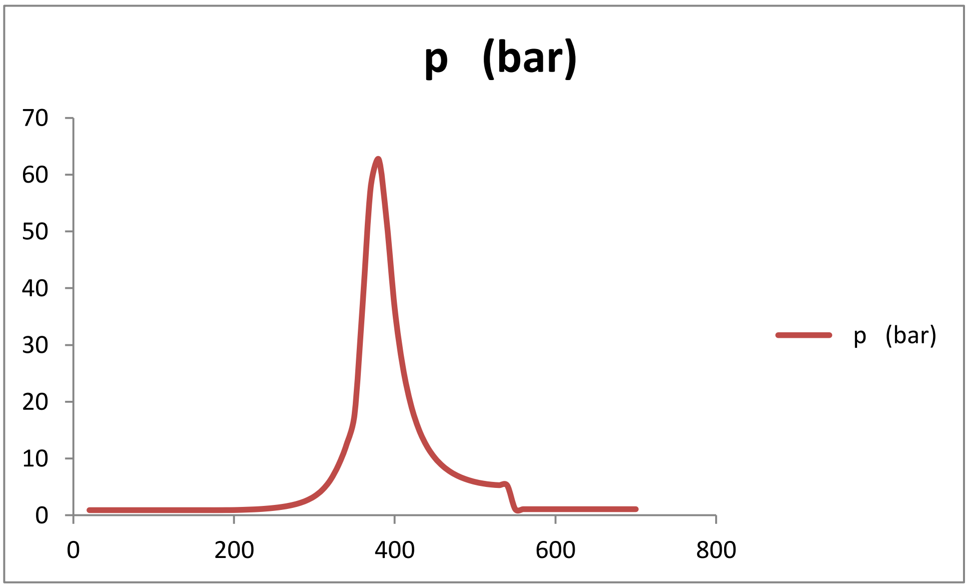


Figure 4.13: variation of pressure with respect to crank angle variation

4.2 Test results

4.2.1 Test result at full load

Table 4. 4:Test Result at full load

Worksheet for data acquisition on CT 100.20				
Name: Yohannis G/tsadik				**Date: 09.08.18**
Ambient temperature: 23°C				
Experiment: Plotting the full load characteristic curve				
Load	**Speed**	**Torque**	**Power**	**Fuel consumption**
Full throttle, 3/4, 1/2, ¼	**In rpm**	**In Nm**	**In kW**	**in kg/h**
Full Load	3438	12.21	1.3	1.3023
	3420	12.52	1.5	0.8992
	3406	13.11	2.6	0.8837
	3367	16.01	4.2	0.8320
	3226	20.12	6.7	0.7958
	3098	22.02	7.0	0.8630
	2984	22.31	7.2	0.8475
	2972	23.01	7.1	0.8475
	2776	23.51	6.8	0.7286
	2640	24.06	6.5	0.7658
	2582	25.02	6.4	0.7545
	2426	25.32	6.2	0.7286
	2306	24.51	6.0	0.6511
	2213	23.38	5.8	0.6925

Note: - Pleas know that, if you go further down to 1000 rpm the power and the torque will be reduced continually. From the table we can understand that the:-

The maximum brake power is 7.2 kw at 2984 rpm

The maximum engine torque is 25.32 at 2426 rpm

The maximum and minimum fuel consumption is 1.3023 kg/h at 3438 rpm and 0.6511 at 2306 rpm respectively.

4.2.2 Test result at partial load

Table 4. 5:Test result of specific fuel consumption

Worksheet for data acquisition on CT 100.20			
Name:		**Date:09/08/2018**	
Ambient temperature: 23°C			
Experiment: Determination of specific fuel consumption at 80% partial load			
Load	**Speed**	**Torque**	**Time for consumption of 1 cm of fuel in measuring tube**
Full throttle, 3/4, 1/2, ¼	**Rpm**	**Nm**	**In s**
80% full throttle	2800	0.8	23.5
	2800	2.9	22.5
	2800	5.1	13.5
	2800	10.5	9
	2800	13.5	8.5
	2800	20	8
	2800	21	7.5
	2800	21.5	6

From the above table we can understand that:

- The maximum engine torque is 21.5 at 2800 rpm at 80% partial load.

CHAPTER FIVE

CONCLUSION AND RECOMENDATIONS

5.1 Conclusion

From the study result the following conclusion are drawn

- For the P-V diagram model the results obtained or the maximum pressure developed in these engine is 62.71 bar.
- The results obtained from the last simulation that variation of pressure, volume and temperature with engine crank angle is good. And the maximum temperature created in these engine is 3410k at 390^o degree of crank angle, maximum volume created in these engine is 480.77 cc at both 180 and 540 degree of crank angle and The maximum pressure is 62.71 bar created at 360^o ,370^o ,380^o and 390^o of crank angle.
- The results obtained from engine performance with respect to engine rpm are good. Which means the maximum brake power is 8.15 kW at 3400 rpm, maximum brake torque is 9.06 NM at 1900 rpm and maximum fuel consumption result is 1.58 kg/kwh at 3900 rpm for these engine.
- The engine kinematics with respect to crank angle outcome is also good. Which means the maximum piston acceleration is at 0 degree of crank angle, the maximum piston velocity is 12.258 m/s2 at 80 degree of crank angle and the maximum piston displacement is 12.6m at 180 degree of crank angle for this engine.
- These computer simulations help us to understanding more clearly the nature of the flows and combustion in internal combustion engines.
- These computer simulations aid us enlarge Innovation and technology transfer, these helps to obtain economic growth in one country and
- These simulation helps to improving the performance of internal combustion engines

5.2 Recommendation

From the study result the following recommendation are drawn:

- To have further research on the field and to get more enhanced results than the present outcomes.
- To use as a teaching methodology, because computer simulation help us to understand complex systems more clearly.
- To have further research on different Engine models, vehicle types and fuel types.
- Automotive companies and industry invest money on the field, because the study helps to improve engine performance and so on.
- To use as a training methodology on the field, since the study helps to make clear and how to operate the complex system

