ENGINE: THE INCREDIBLE POWER HULK
AND THE INEVITABLE

BY

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Engine: The Incredible Power Hulk and the Inevitable

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INTRODUCTION
Any device which derives its energy from the combustion of fuels or any other source and converts this heat energy into mechanical work is considered to be an engine. Combustion as an important phenomenon of an engine operation may be defined as a fairly rapid reaction between a fuel and an oxidant in which heat and flame are liberated. The flame makes combustion differ slightly from a purely chemical reaction. The sustenance of the propagating flame in the engine confinement further ensures and depicts the chemical reaction process and the completeness

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PROLOGUE

For about 100 Centuries now, there has not been much difference in the features of homo sapiens. Their strong urge to stay alive has remained the same till today. Their physical strength, and intelligence still remain. But down through the ages, countless billions of men and women had strived unsuccessfully to keep bare life in wretched bodies, many had died young in mystery and squalor, several others had walked while carrying goods on their straining backs. Many had lived in caves and floorless squalid dwellings without windows or chimneys. They had toiled desperately from dawn to dusk, barefooted and half-naked.

It is incredible, if we could pause to reflect swiftly, that in less than only two hundred years out of the over one million years of man's existence on earth, the world has conquered the darkness of night through her progress from the burning of wood and pine knots to candle light, kerosine lamps, gas jet, then to electric bulbs, neon light, fluorescent tubes etc. The world has made stupendous breakthrough on earth, from oxcarts, rafts and canoes to automobiles, railways, marine ships, subways, highways, trucks, buses, airplanes, rockets and spaceships. In self defence during Warfare, man has created wholly new and astounding defence wares ranging from the use of clubs, sharp stones to automatic guns, artilleries, bombs, warships, submarines, war planes and nuclear weapons. Finally the world has developed from back breaking drudgery into the modern age of incredible powers from engines for haulage, traction, electricity generation, marine, air, outerspace and interplanetary-travels.

INTRODUCTION

Any device which derives heat energy from the combustion of fuels or any other source and converts this heat energy into mechanical work is considered to be an engine. Combustion as an important phenomenon of an engine operation may be defined as a fairly rapid reaction between a fuel and an oxidant in which heat and flame are liberated. The liberation of flame makes combustion defer slightly from a purely chemical reaction. The sustenance of the propagating flame in the engine confinement further ensures and depicts the chemical reaction process and the completeness
of combustion which, however, is the major requirement for power production by the engine.

Engines may conveniently be grouped into two principal and practical classes, namely, Internal combustion engines and External combustion engines:

(1) Internal Combustion Engines: Here, combustion of the fuel with oxygen of the atmospheric air occurs within the engine confinement. The internal combustion engines may be subdivided into two groups, namely, reciprocating and rotary or rotodynamic types.

Reciprocating Internal Combustion Engines: Here, the pressure generated as a result of the compression and combustion processes is employed to operate a piston performing a reciprocating motion within the cylinder. This reciprocating motion of the piston is finally converted into rotary motion of the crankshaft by means of a suitable mechanism, configured by the cylinder walls, connecting-rod and the crank. Examples of the reciprocating internal combustion piston engines are:

(a) Gas engines, in which mixtures of combustible gases and air are employed for combustion and hence power production.
(b) Oil or diesel engines, in which heavier liquid fuels such as oil or diesel and compressed air are employed for combustion and power production by the engine.
(c) Gasoline or Petrol engines, in which lighter liquid fuels or spirit are employed for combustion and power production.

Rotary or Rotodynamic Internal Combustion Engines: Here, the gases under pressure inhibited by a compressor and further augmented by the combustion of the fuel, are applied direct to a series of blades or vanes arranged around the periphery of a cylindrical member called the rotor which is mounted on a shaft, thus imparting a continuous momentum on the latter without the aid of any intermediate mechanism. Examples of rotodynamic internal combustion engines are:

(a) Gas turbine engines, in which the combustion products turn the turbine shaft for power production.

(2) External Combustion Engines: In this case, the combustion of the fuel takes place outside the engine compartment. Examples of the external combustion engines are:

(a) Steam engine, in which the heat of combustion is employed to generate superheated steam which is used to actuate reciprocating motion of the piston in a cylinder for power production.
(b) Steam power plant, in which the heat of combustion from an external combustion chamber is employed to generate superheated steam or water vapour in a boiler to drive a steam turbine designed for power production.

Tremendous improvements and diversification had gone into the various seven major engine families mentioned above. But before I discuss their development and diversification, let us have a look into their historical background.

