1. INTRODUCTION

Internal combustion engines are devices that generate work using the products of combustion as the working fluid rather than as a heat transfer medium. To produce work, the combustion is carried out in a manner that produces high-pressure combustion products that can be expanded through a turbine or piston. The engineering of these high pressure systems introduces a number of features that profoundly influence the formation of pollutants.

There are three major types of internal combustion engines in use today: (1) the spark ignition engine, which is used primarily in automobiles; (2) the diesel engine, which is used in large vehicles and industrial systems where the improvements in cycle efficiency make it advantageous over the more compact and lighter-weight spark ignition engine; and (3) the gas turbine, which is used in aircraft due to its high power/weight ratio and also is used for stationary power generation.

Internal combustion engines are most commonly used for mobile propulsion in vehicles and portable machinery. In mobile equipment, internal combustion is advantageous since it can provide high power-to-weight ratios together with excellent fuel energy density. Generally using fossil fuel (mainly petroleum), these engines have appeared in transport in almost all vehicles (automobiles, trucks, motorcycles, boats, and in a wide variety of aircraft and locomotives).

Aim of this experiment is to determine performance characteristics of a four stroke diesel engine.

1.1. The Four Stroke Diesel Engine

The four-stroke diesel engine is similar to the four stroke gasoline engine. They both follow an operating cycle that consist of intake, compression, power, and exhaust strokes. They also share similar systems for intake and exhaust valves.

A diesel engine is much more efficient than a gasoline engine, such as the diesel engine does not require an ignition system due to the heat generated by the higher compression, the diesel engine has a better fuel economy due to the complete burning of the fuel, and the diesel engine develops greater torque due to the power developed from the high-compression ratio.

Intake Stroke: The piston is at top dead center at the beginning of the intake stroke, and, as the piston moves downward, the intake valve opens. The downward movement of the piston draws air into the cylinder, and, as the piston reaches bottom dead center, the intake valve closes.

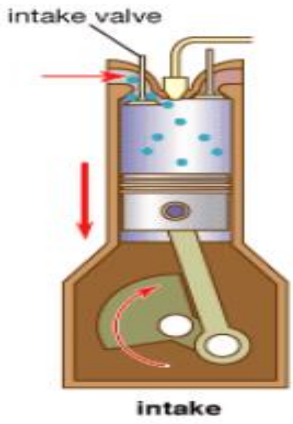


Figure 1. Induction stroke

Compression Stroke: The piston is at bottom dead center at the beginning of the compression stroke, and, as the piston moves upward, the air compresses. As the piston reaches top dead center, the compression stroke ends.

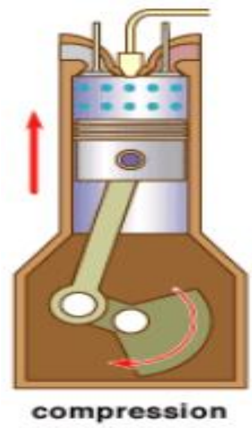


Figure 2. Compression stroke

Power Stroke: The piston begins the power stroke at top dead center. At this point, fuel is injected into the combustion chamber and is ignited by the heat of the compression. This begins the power stroke. The expanding force of the burning gases pushes the piston downward, providing power to the crankshaft. The diesel fuel will continue to bum through the entire power stroke (a more complete burning of the fuel). The gasoline engine has a power stroke with rapid combustion in the beginning, but little to no combustion at the end.

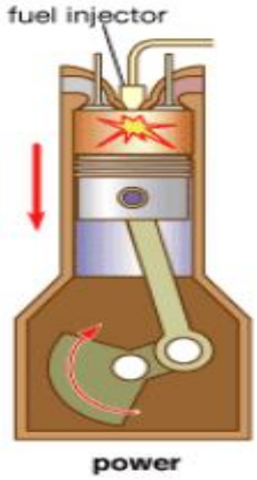


Figure 3. Power stroke

Exhaust Stroke: As the piston reaches bottom dead center on the power stroke, the power stroke ends and the exhaust stroke begins. The exhaust valve opens, and, as the piston rises towards top dead center, the burnt gases are pushed out through the exhaust port. As the piston reaches top dead center, the exhaust valve closes and the intake valve opens. The engine is now ready to begin another operating cycle.

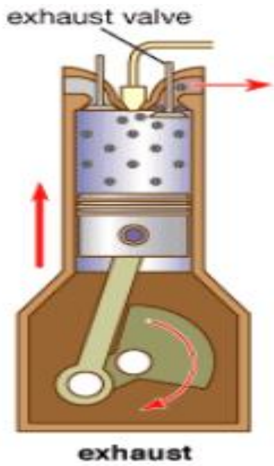


Figure 4. Exhaust stroke

The diesel internal combustion engine differs from the gasoline powered Otto cycle by using a higher compression of the fuel to ignite the fuel rather than using a spark plug ("compression ignition" rather than "spark ignition"). In the diesel engine, air is compressed adiabatically with a compression ratio typically between 15 and 20. This compression raises the temperature to the ignition temperature of the fuel mixture which is formed by injecting fuel once the air is compressed. The ideal air-standard cycle is modeled as a reversible adiabatic compression followed by a constant pressure combustion process, then an adiabatic expansion as a power stroke and an isovolumetric exhaust. A new air charge is taken in at the end of the exhaust, as indicated by the processes a-e-a on the diagram.

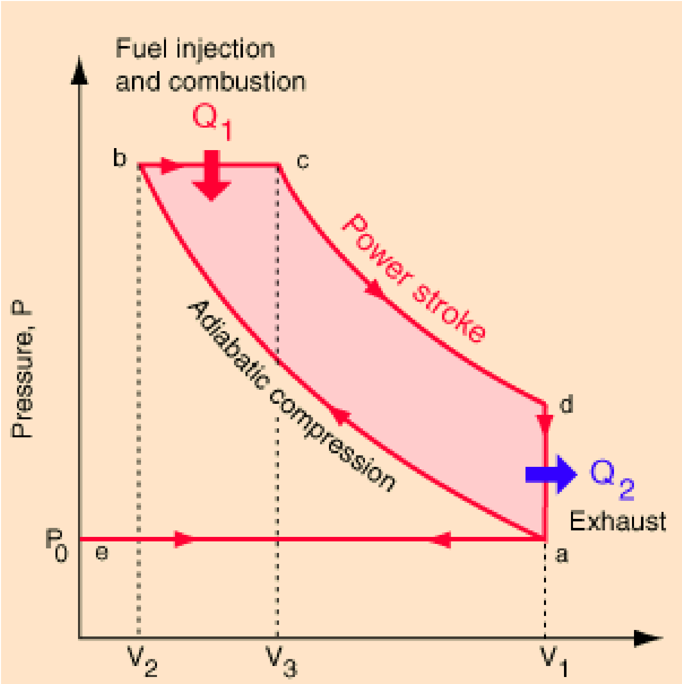


Figure 5. Air standard diesel engine cycle

The main difference between the Diesel and Otto engine is burning of the fuel. In a Gasoline engine, the air/fuel mixture enters the cylinder and creates a stoichiometric homogeneous mixture, which is ignited and the flame travels from the spark and outwards to the liner. In the Diesel engine, air enters the cylinder, fuel is injected, self-ignites and burns with a diffusion type of combustion.