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Appendix

Computer programing

Program one:

```
// Engine Performance (EP)

#include<iostream.h>

#include<conio.h>

#include<math.h>

#include<fstream.h>

#include<iomanip.h>

 void main()

   {

    clrscr();

     float PbEc_ratio,nos,z,sd_ratio,z_ratio,Pb_max,Pb,N,Nmin;

     float bsfc_Pb_max,Tb_max,N_Tb_max,Tb_x,Tb,bsfc,x,bmep,fmep,Zrpc;

     float Ec,N_Pb_max,Nmax,Vs,pp,d,dmm,s,smm,v_pm,bmep_max,x_max,n_cps;

     float imep,ETA_m, ETA_i,ETA_c,ETA_c_per,ETA_b_th,Pi,Qin,Q_LHV,zs;

     float OMEGA,OMEGA_Pb_max,p1,p2,p3,mf_g_h,mf_kg_h,mf_lit_h,sg,ETA_m_per;


     float Pb_Tb_max,n,Nratio_Tbm_Pbm,nos1,Ec_lit,Ec_cc,Vs_cc,d_mm,s_mm;

     float mf_kg_s,mf_lit_s,Vs_lit,v_pm_max,d_cm,Pb_max_kW,bmep1,CF1,CF2;

     float Tbi,bmepi,bsfci;

     const float PI = 3.1416;

     ofstream outfile ("P1-SI.dat");
```

```
cout << "\n\n\t\t  Adama Science and Technology University (ASTU) ";

outfile << "\n\n\t\t  Adama Science and Technology University (ASTU) ";

cout << " \n\t         Department of Mechanical and Vehicle Engineering ";

outfile << " \n\t         Department of Mechanical and Vehicle Engineering ";

cout << " \n\t\t                Yohannes G/tsadik ";

outfile << " \n\t\t             Yohannes G/tsadik ";

cout << "\n\t\t\t       ****************** ";

outfile << "\n\t\t\t         ****************** ";

cout << "\n\n\t\t          A Computer Program in C++";

outfile << "\n\n\t\t          A Computer Program in C++";

cout << " \n\n\t       to plot the Performance Curves of SI Engines ";

outfile << " \n\n\t    to plot the Performance Curves of SI Engines ";

cout << "\n\t    ............................................... ";

outfile << "\n\t    ............................................. ";

cout <<"\n\n  Enter the 'Engine capacity' in 'cc': ";

cin >> Ec_cc;

cout <<"\n  Enter the maximum 'brake Power' in 'kW': ";

cin >> Pb_max;

cout <<"\n  Enter the 'number of cylinders (z)': ";

cin >> z;

cout <<"\n  Enter the ratio of 'stroke (s)' to 'bore (d)' (0.8 to 1.2): ";

cin >> sd_ratio;

cout <<"\n  Enter the 'Engine Speed at Pb_max' (3000 to 7000 rpm): ";
```

```
cin >> N_Pb_max;

cout <<"\n  Enter the 'Minimum (Idling) Speed' (700 to 1000 rpm): ";

cin >> Nmin;

cout <<"\n  Enter the ratio of 'N at Tb_max' to 'N at Pb_max' (0.4 to 0.8): ";

cin >> Nratio_Tbm_Pbm;

cout <<"\n  Enter the 'bsfc' at the Maximum Brake Power in 'kg/kWh': ";

cin >> bsfc_Pb_max;

cout <<"\n  Enter the 'Lower Heating Value of the Fuel (Q_LHV)'(40 to 45 MJ/kg): ";

cin >> Q_LHV;

cout <<"\n  Enter the 'specific gravity (sg) of the Fuel (0.7 to 0.8): ";

cin >> sg;

cout <<"\n  Enter the 'Combustion Efficiency' in (85 to 98 %): ";

cin >> ETA_c_per;

clrscr();

cout << "\n\n\t\t  Adama Science and Technology University (ASTU) ";

outfile << "\n\n\t\t  Adama Science and Technology University (ASTU) ";

cout << " \n\t         Department of Mechanical and Vehicle Engineering ";

outfile << " \n\t         Department of Mechanical and Vehicle Engineering ";

cout << " \n\t\t              Yohannes Gtsadik ";

outfile << " \n\t\t           Yohannes Gtsadik ";

cout << "\n\t\t\t       ****************** ";

outfile << "\n\t\t\t         ****************** ";

cout << "\n\n\t\t          A Computer Program in C++";
```

```
outfile << "\n\n\t\t          A Computer Program in C++";

cout <<"\n.................................................................. ";

outfile <<"\n.................................................................. ";

   cout << "\n\n  Engine Performance Curves";

   cout << "\n ______________________________";

   outfile << "\n\n  Engine Performance ";

   outfile << "\n _______________________";

   cout << "\n\n\t  N\t Pb\t Tb\tbmep\tbsfc ";

   outfile << "\n\n\t  \t Pb\t Tb\tbmep\tbsfc ";

   cout << "\n\t(rpm)\t(kW)\t(Nm)\t(bar)\tkg/kWh \n";

   outfile << "\n\t(rpm)\t(kW)\t(Nm)\t(bar)\tkg/kWh \n";

             ETA_c = ETA_c_per/100.0;  Ec_lit = Ec_cc*1.0e-3;

             zs = 4.0; Zrpc = zs/2.0;  Nmax = N_Pb_max*1.15;

for(N = Nmin; N <= Nmax; N = N+500.0)

  {

    OMEGA = (2.0*PI*N)/60.0;

    x = N/N_Pb_max; n_cps = N/(Zrpc*60.0);

    Pb = Pb_max*(-(x*x*x)+(x*x)+x);

    Tb = (Pb*1000.0)/OMEGA;

    bmep = ((Pb*1.0e3)/(Ec_cc*1.0e-6*n_cps))*1.0e-5;

    bsfc = bsfc_Pb_max*((x*x)-(1.2*x)+1.2);

    mf_kg_h = bsfc*Pb;

    mf_kg_s = mf_kg_h/3600.0;
```

```
//   mf_lit_h = mf_kg_h/sg;

//   mf_lit_s = mf_lit_h/3600.0;

//   Vs_lit = Vs_cc/1000.0;

     Vs_cc = Ec_cc/z;

     pp = (4.0*Vs_cc)/(PI*sd_ratio);

     d_cm = pow(pp,0.333);

     d_mm = d_cm*10.0;

     s_mm = d_mm*sd_ratio;

     v_pm = (2.0*s_mm*1.0e-3*N)/60.0;

     v_pm_max = (2.0*s_mm*1.0e-3*Nmax)/60.0;

  if ( sd_ratio > 1.0 )

     fmep = 0.049+(0.0152*v_pm);

    else if ( sd_ratio <= 1.0 )

     fmep = 0.039+(0.0132*v_pm);

     imep = bmep+fmep;

     ETA_m = bmep/imep;

     ETA_m_per = (bmep/imep)*100.0;

     Pi = Pb/ETA_m;

     Qin = ETA_c*(mf_kg_s*Q_LHV*1.0e3);

     ETA_i = (Pi/Qin)*100.0;

     ETA_b_th = (Pb/(mf_kg_s*Q_LHV*1.0e3))*100.0;

     Tbi = Tb/3.0; Tb = Tbi; bmepi = bmep/1.2; bmep = bmepi;

     bsfci = bsfc*10.0; bsfc = bsfci;
```

```
        cout << setprecision(3)<<"\n\t"<<N;
        outfile << setprecision(3)<<"\n\t"<<N;
        cout << setprecision(2)<<"\t"<<Pb;
        outfile << setprecision(2)<<"\t"<<Pb;
        cout << setprecision(2)<<"\t"<<Tb;
        outfile << setprecision(2)<<"\t"<<Tb;
        cout << setprecision(2)<<"\t"<<bmep;
        outfile << setprecision(2)<<"\t"<<bmep;
        cout << setprecision(2)<<"\t"<<bsfc;
        outfile << setprecision(2)<<"\t"<<bsfc;
//      cout << setprecision(2)<<"\t"<<mf_kg_h;
//      outfile << setprecision(2)<<"\t"<<mf_kg_h;
//      cout << setprecision(2)<<"\t"<<ETA_m_per;
//      outfile << setprecision(2)<<"\t"<<ETA_m_per;
//      cout << setprecision(2)<<"\t "<<ETA_b_th;
//      outfile << setprecision(2)<<"\t "<<ETA_b_th;
      getch();
     }
   cout << " \n\n\n\n\t\t Press 'Enter' twice to proceed ... " ;
   getch();
   getch();
        cout << "\n\n\n\tEngine capacity (Ec) = "<<setprecision(3)<<Ec_cc<<" cc ";
        outfile << "\n\n\n\tEngine capacity (Ec) = "<<setprecision(3)<<Ec_cc<<" cc ";
```

```
cout << "\n\n\tswept Volume (Vs) = "<<setprecision(2)<<Vs_cc<<" cc ";

outfile <<"\n\n\tswept Volume (Vs) = "<<setprecision(2)<<Vs_cc<<" cc ";

cout << "\n\n\tbore (d) = "<<setprecision(2)<<d_mm<<" mm ";

outfile <<"\n\n\tbore (d) = "<<setprecision(2)<<d_mm<<" mm ";

cout << "\n\n\tstroke (s) = "<<setprecision(2)<<s_mm<<" mm ";

outfile <<"\n\n\tstroke (s) = "<<setprecision(2)<<s_mm<<" mm ";

cout << "\n\n\tmaximum piston velocity (V_mp_max) =
"<<setprecision(2)<<v_pm_max<<" m/s ";

outfile <<"\n\n\n\tmaximum piston velocity (V_mp_max) =
"<<setprecision(2)<<v_pm_max<<" m/s ";

cout << "\n\n\tQin = "<<setprecision(2)<<Qin<<" kW ";

cout << " \n\n\n\n\t\t Press 'Enter' twice to end ! " ;

getch();

getch();

getche();

}
```