HISTORY OF ENGINES
Abbe Hautefeuille, a French was credited with the origin of the piston-combustion engine, when in 1678 he proposed using the explosive power of the gunpowder in a cylinder to move the piston and obtain mechanical work.

However, in 1680, another French namely Huyghens put to practice Abbe's proposal and actually built an engine using gunpowder as the fuel. His engine consisted of a vertical cylinder having a sliding-fit type of piston. Whilst the piston was at the top of the cylinder, gunpowder was exploded with some air filling the cylinder. The remaining air, together with the products of combustion, was expelled from the cylinder through non-return valves, thus creating a partial vacuum within the cylinder. The pressure of the atmosphere on the top of the piston forced it downwards and the movement of the piston was utilised to lift a weight by means of a rope and pulley arrangement. The lack of control of the rate of explosion, and particularly the difficulty of charging the cylinder with the solid combustible between each working stroke, prevented the further development of this engine, except for one-stroke
devices such as in artillery and aircraft catapult engines of today. Between 1680 and 1860, many patents were granted inventors and builders of internal and external combustion engines. The desirability of supplying energy directly to working fluid by combustion within the engine cylinder was recognised many years before a practical internal combustion engine was built. The steam engine, which came into use about 1700 was extremely uneconomical in its use of fuel. Its low efficiency was as a result of indirect conversion and application of energy, that is, fuel energy to mechanical work. It was not until 1860 when the first really practical engine was developed in France by Lenoir which resembled structurally the steam engines of that period, differing basically only in that a mixture of fuel and air was supplied to the cylinder of the engine, ignited and burned for power production. Lenoir utilised earlier ideas, in the design and construction of his engine, which in addition contained many carefully thought out details that contributed immensely to its success. The efficiency of Lenoir engine was extremely low because the charge was not previously compressed. It was therefore classified as a non-compression internal combustion engine. However, about 500 of these engines were built for public use in France and England.

Fig. 1a: Indicator Diagrams for Lenoir Engine and the Present Modern Engine

All the early piston engines were provided with combustible charges which were ignited at atmospheric pressure. Barnett, in 1838 in England proposed compressing the mixture by using charging pumps. Also in 1861, Gustav Schmidt in Germany proposed compression of the gas/air mixture in the Lenoir engine before ignition in order to obtain improved power and fuel economy. A few years later, another French Scientist namely Beau de Rochas, published a theory for the operating procedure and the condition under which maximum economy could be obtained from an internal combustion engine which differed fundamentally from that of Lenoir and was destined to become the basic principle of our modern engines. However, Beau did not build any engine, but in 1876, Otto produced in Germany an engine using the theory of Beau which operated successfully. The cycle of operation has since been called the Otto Cycle and is used for the series of events that make up the cycle in today’s four-stroke engines. The last decade of the 19th Century saw the invention of a novel type of internal combustion engine which was configured to burn a liquid fuel oil with no external ignition source. This engine was to become the most efficient prime mover using a liquid fuel oil, and is now known previously compressed.
as Diesel engine named after one of the pioneers in the field, the German engineer, Dr. Rudolf Diesel. Later developments included the work of Dugald Clerk of England who succeeded in supplying the charge to the cylinder in such manners that the necessary processes of the Otto and diesel cycles could be completed in one revolution of the crankshaft (2 stroke engine) instead of requiring two revolutions of the shaft as did the original Otto and Diesel engines (4 stroke engines) Fig 2.

For large power production which requires large volumes of air intake, the piston-cylinder configuration of an internal combustion engine is limited in this regard.

However, this power limitation can be increased if multi-piston – cylinder in radial configuration is applied. This arrangement can further be made compact by using a rotodynamic turbine-driven compressor before the combustion chamber.

The early gas turbines were very inefficient, but in 1791 John Barber of England used a bladed turbine wheel to drive a piston air-compressor which discharged compressed air into a combustion chamber while the gaseous fuel was delivered into the chamber by a pump. The products of combustion were directed to impinge on the blades mounted on the turbine wheel through the nozzle. Long before John Barber, Hero, a Greek philosopher in the second century B.C. demonstrated jet power in a rotating ball that explains a pure reaction turbine of today. Sanford Moss of Cornell University in US, using the elements indicated in Barber's patent utilized a compressor, combustion chamber, nozzle and turbine bladed wheel. The resulting combustion products were delivered through nozzle jet into the impulse turbine wheel to produce mechanical work, part of which was used internally in driving the compressor whilst the rest of the power produced was for external use. Although the early turbines did not produce sufficient power even to drive the compressor the results of experiments and research were amazing enough to encourage the development of these engines until it eventually resulted in the production of the exhaust turbosupercharger engine used extensively on aircrafts in world war II. The turbosupercharger however increased the back pressure imposed on the exhaust mainfold system of the piston engine, but the higher intake manifold pressure due to supercharging, more than offset the loss created by back pressure which however permitted operation of aircraft at higher altitudes.