The Diesel has:

• Higher compression ratio (higher thermodynamic efficiency, no knock)

• No throttle (no pumping losses, power ~ fuel)

• Combustion is always lean (lower heat losses, higher efficiency)

• More flexible about choice of fuel

2. EXPERIMENTAL CALCULATIONS

2.1 Torque and Power Output

The engine torque was measured by the help of a hydraulic dynamometer.

The power output is calculated from the torque by multiplying by the angular velocity in radians per second. Because the dynamometer acts as a brake on the engine, the power at the output shaft is referred as the "Brake Power" (P_B).

$$P_B = \frac{2\pi N}{60} T \qquad (1)$$

where:

P_B is brake power (W),

N is speed (rpm),

T is torque (Nm).

2.2. The Performance of an Ideal Engine

One aspect of engine testing is to determine how the torque and brake power vary with engine speed. To interrupt the results from a real engine, it is necessary to establish the maximum performance that can be expected from an ideal engine, which converts the energy contained in the fuel into mechanical work without loss.

The power output depends on the rate where the fuel can be burned. For complete combustion, the fuel must be mixed with air in the correct chemical proportions. If sufficient oxygen is available, a hydrocarbon fuel can be completely oxidized. The carbon in the fuel is then converted to carbon dioxide CO_2, and the hydrogen to water H_20. The amount of air drawn into the cylinder that determines how much fuel can be burned during each cycle. Ignoring the volume occupied by the fuel, the volume of air induced into the cylinder during each cycle is ideally equal to swept volume. If the air drawn in from atmosphere at a density (ρ_a), then:

$$\text{Ideal mass of air per cycle} = \rho_a . V_s \qquad (2)$$

where:

ρ_a is density of air (kg/m^3)

V_s is swept volume (m^3)

The air consumption rate is given by formula:

$$\dot{m}_a = \frac{N}{60.n} \rho_a . V_s \qquad (3)$$

where:

$\dot{m}_a$ is air consumption rate (kg/s),

N is speed (rpm),

n=1 for two stroke engine

n=2 for four stroke engine

Assuming complete combustion, heat generated per unit mass of fuel is equal to the calorific values, H. This is typically 42000 kJ/kg for petrol, 39000 kJ/kg for diesel fuel. The rate, Q at which heat is supplied to the engine, is given by:

$$Q_{in} = \dot{m}_f . H \tag{4}$$

All the energy could be converted into mechanical power, the power output would be:

$$P_{B,ideal} = Q_{in} \tag{5}$$

Expressing the fuel consumption rate in term of the other variables given by formula 3,4,5 Ideal Brake Power Output:

$$P_{B,ideal} = \frac{H}{R} . \frac{N}{60.n} \rho_a . V_s \tag{6}$$

2.3. Brake Mean Effective Pressure and Specific Fuel Consumption

Another measure of engine efficiency are brake mean effective pressure (bmep) and specific fuel consumption (sfc).

$$bmep = \frac{2.\pi.T.n}{V_s.1000} \text{ (kPa)} \tag{7}$$

$$sfc = \frac{\dot{m}_f}{P_B} . 1000 \text{ (g/kWh)} \tag{8}$$

Specific fuel consumption is a useful measure of engine performance because it relates directly to the economy of an engine. It enables the operator to calculate how much fuel is required to produce a certain power output for a certain power output for a certain length of time. So the specific fuel consumption can be used to estimate the economic performance of the different engine type.

2.4. Thermal Efficiency

In thermodynamics, the thermal efficiency (η_{th}) is a dimensionless performance measure of a device that uses thermal energy, such as an internal combustion engine, a steam turbine or a steam engine, a boiler, a furnace, or a refrigerator for example.

The thermal efficiency is defined as:

$$\eta_{th} = \frac{work\ per\ cycle}{heat\ input\ per\ cycle} = \frac{W}{Q_{in}} = \frac{W}{\dot{m}_f.H} \tag{7}$$

When we expand the terms in η_{th}, we can obtain following equation:

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}} \left(\frac{a^{\gamma} - 1}{\gamma(\alpha-1)}\right) \tag{8}$$

where;

α is the cut-off ratio $\frac{V_3}{V_2}$ (ratio between the end and start volume for the combustion phase)

r is the compression ratio ($\frac{V_1}{V_2}$)

γ is ratio of specific heats ($\frac{c_p}{c_v}$)

2.5. Heat Loss in Exhaust

An estimate heat loss to the exhaust can be made by measuring the difference between the exhaust and ambient temperatures (25 ^{o}C) and assuming a typical value of 1 kJ/kg.K for the specific heat of the exhaust gases.

$$Heat\ Loss\ in\ Exhaust = (\dot{m}_a + \dot{m}_f).C_{exh}.\Delta t$$

3. THE ENGINE TEST RIG

A commercial four cylinders, four stroke, naturally aspirated, water-cooled direct injection compression ignition engine with a 89 kW maximum power at 3200 rpm engine speed and has 295 Nm maximum torque at 1800 rpm engine speed is going to be used to conduct engine performance test. Technical specifications of engine were presented in Table 1.