Programing two

A computer programm in C++ to plot: 'xp', 'vp' and 'ap' vrs.theta

```
#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<iomanip.h>
#include<fstream.h>
 void main()
  {
    float r,rlratio,omega,rad,rpm,rcr,rcrl,theta;
```

```
    const float  phi = 3.14;
    float xp,vp,ap;
  ofstream outfile ("P2-SI.dat");
  clrscr();
  cout << "\n\n\t\t  Adama Science and Technology University (ASTU) ";
  cout << " \n\t           Mechanical Systems and Vehicle Engineering ";
  cout << " \n\t\t         Yohannes g/tsadik ";
  cout << "\n------------------------------------------------------------------------------ ";
  cout << " \n\t\t Design of Spark-Ignition (SI) Engine " ;
  cout << "\n P2-SI: A computer programm in C++ to plot: 'xp', 'vp' and 'ap' vrs. 'theta' " ;
  cout << "\n.................................................................................. ";
   cout <<  "\n Enter the maximum engine speed(in rpm) = ";
   cin >> rpm;
   cout <<  "\n Enter crank radius (in mm) = ";
   cin >> rcr;
   cout <<"\n Enter the ratio of crank to con-rod length (0.2 to 0.3) = ";
   cin >> rcrl;
   r = rcr/1000.0;
   omega = rpm*(phi/30.0);
     cout << "\n\n\ttheta" <<"\t  xp"<<"\t  vp"<<"\t   ap ";
     outfile << "\n\n\ttheta" <<"\t  xp"<<"\t  vp"<<"\t   ap ";
     cout << "\n\t(deg.) " <<"  (m) " <<" \t (m/s) " << "\t  (m/s*s) \n";
     outfile << "\n\t(deg.) " <<"  (m) " <<" \t (m/s) " << "\t  (m/s*s) \n";
      for (theta = 0.0; theta <= 180.0; theta = theta + 10.0 )
      {
            rad = (theta*phi)/180.0;
            xp = (r*((1.0-cos(rad))+(rcrl*(sin(rad)*sin(rad))/2.0)))*200.0;
            vp = omega*r*(sin(rad)+(rcrl*sin(2.0*rad))/2.0);
            ap = (omega*omega*r*(cos(rad)+(rcrl*cos(2.0*rad))))/200.0;
             cout <<"\n\t"<<theta <<"\t"<<setprecision(2)<<
xp<<"\t"<<setprecision(3)<<vp<<"\t "<<setprecision(3)<<ap;
             outfile <<"\n\t"<<theta <<"\t"<<setprecision(2)<<
xp<<"\t"<<setprecision(3)<<vp<<"\t "<<setprecision(3)<<ap;
             getch();
```

```
            }
   cout << " \n\n\t\t Press any key twice to return ! " ;
   getch();
   getche();
    }
```