The first serious attempt to develop the gas turbine engine was made by the Societe Anonyme des Turbomoteurs of France in 1905. Here, the compressed air and the fuel sprays were ignited and water sprays were used for cooling. Compression ratio of 4:1 was achieved, whilst turbine inlet or maximum cycle temperature
was 919°C with a cycle thermal efficiency of 3%. Almost all the power developed was used to drive the compressor. This engine would have been most suitable for aircraft propulsion but for the water medium required for cooling, constituting additional weight. Shortly after, in 1908, Holzwarth of Germany built a gas turbine engine. The combustion chamber was charged with mixture of air and gaseous fuel, and combustion occurred at constant volume. However, the filling process of the Holzwarth combustion chamber with compressed air and fuel and the charging velocity of the nozzle stream, as the pressure in the combustion chamber varied, introduced inherent losses which prevented the further development of this engine.

Further development of the gas turbine engines has continued till today resulting in turbine engines producing up to 200 MW power or more. Gas turbine engines are leading in engine power production if compared with their counterparts the diesel and petrol engines and they have derived extensive applications in electricity generation, aircraft, and marine propulsion. The gas turbine engine of today consists basically of three common components namely, compressor, combustor, and turbine. Air is drawn into the engine through the front intake. The compressor compresses the air to many times its initial atmospheric pressure value and forces it into the combustion chamber. Here, fuel is sprayed into the compressed air, ignited and burned continuously like a blowtorch. The burning gases expand rapidly rearward and pass through the turbine. The turbine extracts energy from the expanding gases to drive the compressor, which rams in more air. After leaving the turbine, hot gases blast their way out the rear of the engine to the chimney, in the case of power plant for power production or to a propelling nozzle in the case of aircraft propulsion, giving the aircraft its forward push or thrust – (Action and reaction are equal and opposite - Newton's third law of motion).

The turbine is the prime mover that produces the incredible power of the gas turbine engine. In doing this, a part of that form of energy of the steam (steam turbine) or hot gases from the combustor (gas turbine) accompanied in both cases by a high pressure and temperature is converted into kinetic energy of the steam or gases flow in channels or passages created by vanes and then into shaft power of the turbine. Fig. 3.
The main application of an engine is the production of mechanical work governed by the first and second laws of thermodynamics and Newton's laws of motion. Whether or not their efficiencies are high, the main objective of the designer is essentially high power production to meet a given requirement. The efficiencies of most internal combustion engines are usually not high, about 40%. Even when augmented with heat saving devices such as heat exchangers, regeneration, intercoolers, reheaters, economizers and effective cooling and lubrication with quality oils, their efficiencies are still below 50%. All these not withstanding, they have superiorities over one another, whether or not they belong to one family or group in terms of fuel economy and power production.

Another important prime mover is the electric motor working on the principles of force exertion on a rotating conductor in a magnetic field. Where the electric motors could not be engaged due to large power requirements, non-existent of electricity supply etc, the internal or external combustion engines are essentially the other alternatives. Power obtainable from internal or external combustion engines ranges from 0.75 KW of a single cylinder petrol engine to over 500 MW of power from gas or steam turbine engines. The internal and external combustion engines are therefore diversified in applications which range from crops or grains grinding to haulage, traction, aircraft propulsion, marine propulsion, railway traction and propulsion, vehicular transportation etc to industrial applications such as electricity generation of several megawatts, process heating in industries and natural gas, crude and refined oil transportations through pipe lines over several kilometres distances. It also has applications in refrigeration and air-conditioning of spaces. A particular application usually determines a choice of engine.
atmosphere or stratosphere up to the tropopause, about 11KM above sea-level. But the rocket engine flies in the outer space carrying along with it, its own oxidant, usually oxygen or hydrogen peroxide $\text{H}_2\text{O}_2$. Basically, the rocket engine is one of the simplest forms of heat engines. Surprisingly, the date of discovery of the principles of rocket propulsion appears lost in antiquity. But interestingly, most of the early comprehensive studies, conducted by scientists envisioned the rocket engine principally as means for accomplishing interplanetary flights and survey.

(4) For National International and Intercontinental travels on the sea or Ocean (Marine):
(a) Multi cylinder compression ignition diesel engines (mainly two-stroke Construction)
(b) Steam engine (reciprocating)
(c) Steam Power Plant which utilizes mainly, a boiler and a steam turbine to provide mechanical power for the propeller of the ship.
(d) Gas turbine engines to provide power to drive the ship’s propeller.
(e) Single or multi- cylinders spark ignition petrol engine, for common outboard boats or ships. (two-stroke cycle is common).