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3907cc
Bore	104mm
Stroke	115mm
Power	89kW @ 3200rpm
Torque	295Nm @ 1800rpm
Oil Cooler	Water cooled
Air Cleaner	Paper element type
Weight	325kg

Table 1. Technical specifications of the test engine

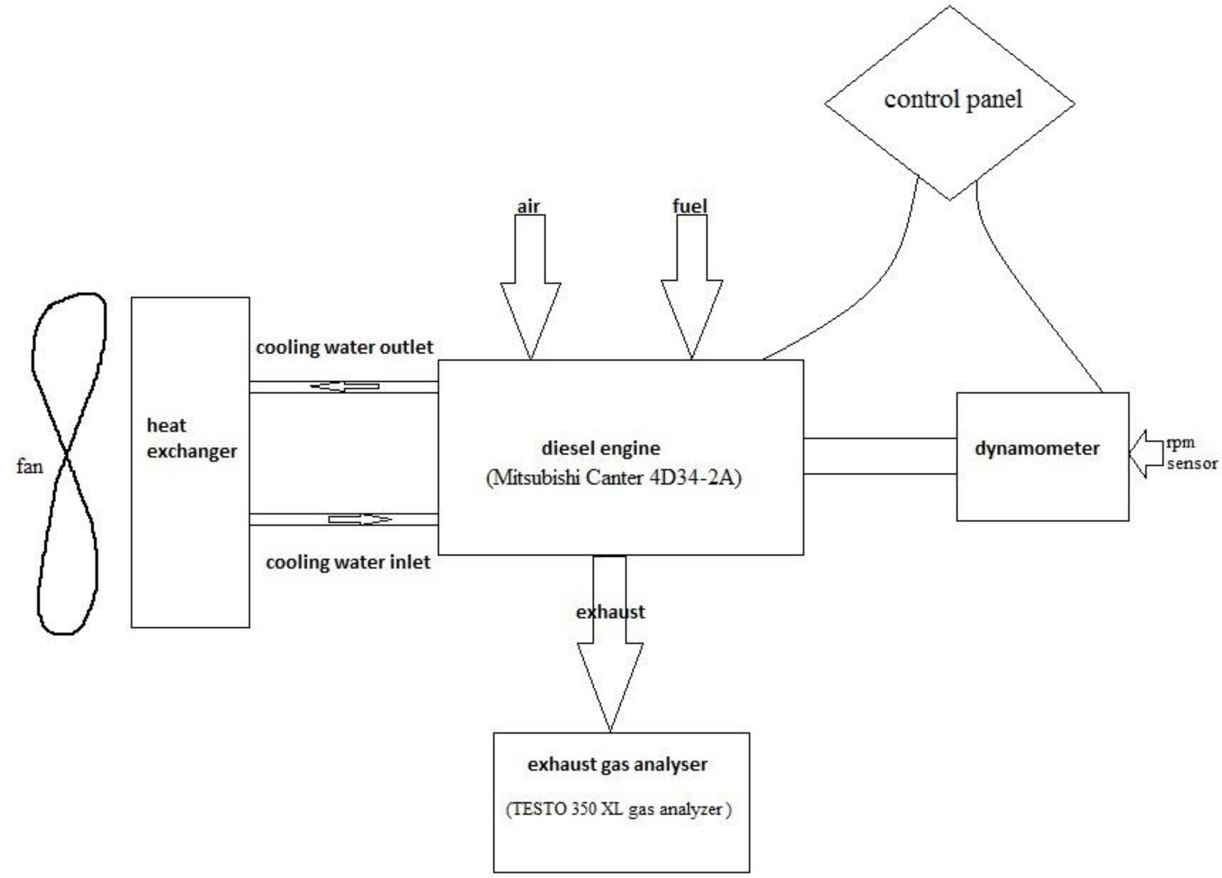


Figure 6. The engine test rig

3.1.Measuring Torque

The engine torque was measured by the help of a hydraulic dynamometer. S type load cell is used to measure the torque of dynamometer (Stainless steel which has a sensivity of 1/3000) Dynamometer control unit was used for receiving and collecting all the data that was used by the system.

Torque range	0-1700 Nm
Speed range	0-7500 rpm
Body weight	45 kgf
Total weight	110 kgf
Body diameter	350 mm
Torque arm length	350mm

Table 2. Technical specifications of the dynamometer

3.2.Measuring Speed

The speed sensor used to detect prime mover speed is the magnetic pickup (MPU). When a magnetic material (usually a gear tooth driven by the prime mover) passes through the magnetic field at the end of the magnetic pickup, a voltage is developed. The frequency of this voltage is translated by the speed into a signal which accurately depicts the speed of the prime mover.

3.3. Measuring Exhaust Gas Temperature

Exhaust gas temperature is measured by a thermocouple. The thermocouple is located in the exhaust pipe closed to the cylinder block of the engine.

3.4. Fuel Measurement

Fuel quantity is measured in every 5 seconds by a load cell unit. Then, fuel consumption (g/s) is calculated with the aid of a control unit.

4. RESULTS and DISCUSSIONS

1) Plot bmep, torque, brake power, specific fuel consumption and exhaust temperature versus engine speed.
2) Plot ideal and actual power output versus engine speed. Discuss the differences.
3) Discuss the all graphs.
4) Discuss the differences between diesel and gasoline engine.
5) Derive thermal efficiency of diesel engine.

m	$\dot{m}_f$ (g/s)	$\dot{m}_a$ (g/s)	Torque (Nm)	P_B (kW)	$P_{B,ideal}$ (kW)	bmep (kPa)	Sfc (g/kWh)	Thermal efficiency	Heat loss in exhaust

CONTENTS

1. INTRODUCTION

The small internal combustion engine is widely used as a convenient and compact source of power. Lawn mowers, cultivator, pumps, cement mixers and motorcycles are just a few of the many applications.

Aim of this experimental is determine to performance characteristic of a mini four stroke diesel, four stroke petrol and two stroke petrol engines. To interpret the results of tests on an engine, it is first necessary to understand how the engine operates, what the ideal performance would be, and what factors affect the performance. These topics are dealt with in the following sections. This provides a suitable basis on which to introduce the various parameters used to assess engine performance and to discuss the significance of these parameters.

Internal combustion engines convert the energy contained in hydrocarbon fuel to mechanical energy by burning a mixture of fuel and air inside combustion chamber. All engines work broadly on the same principle, although there are slight differences between types of engine.

1.1. The Four Stroke Reciprocating Petrol Engine

In a four-stroke petrol engine, air is drawn in through a carburettor in which petrol is mixed with the air. Engine speed is governed by the butterfly valve in the carburettor, which controls the flow of air to the engine. This valve is linked to the engine throttle control. For any given throttle setting, the carburettor controls the flow of petrol in such a way that it is mixed with the air in the correct proportions for subsequent combustion.