Programing three

```
// Actual Engine Cycle - SI Engine (AEC-SI1).
#include<iostream.h>
#include<iomanip.h>
#include<conio.h>
#include<math.h>
#include<fstream.h>
 void main()
  {
    float Ec_cc,Zc,Rsd,Rrl,a,b,RHO_kgplit,QLHV,ZC,ZH,ZO;
    float xR_per,LAMBDA,pim,p1,T1,Rc,N,ETA_mper,theta_ivobTDC;
    float theta_ivcaBDC,theta_scbTDC,theta_dc,theta_evobBDC,theta_evcaTDC;
    float Zs,Z_rpc,ETA_m,xR,theta_a,theta_b,theta_ivc,theta_1,theta_sc;
    float theta_2,theta_ec,theta_3 = theta_ec,theta_evo,theta_4,theta_5;
    float theta_6,theta_0,Ec_liter,Ec,Vs,Vcl,Vt,Vs_cc,Vcl_cc,Vt_cc,d,d_mm;
    float powd,s,s_mm,r,r_mm,lcon,lcon_mm,Ap,g,Ru,mA,mF,mres,Tim,theta_c;
    float a1O2r,a2O2r,a3O2r,a4O2r,cpO2,cvO2,a1N2r,a2N2r,a3N2r,a4N2r,cpN2;
    float cvN2,cpA6b,cvA6b,MmA,cp6b,cv6b,R6b,n6b,RHO6b,v6b,Z6b,Z1,V1,R1;
    float mm,MmO,MmN,MmC,MmH,yO2,yN2,MmO2,MmN2,xG,xF,MmG,QLHV_G;
    float nG,yG,yF,MmF,n1th,n2th,atha,ath,n3th;
    float
n10,n3,n1r,n1,n2,nt,y1,y2,y3,y10,MmAth,MmFth,nO2,nN2,nA,AFth,AF,QLHV_F;
    float RHO_Fkgplit,RHO_F,ETA_cmax,ETA_c,ETA_cper,T6bi,RHO_Gkgplit;
    float Rm,Zm,Vm,n4,n5,y4,y5,Mm1,Mm2,Mm3,Mm4,Mm5,nF,Tb_NM;
    const float PI = 3.1416; g = 9.81; Ru = 8.314;
// process 0-b (constant pressure intake process).
    float V0bi,p0bi,T0bi,m0bi,R0bi,rad,Z0b,xp0b,Vs0b,V0b,p0b,T0b,R0b,m0b;
```

```
    float Vb,pb,Tb,mb,thetab,deltheta,theta,mb1i;
// process b-1 (polytropic compression):
    float Vb1i,pb1i,Tb1i,Rb1i,xpb1,Vsb1,Vb1,delmb1,VbVb1,nb1,nb1T,Rb1;
    float Zb1,pb1,Tb1,mb1,theta1;
// process 1-2 (polytropic effective compression):
    float m12i,V12i,p12i,T12i,xp12,Vs12,V12,V1V12,n12,n12T,R12,Z12;
    float p12,T12,m12,V2,p2,T2,theta2;
// process 2-3 (polytropic combustion):
    float V23i,p23i,T23i,T23,W23i,xp23,Vs23,V23,m23,theta2dc,rad2dc;
    float xb,Qin,Q1,Q23,cpO2o2,R23;
    float cpN2o2,cpFo2,cpr2,cvr2,Mmr2,cp2,cv2,R2,m2,RHO2;
    float v2,hfoF,hfoO2,hfoN2,delhFo2,delhO2o2,delhN2o2,UrFo2,UrO2o2,UrN2o2;
    float
Ur2,Ur,a1CO2p,a2CO2p,a3CO2p,a4CO2p,cpCO2,cvCO2,cp123,a1H2Op,a2H2Op;
    float a3H2Op,a4H2Op,cpH2O,cvH2O,cp223,a1N2p,a2N2p,a3N2p,a4N2p;
    float cp323,a1O2p,a2O2p,a3O2p,a4O2p,cp423,a1COp,a2COp,a3COp;
    float a4COp,cpCO,cvCO,cp523,cp23_kmol,cv23_kmol,Mm23,n23,cp23,cv23;
    float delh1o23,delh2o23,delh3o23,delh5o23,hfo1,hfo2,hfo3,hfo4,hfo5,U123;
    float U223,U323,U423,U523,U23,Up,Qin23,mF23,nF23,delUpr,error23,T3;
    float p23,delV23,delW23,W23,V3,p3,m3,theta3,To,Qin1,QW23;
// process 3-4 (polytropic expansion):
    float V34i,p34i,T34i,m34i,xp34,Vs34,V34,V3V34,n34,n34T,R34,Z34,p34,T34;
    float delm34,m34,V4,p4,T4,theta4;
// process 4-5 (polytropic exhaust blowdown):
    float V45i,p45i,T45i,m45i,xp45,Vs45,V45,V4V45,n45,n45T,R45,Z45,p45,T45;
    float delm45,m45,V5,p5,T5,theta5;
    // process 5-6 (polytropic exhaust):
    float xp56,Vs56,V56,V5V6,m56,V6,theta6,p6,T6;
// engine parameters
    float Wnet,ETA_ith,ETA_ithper,imep_bar,W12,W2,W3,Q3,W4,W34,W45,W5;
    float Wi,n_cps,Pi,Pb_kW,mF_kgps,mF_kgph,bsfc,LAMBDAMAX,LAMBDAMIN;
    float na,ng,nag,na1,n5r,na2;
 clrscr ();
 ofstream outfile ("EAEC-SI3.dat");
```

```
cout << "\n\n\t\t  Adama Science and Technology University (ASTU) ";
outfile << "\n\n\t\t  Adama Science and Technology University (ASTU) ";
cout << " \n\t         Department of Mechanical and Vehicle Engineering ";
outfile << " \n\t         Department of Mechanical and Vehicle Engineering ";
cout << " \n\t\t         Yohannes g/tsadik ";
outfile << " \n\t\t         Yohannes g/tsadik ";
cout << "\n.................................................................................. \n";
outfile << "\n....................................................................... \n";
cout <<"\n Enter the 'Engine capacity (Ec_cc)' in 'cc' = ";
cin >> Ec_cc;
cout <<"\n Enter the 'Number of cyliders (Zc)' = ";
cin >> Zc;
cout <<"\n Enter the 'Ratio of stroke-to-bore (Rsd)' = ";
cin >> Rsd;
cout <<"\n Enter the 'Ratio of crank-to-con rod legnth (Rrl)' = ";
cin >> Rrl;
cout <<"\n Enter the 'number of Carbon atoms in Gasoline (a)' = ";
cin >> a;
cout <<"\n Enter the 'number of Hydrogen atoms in Gasoline (b)' = ";
cin >> b;
cout <<"\n Enter the 'density of Gasoline (RHO_G)' in 'kg/liter' = ";
cin >> RHO_kgplit;
cout <<"\n Enter the 'Lower Heating Value of Gasoline (QLHV_G)' in 'MJ/kg' = ";
cin >> QLHV_G;
cout <<"\n Enter the 'residual mass fraction (xres) in '%' = ";
cin >> xR_per;
cout <<"\n Enter the 'engine Load (pim)' in 'bar' = ";
cin >> pim;
cout <<"\n Enter the 'pressure (p1)' in 'bar' = ";
cin >> p1;
cout <<"\n Enter the 'Temperature (T1)' in 'K' = ";
cin >> T1;
cout <<"\n Enter the 'compression Ratio (Rc)' = ";
cin >> Rc;
```

```
cout <<"\n Enter the 'required engine speed (N)' in 'rpm' = ";
cin >> N;
cout <<"\n Enter the 'mechanical Efficiency (ETA_m)' in '%' = ";
cin >> ETA_mper;
cout <<"\n Enter 'theta_ivobTDC' in 'deg.' = ";