(5) For Electricity Generation in homes and Industries:
(a) Single or double cylinder spark ignition petrol engine (2 - stroke), Used domestically in homes for electricity production during NEPA outages or in rural area not connected to the national grid.
(b) Multi-cylinder compression ignition diesel engine (2 or 4 - strokes ) for Electricity generation, providing power to drive alternators of up to about 2 Mega Watts electrical output. These are more prevalent in private homes, private industries, institutions and Government establishments.
(c) Steam power plant: This plant uses water as its working fluid. The water is turned into steam in the Boiler and the superheated steam thereafter expands in a steam turbine resulting in mechanical power production by the turbine. This power is used to drive the alternator which generates electricity sometimes in excess of 200 Megawatts.
(d) Gas turbine engine: Power produced here also drives the alternators of up to 200 Megawatts power rating.

(6) Transportation of liquids or gases over long distances.
(a) Diesel engines and gas turbine engines are mainly the internal combustion engines that are used to provide power to multi-stage compressors and pumps which transport natural gases etc. and crude or refined oils etc over long distances by applying pressure to them up-stream.
IGNITION IN ENGINES
Traditionally, the high power output engines have operated with over-rich mixtures with consequent exhaust emissions of carbon-monoxide, unburnt hydrocarbons, and oxides of nitrogen.

In view of the harmful tendencies of these emissions, researchers are working towards improving emission characteristics and efficiency of the internal combustion engines. This may be achieved by greater insight into the nature and characteristics of the electric spark and the combustion processes that follow. Ignition, which is the process of initiating chemical reaction in a combustible system involving the gas, solid or liquid phases has various techniques such as heated surfaces, pilot flames, hot gases, shock waves, and electrical spark for initiating it. Because the electrical spark offers a comparatively efficient means of heating a compact region to a high temperature, it is most common. Nevertheless, the use of electrical sparks cannot always guarantee ignition, and there are many factors which govern this. Other methods of ignition, particularly of lean mixtures have been found to be more reliable than the electrical spark.

The insight into the combustion process involves starting with burning lean mixtures in new designs of lean-burn engines to reduce emissions and fuel consumption while retaining, or improving the normal engine power output.

The Nature of a Spark
A gap between two electrodes separated by air or some other gas is essentially a non-conductor until a certain critical voltage is applied. Thereafter, the gap breaks down, the current increases very rapidly and the gap electrical resistance drops. Breakdown results in a narrow conducting channel of ionized gases at high temperature in excess of 10,000K.

The actual breakdown voltage is governed by such factors as:
(i) Material of the electrodes, especially the cathode.
(ii) Length of the gap.
(iii) Shape and size of the electrodes.
(iv) Condition of the electrode tips.

Breakdown is usually manifested by light emission and abrupt change of potential and current. The rapid heating of the gas generates a shock wave which persists for about 10 to 20 microsecond. This travels with a supersonic velocity spherically away from the sparking source. The shock wave could be strong enough to induce ignition.

Only about 10% of the energy stored in the ignition circuit is useful in igniting a mixture by an electric spark in an engine. The rest of the energy is lost in the circuit, by radiation, and conduction to the electrodes. The spark heats up the surrounding cold gas, and the temperature increase is manifest as a thermal wave that spread radially through the agency of thermal diffusivity or thermometric conductivity (K). In the presence of turbulence, contribution to this spreading process might be expected from the eddy diffusivity. A variety of electrode configurations may be employed to produce the plasmas and the associated hot gas kernel. Under certain
circumstance, for example, when electrodes are arranged parallel, the spark kernel moves away from electrode gap. This outward motion would reduce conductive heat loss to the electrodes as well as facilitate ignition. This electrode configuration is used in the aircraft gas turbine igniter plug and is called "The surface discharge igniter". The surface discharge igniter plug consists of a central, circular electrode separated from an outer circular, earthed electrode by a short annular ring of a semiconductor. The central electrode is therefore parallel to the outer electrode whilst the semiconductor facilitates breakdown.