The petrol evaporates in the induction manifold and the resulting mixture of petrol vapour and air is drawn into the cylinder, compressed and then ignited by an electric spark from a sparking plug. The four-stroke petrol engine is thus referred to as a spark ignition engine. The main events, which occur during the four strokes of the piston, are shown in figure 1. and can be summarised as follows.

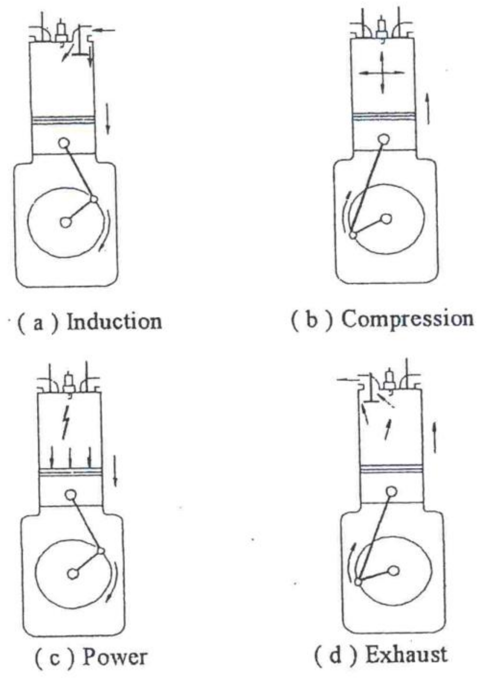


Figure 1. The Four-Stroke Cycle

a.) Induction Stroke

This cycle of four strokes starts with a mixture of petrol vapour and air being drawn into the cylinder through the inlet valve by the downward movement of the piston. Induction occurs at a pressure slightly below atmospheric pressure.

b.) Compression Stroke

The inlet valve closes just after the piston reaches the bottom of its travel, or "Bottom Dead Centre" (BDC). The air/fuel mixture is then compressed as the piston moves upwards. Just before the piston reaches top dead centre, the compressed mixture is ignited by a spark. Typically, the compression ratio of a petrol engine is between 8:1 and 10:1

c.) Expansion or " Power" Stroke

The heat generated by combustion raises the pressure of the gases, which then expand and push the piston downwards. The work is obtained at this stroke. Towards the end of the stroke, the exhaust valve opens and gases blow down the exhaust duct until the pressure falls to approximately atmospheric pressure.

d.) Exhaust Stroke

As the piston again moves upwards, majority of the remaining burnt gases are pushed out of the cylinder through the exhaust valve. During each power stroke, work is done by the gases driving the piston downwards. The force on the piston is transmitted by connecting rod to an offset crank, which turns the crankshaft. The energy produced is averaged over the four strokes by the flywheel an average torque (T) is produced at the engine output shaft.

1.2. The Four Stroke Reciprocating Diesel Engine

The diesel engine works in a very similar way to the petrol engines described in the preceding sections, except that no ignition system is required. Most diesel engines use the four-stroke cycle, but two-stroke engine have also been designed. Diesel engines are also known compression ignition engines, because of the way in which burning of the fuel is initiated. Instead of the air/fuel mixture on the petrol engine, the diesel engine draws in only air on the induction stroke. This is compressed by the piston as it rises. Completed events in cycle that duration piston of four-stroke diesel engine which works by making forward movement is like four stroke petrol engine.

a.) Induction Stroke

The air is drawn to the cylinder while the piston moves TDC to BDC at induction time. In this time the pressure of in the cylinder is approximately P_1 = 0,085-0,095 MPa as a petrol engine. The induction valve is opened before the TDC to more air drawn to cylinder. Also closing of the induction valve is made late.

b.) Compression Stroke

During the compression stroke, inducted air is compressed by the piston, which moves towards BDC to TDC.

After the compression

Pressure	P_2 = 3,0-5,0 MPa
Temperature	T_2 = 900-1200 K

c.) Combustion and Expansion Stroke

As a petrol engines, the work is obtained duration this cycle. Therefore the fuel is injected into the pressured air in the cylinder just before the piston reach to TDC. This early injecting is expressed as injecting tolerant ratio. The fuel that is injected by the injector burns by itself but it burns lately at 900 - 1200 K temperature at the end of the compression stroke. This delay is expressed as delay time.

First the fuel that during the delay time had injected ignites by itself at almost constant pressure and then when it is gone on injecting the fuel the combustion goes on at constant pressure. But when the number of the engine speed over 2500-3000 rpm not to the combustion goes on towards end of the expansion stroke. Part of the fuel is injected at constant volume and rest of the fuel is injected at constant pressure to burn. Flame speed in CI is less than in SI. So the number of the engine speed of CI is less than in petrol engine.

Duration Combustion max. Pressure	
At direct injection engine	P_3 = 7,0-10,0 MPa
At divided combustion chamber engine	P_3 = 4,0-8,0 MPa
Max. Temperature	T_3 = 1700-2100 K

d.) Exhaust Stroke

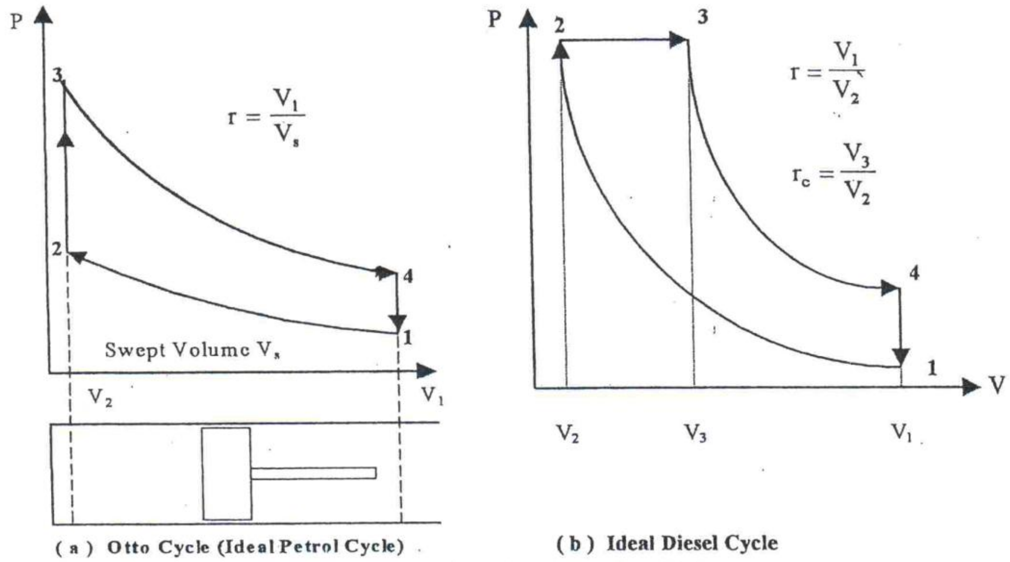
Inlet exhaust valve opens at end of the expanding time before the piston doesn't reach the BDC as a petrol engine and closes after the TDC. Compressing the charge of air raises its temperature to a value greater than the temperature at which the fuel self ignites, so that when diesel fuel is injected into combustion chamber just before the piston reaches TDC, the fuel begins to burn almost immediately.