cin >> theta_ivobTDC;
cout <<"\n Enter 'theta_ivcaBDC' in 'deg.' = ";
cin >> theta_ivcaBDC;
cout <<"\n Enter 'theta_scbTDC' in 'deg.' = ";
cin >> theta_scbTDC;
cout <<"\n Enter 'theta_dc' in 'deg.' = ";
cin >> theta_dc;
cout <<"\n Enter 'theta_evobBDC' in 'deg.' = ";
cin >> theta_evobBDC;
cout <<"\n Enter 'theta_evcaTDC' in 'deg.' = ";
cin >> theta_evcaTDC;
  Zs = 4.0; Z_rpc = Zs/2.0; Tim = T1-10.0; To = 293.0;
  ETA_m = ETA_mper/100.0; xR = xR_per/100.0;
  theta_a = 0.0; theta_0 = theta_evcaTDC; theta_b = 180.0;
  theta_ivc = 180.0+theta_ivcaBDC; theta_1 = theta_ivc;
  theta_sc = 360.0-theta_scbTDC; theta_2 = theta_sc; theta_c = 360.0;
  theta_ec = (theta_dc-theta_scbTDC)+360.0; theta_3 = theta_ec;
  theta_evo = 540.0-theta_evobBDC; theta_4 = theta_evo; theta_5 = 540.0;
  theta_6 = 720.0-theta_ivobTDC;
  Ec_liter = Ec_cc*1.0e-3; Ec = Ec_liter*1.0e-3;
  Vs = Ec/Zc; Vcl = Vs/(Rc-1.0); Vt = Vcl+Vs;
  Vs_cc = Vs*1.0e6; Vcl_cc = Vcl*1.0e6; Vt_cc = Vt*1.0e6;
  powd = (4.0*Vs)/(PI*Rsd); d = pow(powd,0.33); d_mm = d*1.0e3; s = d*Rsd;
  s_mm = s*1.0e3; r = s/2.0; r_mm = r*1.0e-3; lcon = r/Rrl;
  lcon_mm = lcon*1.0e3; Ap = (PI*d*d)/4.0;
cout << "\n\n\t\t Press 'enter' twice to proceed ... ";
getch();
getch();
clrscr ();
```

```
cout << "\n\n\t\t  Adama Science and Technology University (ASTU) ";
outfile << "\n\n\t\t  Adama Science and Technology University (ASTU) ";
cout << " \n\t\t         Yohannes g/tsadik ";
outfile << " \n\t\t         Yohannes g/tsadik ";
cout << "\n................................................................................ \n";
outfile << "\n...................................................................... \n";
cout << "\n  Engine Size ";
outfile << "\n  Engine Size ";
cout << "\n -------------- ";
outfile << "\n ------------- ";
  cout <<setprecision(3)<<"\n  Ec = "<<Ec_cc<<" cc ";
  outfile<<setprecision(3)<<"\n  Ec = "<<Ec_cc<<" cc ";
  cout <<setprecision(2)<<"\n  Vs = "<<Vs_cc<<" cc ";
  outfile<<setprecision(2)<<"\n  Vs = "<<Vs_cc<<" cc ";
  cout <<setprecision(2)<<"\n  Vcl = "<<Vcl_cc<<" cc ";
  outfile<<setprecision(2)<<"\n  Vcl = "<<Vcl_cc<<" cc ";
  cout <<setprecision(2)<<"\n  Vt = "<<Vt_cc<<" cc ";
  outfile<<setprecision(2)<<"\n  Vt = "<<Vt_cc<<" cc ";
cout << "\n\n\t\t Press 'enter' twice to proceed ... ";
getch();
getch();

      MmO = 16.0; MmN = 14.0; MmC = 12.0; MmH = 1.0;
      yO2 = 0.21; yN2 = 0.79; MmO2 = 2.0*MmO; MmN2 = 2.0*MmN;
      xG = 1.0; xF = xG;
      MmG = (a*MmC)+(b*MmH);
      nG = xG/MmG;
      yG = 1.0; yF = yG;
      MmA = (yO2*MmO2)+(yN2*MmN2); MmF = (yG*MmG);
      n1th = (ZC*yAl)+(a*yG); n2th = ((ZH*yAl)+(b*yG))/2.0;
      LAMBDAMAX = 1.2; LAMBDAMIN = 0.8;
      LAMBDA = (LAMBDAMIN*xG);
      atha = ((2.0*n1th)+n2th-(ZO*yAl))/2; ath = atha*LAMBDA;
```

```
      getch();
      clrscr();

  if (LAMBDA == 1.0)
   {
// Considering 'one Kilo mole (nF = 1 kmol)' of HydroCarbon Fuel (CaHb)',
// the 'theoretical combustion equation (LAMBDA = 1)'is:
//   nF*Ca+Hb+LAMBDA*ath*(O2+3.76*N2) - n1*CO2+n2*H2O+n3*N2
     yO2 = 0.21; yN2 = 0.79; MmO2 = 2.0*MmO; MmN2 = 2.0*MmN;
      xG = 1.0; xF = xG;
      MmG = (a*MmC)+(b*MmH);  nG = xG/MmG;
      yG = 1.0
      MmA = (yO2*MmO2)+(yN2*MmN2); MmF = (yG*MmG);
      n1th = (ZC*yAl)+(a*yG); n2th = ((ZH*yAl)+(b*yG))/2.0;
     atha = (2.0*n1th)+n2th-(ZO*yAl); ath = atha*LAMBDA;
     n3 = (2.0*3.76*LAMBDA*atha)/2.0;
     n1 = n1th; n2 = n2th; n3th = n3th; n4 = 0.0; n5 = 0.0;
     nt = n1+n2+n3+n4+n5;
     y1 = n1/nt; y2 = n2/nt; y3 = n3/nt; y4 = n4/nt; y5 = n5/nt;
   cout<<setprecision(2)<<"\n\n  n1= "<<n1;
   outfile<<setprecision(2)<<"\n\n  n1= "<<n1;
   cout <<setprecision(2)<<"\n\n  n2= "<<n2;
   outfile<<setprecision(2)<<"\n\n  n2= "<<n2;
   cout<<setprecision(2)<<"\n\n  n3= "<<n3;
   outfile<<setprecision(2)<<"\n\n  n3= "<<n3;
   cout<<setprecision(2)<<"\n\n  n4= "<<n4;
   outfile<<setprecision(2)<<"\n\n  n4= "<<n4;
   cout<<setprecision(2)<<"\n\n  n5= "<<n5;
   outfile<<setprecision(2)<<"\n\n  n5= "<<n5;
   cout<<setprecision(2)<<"\n\n  y1= "<<y1;
   outfile<<setprecision(2)<<"\n\n y1= "<<y1;
   cout<<setprecision(2)<<"\n\n y2= "<<y2;
   outfile<<setprecision(2)<<"\n\n y2= "<<y2;
   cout<<setprecision(2)<<"\n\n y3= "<<y3;
```

```
   outfile<<setprecision(2)<<"\n\n y3= "<<y3;
   cout<<setprecision(2)<<"\n\n  y5 "<<y5;
   outfile<<setprecision(2)<<"\n\n y5= "<<y5;
            }
 if (LAMBDA > 1.0)
   {
// Considering 'one Kilo mole (nF = 1 kmol)' of HydroCarbon Fuel (CaHb)',
// the 'theoretical combustion equation (LAMBDA < 1)'is:
//   nF*Ca+Hb+LAMBDA*ath*(O2+3.76*N2) - n1*CO2+n2*H2O+n3*N2+n4*O2
      yO2 = 0.21; yN2 = 0.79; MmO2 = 2.0*MmO; MmN2 = 2.0*MmN;
      xG = 1.0; xF = xG;
      MmG = (a*MmC)+(b*MmH);
      nG = xG/MmG;;
      yG = 1.0; yF = yG;
      MmA = (yO2*MmO2)+(yN2*MmN2); MmF = (yG*MmG);