The developing phenomena associated with spark discharge in air and in combustible mixtures are illustrated by the series of photographs shown in Figs. 5 – 11. Each photograph illustrates a separate and independent spark discharge. The thermal spread of the spark appears as a bright spot between or off the electrodes. All the photographs were taken for a spark duration of 130 microseconds. Every spark Kernel photographed, within a time delay range of 2 to 10 micro-second from the commencement of the spark, revealed a shock wave ahead of the spark kernel which was propagating further than the hot gas Kernel boundary.
The photographs were obtained using the schlieren photographic arrangement. This involves focusing a simple parallel beam of light onto a cut-off (or knife edge) and the projection of the divergent beam onto a film. An optical inhomogeneity in the parallel beam of light causes the beam to deflect, with a resulting redistribution of the illumination in the image plane. High speed cine camera (6,000 frames per second) was used to record the events. The light source was either the laser beam or argon spark from an argon jet. The high speed cine camera was synchronised with the ignition circuit and was therefore used to trigger the events as shown in (Fig. 12).

The theoretical model for the thermal spread under turbulent conditions and in the absence of significant chemical heat release involves the application of the equations of global mass and energy conservations.

The global mass conservation equation for spherical coordinate system with angular symmetry is:

\[
\frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 p u \right) + \frac{\partial p}{\partial t} = 0 \tag{1}
\]

And the energy conservation equation for constant pressure, zero viscous dissipation, and zero volumetric heat release rate is:

\[
\frac{1}{r^2} \frac{\partial}{\partial r} \left( \frac{\lambda r^2}{\partial T} \right) = \rho C_p \left( \frac{\partial T}{\partial t} + \frac{\partial T}{\partial t} \right) \tag{2}
\]

Both molecular and turbulent transport processes contribute to the thermal spreading and therefore:

\[
\lambda = (\kappa + \epsilon p C_p) \tag{3}
\]

Where \( \lambda \) is the effective conductivity, \( \kappa \) is the thermal conductivity – molecular contribution, expressed in polynomials of changing temperature.

\( \epsilon \) is the eddy diffusivity – turbulent contribution and \( p \) is the ionized gas or plasma density with compressibility effect.

\( C_p \) is the specific heat capacity at constant pressure expressed in Polynomials of changing temperature.

The polynomials of dimensionless thermal conductivity, \( K/K_o \) and specific heat, \( C_p/C_{p0} \), were expressed in terms of the dimensionless temperature, \( T/T_o \) or \( \theta \). Hence, for thermal conductivity,

\[
K = b_0 + b_1 \theta + b_2 \theta^2 + b_3 \theta^3 + \ldots + b_n \theta^n \tag{4}
\]

And for specific heat,

\[
C_p/C_{p0} = a_0 + a_1 \theta + a_2 \theta^2 + a_3 \theta^3 + \ldots + a_n \theta^n \tag{5}
\]

Where, \( C_{p0} = 1.004592 \text{ KJ/KgK} \)

\( K_0 = 2.57255 \times 10^{-5} \text{ KW/MoK} \)

\( R = 0.287 \text{ KJ/Kg}^0 \text{K} \) and

\( = 1.2051 \text{ Kg/M}^3 \)

for air at ambient temperature.
The global mass conservation and the energy conservation equations were solved after being made dimensionless for the temperature and velocity distributions for various times and radii of spread using a single step of merson's form of the Runge-Kutta method of finite difference. These are shown in Fig. 13 and Fig. 14 for temperature and (Fig. 15 and 16) for velocities distributions.

Detailed time-resolved spectroscopic and interferometric investigations of fundamental aspects of spark ignition revealed that within the range of nanoseconds and several milliseconds from spark initiation, the spark consists of three discharge phases namely breakdown, arc and glow. Dissociation and ionization are however less severe in the glow phase than the arc phases because the temperature during the glow phase is much less than 10,000K.

Influence of Circuit Parameters on Spark Energy And Ignition.

The design of the electrodes, and the electrical circuitry can also affect breakdown, nature of the spark and ignition. The nature of the spark discharge is influenced by such circuit parameters as resistance, inductance and capacitance. The actual values of the breakdown voltage and the spark energy, as well as the transition range from arc to glow phases depend on these parameters. The most obvious effect of an increase in the value of a resistor in series with the spark gap is an increase in the ohmic losses in the circuit, where \( I \) is the current and \( R \) is the resistance of the resistor. Therefore, more stored energy becomes inevitable to achieve a given energy-release at the Spark gap.

The component responsible for the energy storage in the discharge circuit is the capacitor. Any increase in the value of the capacitance will increase the stored energy \( \frac{1}{2}CV^2 \), and hence the energy available for ignition. \( C \) and \( V \) are respectively the capacitance and the applied voltage. Also, the numerical integration of the product of the voltage and current across the gap with respect to discharge time gave the spark energy as,

\[
E_s = \int V_s(t) \times I_g(t) \, dt
\]

where \( V_s \) is the voltage, \( I_g \) is the current and \( t \) is the time.