During opening of the exhaust valve	
Pressure	P_4 = 0,4-0,5 MPa
Temperature	T_4 = 1000-1100 K

The compression ratio of the diesel engine is much higher than that of a petrol engine, being between 11:1 and 26:1. These values are 8:1 to 10:1 for the modern petrol engine. CR of diesel engine below 11:1 cannot generate a sufficient increase in air temperature to enable the fuel to burn. This places a restriction on the range of compression ratios that can be used. The specific fuel consumption of the diesel engine is lower than of a petrol engine, but the diesel engine tends to be much heavier than a petrol engine as it has to operate at much higher compression ratios.

As a result at four stroke cycle

- Useful work is obtained only at combustion and expanding stroke
- The energy is observed by helping events at other three stroke



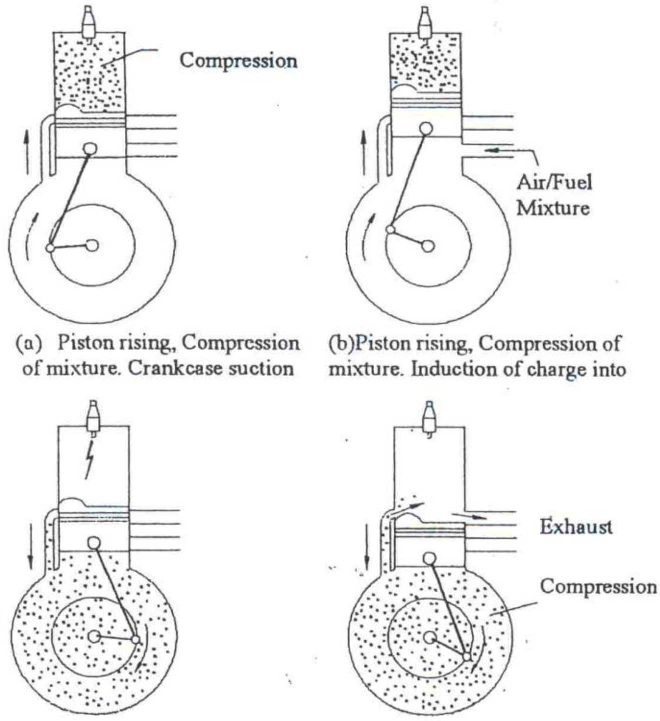
(a) Otto Cycle (Ideal Petrol Cycle) (b) Ideal Diesel Cycle

Figure 2. Ideal Engine Operating Cycles

1.3. The Two Stroke Reciprocating Petrol Engine

One disadvantage of the four-stroke cycle is that power is only produced on one of the four strokes. The two stroke engine completes the same cycle of events in only two strokes of the piston and so has twice as many power strokes for a given engine speed. In the two stroke engine the inlet and exhaust valves are eliminated by using the piston to cover and uncover "ports" or passages in the cylinder and crankcase as shown in figure 3. This figure also shows the operation of the engine.

Beginning the cycle with the piston about halfway through its compression stroke, all three ports are covered. The upward movement of the piston compresses a fresh charge of mixture in the combustion chamber. At the same time the pressure in the crankcase is reduced below atmospheric pressure. Near the top the stroke the lower edge of the piston uncovers the inlet port, allowing the pressure of the atmosphere to fill the crankcase of the engine with fresh mixture from the carburettor.



(a) Piston rising, Compression of mixture. Crankcase suction

(b)Piston rising, Compression of mixture. Induction of charge into

(c) Power Stroke. Crankcase mixture compressed.

(d) Exhaust of spent charge. Transfer of crankcase charge to cylinder

Figure 3. The Two-Stroke Cycle

The mixture in the combustion chamber is ignited the same way as in the four-stroke engine near the top of the stroke. The high pressure of the burned gases drives the piston down the cylinder. Just below TDC the piston covers the inlet port and further downward movement compresses the mixture in the crankcase. Near the bottom of the stroke the top edge of the piston uncovers the exhaust port, allowing the burnt gases to flow out of the cylinder under their own pressure.

Slightly further down, the piston uncovers the transfer port and the compressed mixture in the crankcase flows into the cylinder above the piston. The shaped piston deflects the mixture upwards, preventing it from flowing straight across the cylinder and out through the exhaust port. Some engines use shaped transfer ports instead of a deflecting piston. As the piston rises on its next stroke, the transfer and exhaust ports are covered and the cycle of operations begins again.

An ideal two-stroke engine would develop twice the power of a four-stroke engine of the same size. In practice, however, the operations are less effectively carried out and despite the shaped piston or transfer ports, mixing the fresh charge with burnt gas cannot be avoided. This results in some loss of fresh mixture through the exhaust port and incomplete scavenging of burnt gas from the cylinder.

The main advantages of the two-stroke engine are its greater mechanical simplicity and smoothness of operation. However, the engine is less efficient than a four-stroke engine and tends to emit a higher level of noxious products of combustion. The two-stroke engine is most commonly used for small motorcycles.

2. EXPERIMENTAL CALCULATIONS

2.1. Measuring of Torque and Power Output

Engine's torque (T) is measured directly using a dynamometer coupled to the output shaft. The power output is calculated from the torque by multiplying by the angular velocity in radians per second. Because the dynamometer acts as a brake on the engine, the power at the output shaft is referred to as the " Brake Power"(P_B).

$$P_B = \frac{2.\pi.N}{60} \cdot T \qquad (W) \qquad (1)$$

2.2. The Performance of an Ideal Engine

One aspect of engine testing is to determine how the torque and brake power vary with engine speed. To interpret the results from a real engine, it is necessary to establish the maximum performance that can be expected from an ideal engine, which converts the energy contained in the fuel into mechanical work without loss.