      n2 = ((ZH*yAl)+(b*yG))/2.0; n3 = (2.0*3.76*LAMBDA*atha)/2.0;
      n1r = (yAl+(2.0*ath)); n4 =((yAl+(2.0*ath))-(2*n1)-n2)/2;
      n5 = ((ZC*yAl)+(a*yG))-n1r; nt = n1+n2+n3+n4+n5r;
      n1= ((ZC*yAl)+(a*yG));
      na1 = ZC;na2=(yAl+(2.0*ath))-((ZH*yAl)+(b*yG))/2-2*((ZC*yAl)+(a*yG));
      na= ZC*yAl;ng=a*yG;nag =na+ng;
      n5r= 0;
      y1 = n1/nt; y2 = n2/nt; y3 = n3/nt; y4 = n4/nt; y5 = n5r/nt;
   cout<<setprecision(2)<<"\n\n  n1= "<<n1;
   outfile<<setprecision(2)<<"\n\n  n1= "<<n1;
   cout <<setprecision(2)<<"\n\n  na2= "<<na2;
   cout<<setprecision(2)<<"\n\n  n1r= "<<n1r;
   cout <<setprecision(2)<<"\n\n  n2= "<<n2;
   outfile<<setprecision(2)<<"\n\n  n2= "<<n2;
   cout<<setprecision(2)<<"\n\n  n3= "<<n3;
   outfile<<setprecision(2)<<"\n\n  n3= "<<n3;
   cout<<setprecision(2)<<"\n\n  n4= "<<n4;
   outfile<<setprecision(2)<<"\n\n  n4= "<<n4;
   cout<<setprecision(2)<<"\n\n  n5= "<<n5r;
```

```
   outfile<<setprecision(2)<<"\n\n  n5= "<<n5r;
   cout<<setprecision(2)<<"\n\n  y1= "<<y1;
   outfile<<setprecision(2)<<"\n\n y1= "<<y1;
   cout<<setprecision(2)<<"\n\n y2= "<<y2;
   outfile<<setprecision(2)<<"\n\n y2= "<<y2;
   cout<<setprecision(2)<<"\n\n y3= "<<y3;
   outfile<<setprecision(2)<<"\n\n y3= "<<y3;
   cout<<setprecision(2)<<"\n\n y4= "<<y4;
   outfile<<setprecision(2)<<"\n\n y4= "<<y4;
   cout<<setprecision(2)<<"\n\n  y5 "<<y5;
   outfile<<setprecision(2)<<"\n\n y5= "<<y5;
   }
  if (LAMBDA < 1.0)
   {
// Considering 'one Kilo mole (nF = 1 kmol)' of HydroCarbon Fuel (CaHb)',
// the 'theoretical combustion equation (LAMBDA < 1)'is:
//   nF*Ca+Hb+LAMBDA*ath*(O2+3.76*N2) -
n1*CO2+n2*H2O+n3*N2+n4*O2+n5*CO
       yO2 = 0.21; yN2 = 0.79; MmO2 = 2.0*MmO; MmN2 = 2.0*MmN;
       xG = 1.0; xF = xG;
       MmG = (a*MmC)+(b*MmH);
       nG = xG/MmG;
       yG = yF = yG;
       MmA = (yO2*MmO2)+(yN2*MmN2); MmF = (yG*MmG);
       n2 = ((ZH*yAl)+(b*yG))/2.0; n3 = (2.0*3.76*LAMBDA*atha)/2.0;
       n1r = (yAl+(2.0*ath)); n4 = 0.0;
       n5 = ((ZC*yAl)+(a*yG))-n1r; nt = n1+n2+n3+n4+n5r;
       n1= ((ZC*yAl)+(a*yG));
       na1 = ZC;na2=(yAl+(2.0*ath))-((ZH*yAl)+(b*yG))/2-((ZC*yAl)+(a*yG));
       na= ZC*yAl;ng=a*yG;nag =na+ng;
       n5r= n1-na2;
       y1 = n1/nt; y2 = n2/nt; y3 = n3/nt; y4 = n4/nt; y5 = n5r/nt;
   cout<<setprecision(2)<<"\n\n  n1= "<<n1;
   outfile<<setprecision(2)<<"\n\n  n1= "<<n1;
```

```
  cout <<setprecision(2)<<"\n\n  na2= "<<na2;
  cout<<setprecision(2)<<"\n\n  n1r= "<<n1r;
  cout <<setprecision(2)<<"\n\n  n2= "<<n2;
  outfile<<setprecision(2)<<"\n\n  n2= "<<n2;
  cout<<setprecision(2)<<"\n\n  n3= "<<n3;
  outfile<<setprecision(2)<<"\n\n  n3= "<<n3;
  cout<<setprecision(2)<<"\n\n  n4= "<<n4;
  outfile<<setprecision(2)<<"\n\n  n4= "<<n4;
  cout<<setprecision(2)<<"\n\n  n5= "<<n5r;
  outfile<<setprecision(2)<<"\n\n  n5= "<<n5r;
  cout<<setprecision(2)<<"\n\n  y1= "<<y1;
  outfile<<setprecision(2)<<"\n\n y1= "<<y1;
  cout<<setprecision(2)<<"\n\n y2= "<<y2;
  outfile<<setprecision(2)<<"\n\n y2= "<<y2;
  cout<<setprecision(2)<<"\n\n y3= "<<y3;
  outfile<<setprecision(2)<<"\n\n y3= "<<y3;
  cout<<setprecision(2)<<"\n\n  y5 "<<y5;
  outfile<<setprecision(2)<<"\n\n y5= "<<y5;
  getch();
 clrscr();
}
     MmAth = MmA; MmFth = MmF; nO2 = atha; nN2 = atha*3.76; nA = nO2+nN2;
     AFth = (nA*MmAth)/MmFth; AF = LAMBDA*AFth;
     QLHV_F = (QLHV_G*xG);
     RHO_Fkgplit = (RHO_Alkgplit*yAl)+(RHO_Gkgplit*yG);
     RHO_F = RHO_Fkgplit*1.0e3; ETA_cmax = 0.95;
     ETA_c = ETA_cmax*(-1.6+(4.65*LAMBDA)-(2.07*LAMBDA*LAMBDA));
     ETA_cper = ETA_c*100.0; Rm = 0.287; Zm = 0.99; Vm = Vt;
     mm = (pim*1.0e5*Vm)/(Zm*Rm*1.0e3*Tim);
     mA = (AF/(AF+1.0))*(1.0-xR)*mm;
     mF = (1.0/(AF+1.0))*(1.0-xR)*mm;
     mres = xR*mm;
  cout <<setprecision(2)<<"\n\n  ath = "<<ath<<"  ;   AF = "<<AF;
  outfile<<setprecision(2)<<"\n\n  ath = "<<ath<<"  ;   AF = "<<AF;
```

```
   cout <<setprecision(2)<<" ;  ETA_c = "<<ETA_cper<<" % ";
   outfile<<setprecision(2)<<" ;  ETA_c = "<<ETA_cper<<" % ";
   cout <<setprecision(6)<<"\n\n  mm = "<<mm<<" kg ";
   outfile<<setprecision(6)<<"\n\n  mm = "<<mm<<" kg ";
   cout <<setprecision(6)<<"\n  mA = "<<mA<<" kg ";
   outfile<<setprecision(6)<<"\n  mA = "<<mA<<" kg ";
   cout <<setprecision(6)<<"\n  mF = "<<mF<<" kg ";
   outfile<<setprecision(6)<<"\n  mF = "<<mF<<" kg ";
   cout <<setprecision(6)<<"\n  mres = "<<mres<<" kg ";
   outfile<<setprecision(6)<<"\n  mres = "<<mres<<" kg ";
   cout << "\n\n\t\t Press 'enter' twice to proceed ... ";
   getch();
   getch();
 clrscr();
 cout << "\n\n\t\t  Adama Science and Technology University (ASTU) ";
 cout << " \n\t         Department of Mechanical and Vehicle Engineering ";
 cout << " \n\t\t         Yohannes g/tsadik ";
 cout << "\n.......................................................................... \n";
 cout << "\n\n   'V', 'p' and 'T' as a function of 'theta' ";
 outfile << "\n\n  'V', 'p' and 'T' as a function of 'theta' ";