The current and voltage traces on the oscilloscope gave well defined rectangular pulses as shown in Fig. 17.
The problem of spark ignition in a practical combustor is complicated by the complex interplay of chemistry, aerodynamics, electrical aspects and particularly turbulence. In the propagation of the initial thermal wave in a turbulent system it is to be expected that there will be contributions due to the turbulent diffusivity, as well as molecular processes in the form of purely thermal diffusivity.

Minimum Ignition Energy
An important parameter of ignition is therefore the minimum ignition energy. This exist for various gases under different conditions of mixture strength, spark gap length, temperature and pressure. The minimum ignition energy is the minimum amount of energy that must be released into a critical volume to raise the temperature of the gases within the volume to its ignition temperature under specified conditions.

The minimum ignition energy is not the energy originally stored in the circuit by the capacitor but that contained in a critical volume as internal energy. This is always a small fraction of the energy originally stored in the circuit as there are various energy losses such as:

(i) Conductive heat transfer to the electrodes.

(ii) Electrical loss in the circuit.

(iii) Radiative energy loss to the surroundings.

(iv) Energy dissipated in driving the shock wave.

Increases in the value of the inductance $L$ of a capacitor spark discharge circuit, increase the total impedance $Z$ of the circuit by an amount $X_L$ proportional to the frequency of the current and voltage oscillations $f$, if the circuit is not critically damped, thus

$$X_L = 2\pi fL \quad \text{----------------------}(7)$$

and

$$Z = \sqrt{R^2 + X_L^2} \quad \text{--------------------}(8)$$

Where $X_L$ is the inductive reactance in ohms and $R$ is the circuit resistance in ohms. The efficiency of the energy transfer to the spark would therefore be lowered as a result of the extra inductive loss.

Ignition with Molecular and Turbulent Transports
The spark ignition of quiescent mixture inevitably simplifies the mechanism of a thermal wave spread from the spark source which is an essential pre-requisite for ignition. If the system is quiescent, flame propagation after the pre-flame reaction is transient and both the thermal and the addy diffusivities come into play.

Fig. 17 Voltage and Current Traces; Voltage: 50vcm\(^{-1}\); current-5vcm\(^{-1}\); Time - 50\(\mu\)sec\(cm\(^{-1}\)

Where $X_L$ is the inductive reactance in ohms and $R$ is the circuit resistance in ohms. The efficiency of the energy transfer to the spark would therefore be lowered as a result of the extra inductive loss.

The first loss brings about the existence of a critical quenching distance for ignition and for electrode spacings below this, ignition would fail. Under this condition, the electrodes are so close that a large amount of heat is lost by conduction to the electrodes and this can lead to apparent increases in the value of minimum ignition energy. In addition, flow velocity, turbulence intensity, reduction in pressure, and departures from stoichiometric fuel-air ratio are factors that can lead to increase in quenching distance and minimum ignition energy.

Chemical Kinetics
A chemical kinetic treatment of spark ignition involves analysis of all possible chemical reactions at the temperatures arising from the passage of the spark. A complete model would therefore involve
the energy equation and a complete kinetic treatment with the appropriate conservation equations for each chemical species. However, a problem arises from the uncertainty about the composition and temperature arising from the spark. It may also be noted that the action of turbulence, in creating time-fluctuating chemical concentrations would make analysis more difficult.

Simplification can be achieved through the concepts of an ignition delay time, which is the time that elapses from spark application to the initiation of ignition, and thermal theories of ignition which avoid the complexities of a full kinetic treatment.

For an ignition to occur two major requirements must be fulfilled.
(i) The ignition delay time must elapse to allow for pre-flame reactions; and
(ii) The rate of heat loss from a critical volume must be less than or equal to the rate of heat generation by chemical reaction.

As a thermal wave propagates outwards from the initial spark channel the temperature of the gases is continually changing with time as well as with distance. As a result of this, the apparent ignition delay time at a point also is continually varying. Under these conditions, the first ignition requirement becomes

$$\int_0^t \frac{dt}{t_{ig}} > 1$$

where \(t_{ig}\) is the ignition delay time of the mixture at time \(t\) and is a function of mixture composition, temperature and pressure. With suitable ignition delay data, ignition of a flammable gas can be predicted. Generally, the experimental data for ignition delays in shock tubes are correlated by an expression in the form:

$$t_{ig} = A \exp \left( \frac{E}{RT} \right) [O_2]^a [CH_4]^b$$

Where methane and oxygen concentrations are in moles \(\text{cm}^{-3}\), \(t_{ig}\) is the induction time in seconds, \(T\) is the temperature in \(\text{K}\), \(R\) is the universal gas constant, \(A\) is a constant, \(a\) and \(b\) are correlation parameters and \(E\) is the activation energy.