An engine produces useful work from the heat energy released by burning the fuel. The power output depends on the rate where the fuel can be burned. For complete combustion, the fuel must be mixed with air in the correct chemical proportions. It the amount of air drawn into the cylinder that determines how much fuel can be burned during each cycle. Ignoring the volume occupied by the fuel, the volume of air induced into the cylinder during each cycle is ideally equal to swept volume (V_s). If the air is drawn in from atmosphere at a density (ρ_a), then:

Ideal mass of air Per cycle $= \rho_a . V_s$ (2)

The air consumption rate is given by formula below

$$\dot{m} = \frac{N}{60 \cdot n} . \rho_a . V_s \qquad (kg/h) \qquad (3)$$

Where n=1 for two stroke engines
n=2 for four stroke engines

The rate that fuel is burned depends on the air/fuel ratio, (R)

$$\dot{m}_f = \frac{\dot{m}_a}{R} \qquad (kg/h) \qquad (4)$$

Ideally, "R" has the "stoichiometric" value of about 14,7.

Assuming complete combustion, the heat generated Per unit mass of fuel is equal to the calorific values, H. This is typically 42.000 kJ/kg for petrol, 39.000 kJ/kg for diesel fuel.
The rate, Q at which heat is supplied to the engine, is given by:

$$Q = \dot{m}_f \cdot H \qquad (KW) \qquad (5)$$

All the energy could be converted into mechanical power, the power output would be

$$P_B = Q \qquad (6)$$

Expressing the fuel consumption rate in term of the other variables given by formulas 4, 5
Ideal Brake Power Output

$$P_B = \frac{H}{R} \cdot \frac{N}{60 \cdot n} . \rho_a . V_s \qquad (KW) \qquad (7)$$

Values of H, ρ_a and V_s are constant during a test on a given engine. R is also constant the speed range of the engine, so that

$$P_B = Const. N \qquad (8)$$

2.3. Criteria of Performance for Real Engine

2.3.1 Volumetric Efficiency

The first assumption was that during each cycle an engine could draw in a mass of air equal to the swept volume multiplied by the ambient air density. In practice, the mass of air is less than this, partly because of pressure losses in the induction system and also due to heating effects, which reduce the density of air as it enters the engine cylinder. For practical reasons, consumption rate for engines are usually expressed in kg/h rather than in kg/s. If the consumption rate is m_a kg/h, then

$$\text{Actual mass per cycle} = \frac{\dot{m}_a}{60} \cdot \frac{n}{N} \quad \text{(kg)} \tag{9}$$

The ratio of the actual to the ideal air mass flow is a measure of the "breathing" ability of the engine.

$$\eta_v = \frac{m_a}{60.N} \cdot \frac{n}{\rho_a . V_s} \tag{10}$$

These equations can be written as:

$$\eta_v = \frac{V_1}{V_s} \tag{11}$$

2.3.2 Thermal Efficiency and The Ideal Cycle

The second assumption was that all of the heat generated by combustion could be converted into useful mechanical work. There are two reasons why this is not possible:

(i) Some of the heat generated must always be lost in the exhaust gases. This can be demonstrated by considering the ideal cycle for reciprocating engines.

(ii) Some of the energy produced at the piston has to be used up in pumping the air into and out of the and out of the cylinder, in overcoming mechanical friction and in driving the engine accessories.

The thermal efficiency is defined as the work done in the cycle divided by the heat input. By analysing the cycle it can be shown that the ideal thermal efficiency is given by:

For petrol engine

$$\eta_t' = 1 - \frac{1}{r^{\gamma-1}} \tag{12}$$

For diesel engine

$$\eta_t = 1 - \frac{1}{r^{\gamma-1}} \cdot \frac{r_c^{\gamma-1}}{\gamma(r_c - 1)} \tag{13}$$

Where r is the compression ratio, γ is the ratio of specific heats and r_c is the cutting ratio are defined. For air, $\gamma = 1,4$

The four-stroke petrol engine has a compression ratio (r) of 6,5. Substituting this value into Equation (12) gives an ideal thermal efficiency of 0,53. This means that only 53% of the energy can be expected to be converted into useful work, the remainder being lost as heat in the exhaust. In practise, real pressure-volume cycle does not follow the Ideal Otto Cycle and shown in figure 2.a. An estimate of the heat loss to the exhaust can be made by measuring the difference between the exhaust and ambient temperatures and assuming a typical value of 1 kJ/kg.K for the specific heat of the exhaust gases.

$$\text{Heat Loss in Exhaust} = (\dot{m}_a + \dot{m}_f).C_{exh}.\Delta t \tag{14}$$

The heat supplied to the engine is given by the following equation

$$Q = m_f \cdot H \qquad \text{(KW)} \qquad (15)$$

The heat carried away by the exhaust, expressed as a percentage of the heat input, is

$$\%\ \text{Heat Loss in Exhaust} = \frac{(\dot{m}_a + \dot{m}_f).1.\Delta t.100}{\dot{m}_f.H} \qquad (16)$$

The diesel engine tends to have a higher ideal thermal efficiency than the petrol engine, because the compression ratio is much higher. If the cut-off ratio is closed to 1 point, the ideal thermal efficiency is 68% at a compression ratio of 17:1.

2.3.3 Mechanical and Brake Thermal Efficiency

The thermal efficiency is a measure of the amount of heat energy converted into mechanical energy at the piston. However, it does not indicate the amount of useful work available at the shaft output. To determine this it is necessary to know the mechanical efficiency (η_m), defined as:

$$\eta_m = \frac{\text{useful work output}}{\text{energy available at piston}} \qquad (17)$$

The work output is always less than the energy developed at the piston because some of this energy has to be used in overcoming mechanical losses. For economic reasons, it is important to obtain the maximum work output from a given amount of fuel, that is, to obtain the maximum overall efficiency of energy conversion. This efficiency is expressed as the brake thermal efficiency (η_b), defined as:

$$\eta_b = \frac{\text{Actual power output}}{\text{Rate of heat input}} \qquad (18)$$

$$\eta_b = \frac{P_B}{\dot{m}_f.H} \cdot 3600 \qquad (19)$$

Since power is the rate of doing work, it is clear from the earlier discussion that η_b can be expressed as the product of the actual thermal and mechanical efficiencies, i.e.

$$\eta_b = \eta_t \cdot \eta_m \qquad (20)$$

Thus the brake efficiency accounts for all of the losses, which occur in the engine. It is therefore a very important measure of engines performance and can be used both to compare the performance of different engines of the same type and to compare different types of engines. Value of the brake thermal efficiency is typically 30% but this is lower on small engine.