 cout << "\n ------------------------------------------- \n";
 outfile << "\n\t---------------------------------------------------- ";
 cout <<"\n\ttheta\t  V\t  p\t  T ";
 cout <<"\n\t(deg.)\t (cc)\t (bar)\t (K) \n";
 outfile <<"\n\t   theta\t   V\t   p\t  T ";
 outfile <<"\n\t   (deg.)\t  (cc)\t  (bar)\t  (K) \n ";
           deltheta = 10.0;
  for (theta = 0.0; theta <= 720.0; theta = theta+deltheta)
   {
           V0bi = Vcl; p0bi = pim; T0bi = Tim; m0bi = mres; R0bi = R6b;
    if (theta >= theta_0 && theta <= theta_b)
     {
// process a-7 (constant pressure intake process).
       rad = theta*(PI/180.0); Z0b = 0.99;
```

```
      xp0b = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
      Vs0b = Ap*xp0b; V0b = Vcl+Vs0b; p0b = p0bi; T0b = T0bi; R0b = 0.287;
      m0b = m0bi+((pim*1.0e5*V0b)/(Z0b*R0b*1.0e3*T0b));
      Vb = V0b*1.0e6; pb = p0b; Tb = T0b; mb = m0b; thetab = theta;
            cout << setprecision(2)<<"\n\t"<<thetab;
            outfile << setprecision(2)<<"\n  " <<thetab;
            cout << setprecision(2)<<"\t "<<Vb;
            outfile << setprecision(2)<<"\t"<< Vb;
            cout <<setprecision(2)<<"\t "<<pb;
            outfile <<setprecision(2)<<"\t " << pb;
            cout <<setprecision(2)<<"\t"<<Tb;
            outfile <<setprecision(2)<<"\t " << Tb;
            getch();
             }
          Vb1i = Vb*1.0e-6; pb1i = pb; Tb1i = Tb; mb1i = mb;
    if (theta > theta_b && theta <= theta_1)
     {
// process b-1 (polytropic compression):
      rad = theta*(PI/180.0);
      xpb1 = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
      Vsb1 = Ap*xpb1; Vb1 = Vcl+Vsb1; VbVb1 = Vb1i/Vb1;
      nb1 = 1.35; nb1T = nb1-1.0; Rb1 = 0.287; Zb1 = 0.99;
      pb1 = pb1i*pow(VbVb1,nb1); Tb1 = Tb1i*pow(VbVb1,nb1T);
      delmb1 = mb1i-((pb1*1.0e5*Vb1)/(Zb1*Tb1*Rb1*1.0e3));
      mb1 = mb1i-delmb1;
      V1 = Vb1*1.0e6; p1 = pb1; T1 = Tb1; theta1 = theta;
            cout << setprecision(2)<<"\n\t"<<theta1;
            outfile << setprecision(2)<<"\n  " <<theta1;
            cout << setprecision(2)<<"\t "<<V1;
            outfile << setprecision(2)<<"\t"<< V1;
            cout <<setprecision(2)<<"\t "<<p1;
            outfile <<setprecision(2)<<"\t " << p1;
            cout <<setprecision(2)<<"\t"<<T1;
            outfile <<setprecision(2)<<"\t " << T1;
```

```
            getch();
             }
           m12i = mb1;
           V12i = V1*1.0e-6; p12i = p1; T12i = T1; m12i = mb1;
     if (theta > theta_1 && theta <= theta_2)
      {
// process 1-2 (polytropic effective compression):
        rad = theta*(PI/180.0);
        xp12 = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
        Vs12 = Ap*xp12; V12 = Vcl+Vs12; V1V12 = V12i/V12;
        n12 = 1.35; n12T = n12-1.0; R12 = 0.287; Z12 = 0.99; m12 = m12i;
        p12 = p12i*pow(V1V12,n12); T12 = T12i*pow(V1V12,n12T);
        W12 = (m12*R12*(T12-T12i))/(1.0-n12); W2 = W12;
        V2 = V12*1.0e6; p2 = p12; T2 = T12; theta2 = theta;
            cout << setprecision(2)<<"\n\t"<<theta2;
            outfile << setprecision(2)<<"\n  " <<theta2;
            cout << setprecision(2)<<"\t "<<V2;
            outfile << setprecision(2)<<"\t"<< V2;
            cout <<setprecision(2)<<"\t "<<p2;
            outfile <<setprecision(2)<<"\t " << p2;
            cout <<setprecision(2)<<"\t"<<T2;
            outfile <<setprecision(2)<<"\t " << T2;
            cout<<setprecision(2)<<"\t " << W12;
            getch();
             }
            W12 = W2;
            V23i = V2*1.0e-6; p23i = p2; T23i = T2; T23 = T2+5.0;
     if (theta > theta_2 && theta <= theta_3)
      {
        rad = theta*(PI/180.0); p23 = p3;
        xp23 = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
        Vs23 = Ap*xp23; V23 = Vcl+Vs23; m23 = m12i;
        theta2dc = ((theta-theta_2)/theta_dc)*PI; rad2dc = theta2dc;
        cv23 = 0.821; R23 = 0.287; n23 = 1.3; // Z23 = 0.98;
```

```
    xF = 1.0/(AF+1.0); mF = (xF*(1.0-xR))*m23; xb = 0.5*(1.0-cos(rad2dc));
    Qin = (mF*QLHV_F*1.0e6)*ETA_c; Q1 = Qin*xb; Q23 = Q1;
    W23 = (p23*1.0e5)*(V23-V23i);
    QW23 = (Q23-W23)/(m23*cv23*1.0e3);
    T23 = QW23+T23i; p23 = ((T23/T23i)*(V23i/V23))*p23i;
    W3 = W23/1000.0; Q3 = Q23/1000.0;
    V3 = V23*1.0e6; p3 = p23; T3 = T23; T23 = T3;
    m3 = m23; theta3 = theta;
        cout << setprecision(2)<<"\n\t"<<theta3;
        outfile << setprecision(2)<<"\n  " <<theta3;
        cout << setprecision(2)<<"\t "<<V3;
        outfile << setprecision(2)<<"\t"<< V3;
        cout <<setprecision(2)<<"\t "<<p3;
        outfile <<setprecision(2)<<"\t " << p3;
        cout <<setprecision(2)<<"\t"<<T3;
        outfile <<setprecision(2)<<"\t " << T3;
        getch();
         }
      W23 = W3; Q23 = Q3;
      V34i = V3*1.0e-6; p34i = p3; T34i = T3; m34i = m3;
  if (theta > theta_3 && theta <= theta_4)