The second ignition requirement necessitates a definition of the critical volume. There have been several theoretical attempts to obtain this. The critical radius had been observed to be of the order of half the quenching distance by Lewis and Von Elbe (1961).

**Ignition Problems in Engines:**

**Turbulence**

Although, high levels of turbulence are desirable in that they increase burning velocities and create homogeneity of the charge the ignition of the mixture may ultimately fail as a result of the turbulent levels. Experimentally, it has been established by Akindele (1980) that turbulence makes ignition more difficult. But this difficulties may be countered by an increase in spark energy. The difficulties arise from the rapid dissipation of the thermal energy required for ignition by the action of turbulence.

In the continuous combustion process prevailing in the gas turbine combustion chamber, the rate of energy release can be increased by the use of the recirculation device. This recirculation process increases the turbulence of the charge and enhance the burning velocity, thereby improving the overall performance of the combustion chamber. In the reciprocating engine, the energy release rate is increased by suitable motion of the charge and its associated turbulence. Such motion of the unburnt gases can be generated by:

(i) Restriction of the passage way in a 'turbulent head. During compression the gases through the passage are made turbulent.

(ii) Rapid ejection of the charge compressed between the piston and a corresponding surface in the cylinder head as top dead centre is approached.

(iii) Swirling of charge. The inlet ports directs the charge in a tangential direction into the cylinder or by the use of shrouded valve. This creates some angular momentum in the charge during induction. This swirling motion increases the charge turbulence.
The afore-mentioned motions generate turbulence and the turbulence energy is finally dissipated in small scale high frequency eddies.

**Lean Burning in Engines**

Traditionally, the gasoline engines have operated with air-fuel ratio slightly richer than stoichiometric. These have given high power outputs but only tolerable idling characteristics because the adiabatic flame temperature is maximum at fuel-air ratio slightly above stoichiometric.

Operating engines with over-rich mixture provides the unfortunate consequence of excessive harmful exhaust emissions and higher fuel consumption. In order to reduce these, weak mixtures are to be preferred. Weakening the mixture can have the unfortunate effect of reducing the power output as a result of lower burning velocity, and can also make ignition more difficult to achieve. In order to achieve a rate of burning adequate to normal engine running speeds with a lean mixture, it is necessary to compensate for the associated reduction in burning velocity by an increase in the intensity of turbulence. On the other hand, an increase in turbulence makes ignition more difficult.

Within certain limits, an increase in spark energy might render ignition possible although the energy requirement might eventually become excessive and the flame in the early stages will be regarded as an electrically boosted flame or plasma. However, increase in spark plug gap, spark duration as well as of spark energy, all increase the initial spark kernel diameter and hence facilitate ignition. The initial spark diameter can also be increased by introducing a drop of liquid fuel on the igniter tips. Provided a spark can occur, the initial spark kernel diameter increases as a result of the burning of the fuel drops. This is a chemically boosted spark and can be found useful in gas turbine and gasoline engine, Akindele (1980).

In cold start, ignition of the lean mixture can be achieved by these means, but the associated propagating flame can be quenched by the cold walls of the chamber before a fully developed flame front is achieved because of the lower chemical reactivity of lean mixtures.

**SOLUTIONS TO PROBLEMS**

An approach to the solution of ignition problems in turbulent and lean mixtures and exhaust emissions is to introduce a degree of heterogeneity into the charge that exists during combustion. Ignition can be facilitated by stratification of the mixture. This involves initiating flame propagation in a near stoichiometric reactive mixture and allow the flame to spread into a region with lean and less reactive mixture. This brings about the concept of stratified charge engines.

**Stratification**

A stratified charge engine is desirable for the provisions of both fuel economy and low emissions. Two design approaches are possible, one with a single combustion chamber, the other with prechamber-main chamber configuration.

**Single Combustion Chamber Stratification**

This involves charge heterogeneity or stratification in a single cylinder. A cup-shaped combustion chamber is formed on the Piston surface. The air is made to swirl in the cylinder as described earlier and fuel is injected into this swirling air, ignition is by means of electric spark. The swirling motion tends to homogenise the mixture and also creates a high turbulence intensity which promotes nearly complete combustion during the expansion stroke. High compression ratio are also possible with knock free combustion. This has been adopted in designs by American Ford and Mitsubishi.