2.3.4 Specific Fuel Consumption and brake main effective pressure (bmep)

Another measure of engine efficiency are brake main effective pressure and the specific fuel consumption. Calculation of these is given below.

$$\text{bmep} = \frac{12.56 \cdot T\,(\text{Nm})}{V_s\,(\text{dm}^3)} \qquad (21)$$

$$\text{Sfc} = \frac{\dot{m}_f}{P_B} 10^3 \qquad \text{(g/kWh)} \qquad (22)$$

Specific fuel consumption is a useful measure of engine performance because relates directly to the economy of an engine. It enables the operator to calculate how much fuel is required to produce a certain power output for a certain length of time. So specific fuel consumption can be used to estimate the economic performance of the differences engine type.

2.3.5 Summary of Losses

An internal combustion engine releases the energy contained in hydrocarbon fuels by burning the fuel mixed with air in the combustion chamber. The increase in temperature increases the pressure on the piston, which is forced downwards, turning an output shaft. Mechanical power is obtained from the speed of rotation of the output shaft. The power output of an ideal engine varies linearly with speed but losses inherent in a practical engine result in less power being achieved. The amount of heat generated in the combustion chamber depends on the rate at which fuel is consumed. This depends on the rate where air is induced into the cylinder, which is limited by the volumetric efficiency of the engine.

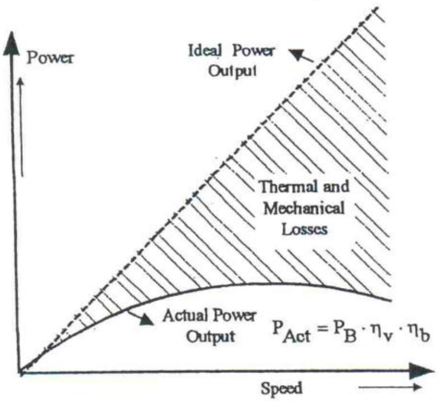


Figure 4. Power versus speed characteristic

Each type of engine has an ideal operating cycle, which determines the maximum output that can be expected. This is expressed in term of the Ideal Thermal Efficiency. However real engines tend to operate on cycles different from the ideal and the maximum power output that can be achieved in a mechanically perfect engine is expressed by the actual thermal efficiency. Not all of the work done on the piston is transferred to the output shaft because of mechanical losses within the engine, expressed in terms of the Mechanical Efficiency of the engine. By using the brake thermal efficiency,

$$\text{Actual Power Output} = \text{Ideal power output} \cdot \eta_v \cdot \eta_b \quad (22)$$

3. THE ENGINE TEST RIG

The basic test rig for each engine consists of the engine, hydraulic dynamometer and instrumentation unit (Figure 5.). A stopwatch, thermometer and barometer are also required.

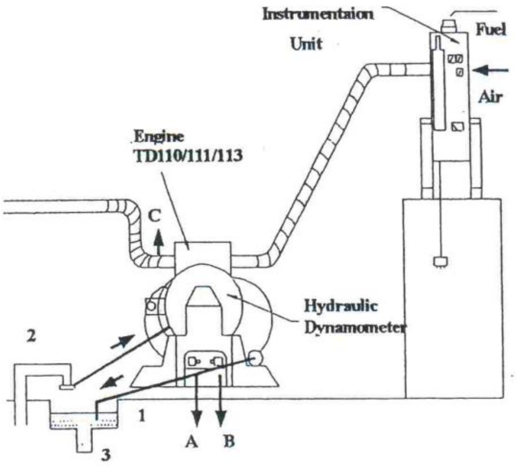


Figure 5. Engine Test Rigs.

3.1 Measuring of Speed

Engine speed is measured electronically by a pulse counting system. Optical head mounted on the dynamometer chassis contains an infrared transmitter and receiver. A rotating disc with radial slots is situated between the optical source and sensor as the engine rotates, the beam is interrupted. The resulting pulse is electronically processed to provide readout of engine speed.

3.2 Measurement of Exhaust Temperature

Exhaust gas temperature is measured by a chrome/alumel thermocouple. The thermocouple is located in the exhaust pipe close to the cylinder block of the engine. Blue and brown leads from the thermocouple are connected to similarly coloured terminals underneath the Instrumentation Unit. The temperature is indicated on a reading meter scaled from 0° to 1000 °C.

3.3 Engines

The specification of the 4 stroke diesel engine, 4 stroke petrol engine and 2 stroke petrol used with engine used with the mini engine test rig is given in Table 2.

Table 2. The specification of the four and two stroke engines

	4 Stroke Diesel	4 Stroke Petrol	2 Stroke Petrol
Swept Volume	219 cm^3	199,6 cc	151 cm^3
Bore	70 mm	66,69	60 mm
Stroke	57 mm	57,15	54 mm
Compression	17:1	6:1	8:1
Maximum Torque	8.2 Nm at 2700 rpm	10,3 Nm at 2500 rpm	10,6 Nm at 3000 rpm
Maximum Brake power	2.6 kW at 3600 rpm	3,75 kW at 3600 rpm	4,4 kW at 4500 rpm
Recom. Max. Speed	3600 rpm	3600 rpm	5000 rpm

3.4 Measurement of Torque by Dynamometer

Engine torque is measured by the hydraulic dynamometer and transmitted to a torque meter located on the instrumentation unit. Figure 6. shows the principles and layout of the dynamometer. The flow of water is controlled by a needle valve (A) mounted on the engine bed. Water flows into the top of the dynamometer casing (B) and out through the bottom, discharging into a drain or sump trough a tap (C). The dynamometer also has an air vent. The quantity of water in the dynamometer and hence the power absorbed from the engine, depends on the setting of the needle valve (A) and tap (C). The engine shaft drives a paddle (D) inside the vaned casing (B) churning up the water inside the dynamometer. Rotate casing (B) is tried by effect of water moving. Torque is obtained by determining components of radial force, which is on the dynameters casing.