   {
// process 3-4 (polytropic expansion):
    rad = theta*(PI/180.0);
    xp34 = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
    Vs34 = Ap*xp34; V34 = Vcl+Vs34; V3V34 = V34i/V34; m34 = m12i;
    n34 = 1.35; n34T = n34-1.0; R34 = 0.287; Z34 = 0.99;
    p34 = p34i*pow(V3V34,n34); T34 = T34i*pow(V3V34,n34T);
    delm34 = m34i-((p34*1.0e5*V34)/(Z34*T34*R34*1.0e3));
    m34 = m34i-delm34; W34 = (m34*R34*(T34-T34i))/(1.0-n34);
    W4 = W34;
    V4 = V34*1.0e6; p4 = p34; T4 = T34; theta4 = theta;
        cout << setprecision(2)<<"\n\t"<<theta4;
        outfile << setprecision(2)<<"\n  " <<theta4;
```

```
            cout << setprecision(2)<<"\t "<<V4;
            outfile << setprecision(2)<<"\t"<< V4;
            cout <<setprecision(2)<<"\t "<<p4;
            outfile <<setprecision(2)<<"\t " << p4;
            cout <<setprecision(2)<<"\t"<<T4;
            outfile <<setprecision(2)<<"\t " << T4;
            cout<<setprecision(2)<<"\t " << W34;
            getch();
             }
          W34 = W4;
          V45i = V4*1.0e-6; p45i = p4; T45i = T4; m45i = m12i;
    if (theta > theta_4 && theta <= theta_5)
     {
// process 4-5 (polytropic exhaust blowdown):
       rad = theta*(PI/180.0);
       xp45 = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
       Vs45 = Ap*xp45; V45 = Vcl+Vs45; V4V45 = V45i/V45; m45 = m12i;
       n45 = 1.35; n45T = n45-1.0; R45 = 0.287; Z45 = 0.99;
       p45 = p45i*pow(V4V45,n45); T45 = T45i*pow(V4V45,n45T);
       delm45 = m45i-((p45*1.0e5*V45)/(Z45*T45*R45*1.0e3));
       m45 = m45i-delm45; W45 = (m45*R45*1.0e3*(T45-T45i))/(1.0-n45);
       W5 = W45/100.0;
       V5 = V45*1.0e6; p5 = p45; T5 = T45; theta5 = theta;
            cout << setprecision(2)<<"\n\t"<<theta5;
            outfile << setprecision(2)<<"\n  " <<theta5;
            cout << setprecision(2)<<"\t "<<V5;
            outfile << setprecision(2)<<"\t"<< V5;
            cout <<setprecision(2)<<"\t "<<p5;
            outfile <<setprecision(2)<<"\t " << p5;
            cout <<setprecision(2)<<"\t"<<T5;
            outfile <<setprecision(2)<<"\t " << T5;
            getch();
             }
            W45 = W5;
```

```
      V45i = V4*1.0e-6; p45i = p4; T45i = T4; m45i = m12i;
    if (theta > theta_5 && theta <= theta_6)
     {
// process 4-5 (polytropic exhaust blowdown):
      rad = theta*(PI/180.0);
      xp56 = r*((1.0-cos(rad))+((Rrl*sin(rad)*sin(rad))/2.0));
      Vs56 = Ap*xp56; V56 = Vcl+Vs56; V5V6 = V45i/V56; m56 = m12i;
      n45 = 1.35; n45T = n45-1.0; R45 = 0.287; Z45 = 0.99;
      p45 = p45i*pow(V4V45,n45); T45 = T45i*pow(V4V45,n45T);
      delm45 = m45i-((p45*1.0e5*V45)/(Z45*T45*R45*1.0e3));
      m45 = m45i-delm45; W45 = (m45*R45*1.0e3*(T45-T45i))/(1.0-n45);
      W5 = W45/100.0;
      V6 = V56*1.0e6; p6 = p1; T6 = T1; theta6 = theta;
            cout << setprecision(2)<<"\n\t"<<theta6;
            outfile << setprecision(2)<<"\n  " <<theta6;
            cout << setprecision(2)<<"\t "<<V6;
            outfile << setprecision(2)<<"\t"<< V6;
            cout <<setprecision(2)<<"\t "<<p6;
            outfile <<setprecision(2)<<"\t " << p6;
            cout <<setprecision(2)<<"\t"<<T6;
            outfile <<setprecision(2)<<"\t " << T6;
            getch();
             }
              }
            Wnet = W12+W34; Qin = Q23;
            ETA_ith = Wnet/Qin; ETA_ithper = ETA_ith*100.0;
            imep_bar = ((Wnet*1.0e3)/Vs)*1.0e-5;
            Wi = Wnet*Zc; n_cps = N/(60.0*Z_rpc); Pi = Wi*n_cps;
            Pb_kW = Pi*ETA_m; mF_kgps = mF*Zc*n_cps;
            mF_kgph = mF_kgps*3600.0; bsfc = mF_kgph/Pb_kW;
            Tb_NM = (Pb_kW*60*1000)/(2*3.14*N);
   cout <<setprecision(6)<<"\n\n  mm = "<<mm<<" kg ";
   outfile<<setprecision(6)<<"\n\n  mm = "<<mm<<" kg ";
   cout <<setprecision(6)<<"\n  mb1i = "<<mb1i<<" kg ";
```

```
outfile<<setprecision(6)<<"\n  mb1i = "<<mb1i<<" kg ";
cout <<setprecision(6)<<"\n  m12i = "<<m12i<<" kg ";
outfile<<setprecision(6)<<"\n  m12i = "<<m12i<<" kg ";
cout <<setprecision(2)<<"\n\n  Wnet = "<<Wnet<<" kJ ";
outfile<<setprecision(2)<<"\n\n  Wnet = "<<Wnet<<" kJ ";
cout <<setprecision(2)<<";  Qin = "<<Qin<<" kJ ";
outfile<<setprecision(2)<<";  Qin = "<<Qin<<" kJ ";
cout <<setprecision(2)<<";  ETA_ith = "<<ETA_ithper<<" % ";
outfile<<setprecision(2)<<";  ETA_ith = "<<ETA_ithper<<" % ";
cout <<setprecision(2)<<";  imep = "<<imep_bar<<" bar ";
outfile<<setprecision(2)<<";  imep = "<<imep_bar<<" bar ";
cout <<setprecision(2)<<"\n\n  Pb = "<<Pb_kW<<" kW ";
outfile<<setprecision(2)<<"\n\n  Pb = "<<Pb_kW<<" kW ";
 cout <<setprecision(2)<<"\n\n  Tb= "<<Tb_NM<<" NM ";
outfile<<setprecision(2)<<"\n\n  Tb = "<<Tb_NM<<" NM ";
cout <<setprecision(2)<<";  bsfc = "<<bsfc<<" kg/kWh ";
outfile<<setprecision(2)<<";  bsfc = "<<bsfc<<" kg/kWh ";
cout << "\n\n\n\t\t Press 'enter' twice to exit ! ";
getch();
getch();
getche();
 }
```