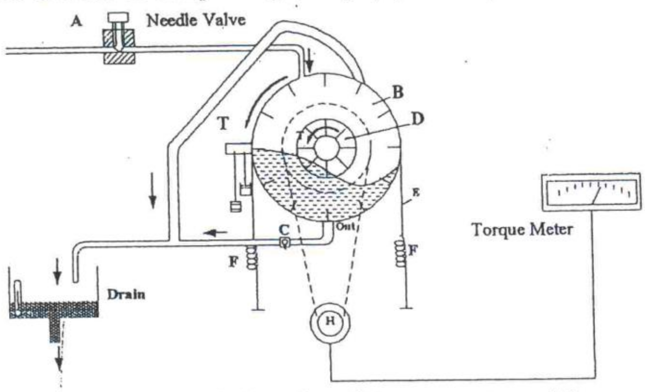


Figure 6. Schematic Drawing of Dynamometer and Torque

3.5 Fuel Systems and Measurement of Fuel Consumption

The fuel system is fed from a 4,5 litre fuel tank mounted on top of the instrumentation unit. Being gravity fed, the engine carburettor must be below the level of the tank. Figure 7. shows the fuel system.

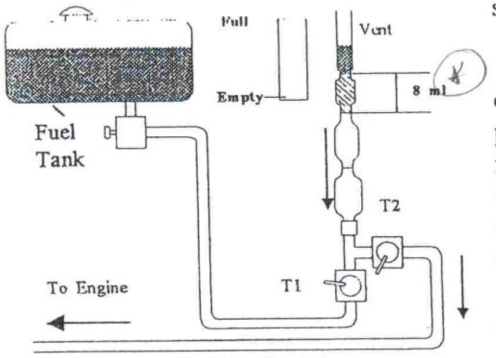


Figure 7. The Fuel System

The tap T1 isolates the tank from the engine, enabling fuel to be consumed from the pipette. The fuel consumption is determined by measuring time (t) taken for the engine to consume a given volume of fuel, say 8,16 and 32 ml. The tap T2 isolates the engine from the fuel supply.

Assuming a specific gravity for water of 1000 kg/m^3.

Typical values of specific gravity are for petrol engine δ = 0.74 and diesel engine δ = 0.84.

$$\dot{m}_f = \frac{\delta.1000.V_p.10^{-6}}{t} \quad \text{(kg/s)} \qquad (23)$$

It is more convenient to express the consumption

$$\dot{m}_f = \frac{\delta.1000.V_p.10^{-6}}{t} 3600 \quad \text{(kg/h)} \qquad (24)$$

3.6 Measurement of Air Consumption

Single cylinder engines tend to induce a pulsating flow of air since the air is being drawn in during only one of two or four strokes. An orifice cannot be used reliably under these conditions, unless a very large damping volume is introduced between the orifice and the engine. For given air density the mass flow rate of air is proportional to the average velocity, so that the pressure drop across the viscous element is directly proportional to the flow rate, unlike the parabolic, relationship associated with an orifice. The pressure drop is measured by an inclined tube manometer, calibrated in millimetres of water.

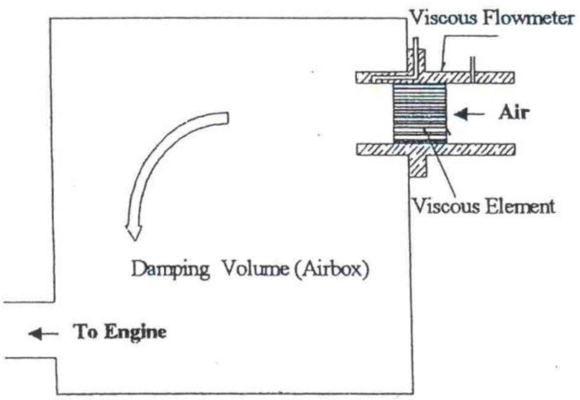


Figure 8. Measurement of Air Consumption

Figure 8. shows a sketch of the flow meter. Air is drawn in trough an inlet and flows trough an element consisting of thousand of small-bore tubes before entering the damping volume.

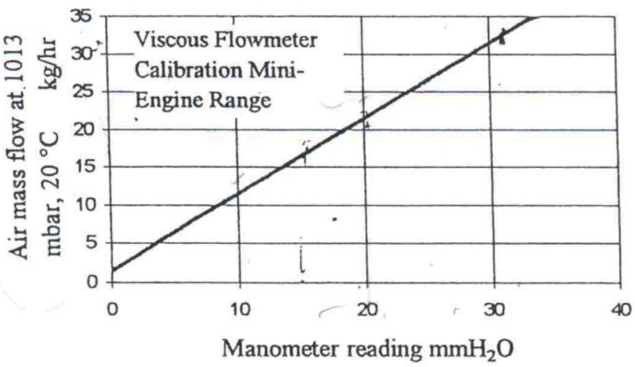


Figure 9. Calibration curve of viscous flow meter

The viscous flow meter is calibrated at the factory and a calibration curve is supplied with the engine. Figure 9. shows a typical calibration curve for air at 1013 mbar and 20 °C.

4. EXPERIMENTAL PROCEDURE

4.1. Calibrating the Torquemeter

Before each engine test, the torque meter must be zeroed and calibrated before use. To do this;

1. Set the SPAN control to its maximum clockwise position.
2. Hang a load of 3,5 kg on the calibration arm.

3. Adjust the SPAN control to give a torque reading of 8,6 Nm.
4. Remove the calibration load and repeat steps 2 to 5 until satisfied that the zero and Span setting are correct.

5.2. Experimental Results

1. Plot exhaust temperature, torque, brake power, air/fuel ratio and specific fuel consumption versus engine speed with the correction of ambient pressure and temperature (for diesel engine).
2. Plot % heat loss to exhaust, volumetric and brake thermal efficiencies (%) versus engine speed (for diesel engine).
3. Plot ideal and actual power output versus engine speed (for all engines).
4. Plot brake power, exhaust gas temperature, torque and AFR versus engine speed for each throttle setting (for petrol engines).
5. Plot brake power, torque and AFR versus exhaust gas temperature for each throttle setting (for petrol engines).
6. Plot bmep versus Sfc for each throttle setting (for petrol engines).

5.3. Discussion

Discuss experimental errors and all your graphs one by one. Where is the diesel engines, four stroke petrol engines and two stroke petrol engines used and why?

5.4. Report Order

1. Experimental and calculated results, discussion and conclusion have to be included in your report.
2. Required calculation should be done; experimental and calculated results must be tabulated.
3. Required graphs have to be plotted by a computer.
4. Discuss the graphs and experimental errors.
5. Conclude the experimental setup and results