**Prechamber Stratification**

Prechamber-main chamber configuration is adopted in this approach. The prechamber is provided mainly for ignition purposes and the main chamber provides the power output from the engine. The prechamber working volume is about 1% that of the main chamber. Slightly over-rich combustion occurs in a prechamber and the higher temperature products of combustion pass through a nozzle to ignite a lean mixture in the main chamber. Akindele (1992) has observed that performance largely depends on the prechamber and nozzle sizes. This mixture in the main chamber is ignited by the mechanism of torch ignition from the issuing jet.
The high velocity jet of combustion products from the prechamber penetrates into the main chamber, creating intense turbulence and homogeneity in the main chamber charge. Because of this high turbulence intensity, the burning velocity of the charge there is increased and the overall performance of the combustion chamber is improved. The deep penetration of the charge from the prechamber into the main chamber also facilitate more reliable ignition of the lean mixture in the main chamber because this can occur at all points along the line of penetration of the charge in the main chamber.

Since the working volume of the prechamber is only about 1% of the main chamber volume, the slightly rich mixture required there would be very small. This, coupled with lean burning in the main chamber reduce the overall fuel consumption of the engine tremendously. Akindele (1992), in his research works on the above used a commercial Rotax type 12J ignition unit, operating at 2KV as used in aero-engine gas turbines to provide the electrical power pulse to the igniter. High tension, screened cable of the coaxial type was used for connecting the unit to the igniter. The igniter was a surface discharge type and consisted of a central electrode rod of inconel separated by insulation from the surroundings, cylindrical, outer electrode. The discharge took the form of a high intensity flashover between the electrodes. It was located in the prechamber with its surface flush with the wall and well away from the nozzle.

The results are conveniently summarised by the comparison of the variation of time to the attainment of maximum pressure for different mixture compositions in the main-chamber as shown in (Fig 18 below) for the conditions of both central spark and also torch ignition. Two of the most effective and one of the least effective torch ignition results are presented, along with those for central spark ignition, with both 40 MJ, and 12J nominal energies. It was observed that, for any mixture composition in the main-chamber, the time to the attainment of maximum pressure is much reduced by torch ignition depicting more rapid combustion. Curve C gives the time to maximum pressure for one of the worst torch ignition conditions, namely 0.7% volume ratio and 7.25mm nozzle diameter. However, this gives significantly more rapid burning than
This approach can also be useful in reducing the NOx emissions. The reason is that the hot gases from the prechamber are rapidly quenched to temperatures which are sufficiently low for little formation of NOx. The temperatures are however, sufficiently high for rapid oxidation of CO into \( \text{CO}_2 \) and the hydrocarbons.

**Plasma Plug**

Another ignition mode suitable for igniting lean mixtures and reducting exhaust emissions dispenses with a combustible mixture in the prechamber but uses plasma, formed by the intense flash over of the spark through an appropriate gas or gaseous mixture there. Highly active species can be ejected through the nozzle and cause ignition in the mainchamber. This process is known as plasma jet ignition by Oppenheim *et al.* and a practical application of this technique is the plasma plug. High concentration of chemically active species in the products of incomplete torch combustion can initiate chemical reaction during their life time of 5 to 10 milliseconds. The concentration of these active elements diminishes as the mixture is leaned. In comparison with the torch ignition concept described earlier, the active species or radicals are generated in the igniting plasma, rather than by the use of chemical energy as in the stratified charge or torch ignition concept. Also, in the plasma plug concept, the prechamber volume is confined to a very small space within the plug, where very high temperature and high ejection velocity are produced by means of electrical energy by the spark. It is envisaged that in the near future, the conventional spark plugs currently in use in the gasoline engine will be entirely replaced by plasma plugs. In so doing, lean mixtures can be employed with reduction in the emission of Pollutants, while retaining the conventional engine power output.

The combustion process can be considered in two stages. The first stage is the growth and development of a self-propagating nucleus of chemical reaction observed as thermal spread caused by the spark as observed earlier. This stage can also be called ignition-delay period or induction period. The other stage commences from when flame is liberated and propagates to cover the entire combustion chamber. The former is a purely chemical process depending mainly upon the nature of the fuel, temperature, pressure, and turbulence. The second stage is both chemical in nature, commencing from where the first measurable rise in pressure can be observed on an indicator diagram, that is, the point where the line of combustion departs from the compression line. Once combustion commences, the rate of chemical reaction is controlled by the Arrhenius equation as:

\[
\text{Rate} = \text{constant} \times e^{-\frac{E}{RT}} \tag{11}
\]

Where \( E \) = activation energy, \( T \) = Temperature, \( R \) = gas constant.
At low T, rate is low and at high T, rate is high. Very low rates of reaction produce negligible heat release. However, in turbulent diffusion flames, as observed in boilers, diesel engines, or gas turbine combustion chambers, the important structures of flames such as rate of spread, combustion length, stability and radiation from the flame depend largely upon the mechanism of mixing of the fuel, air and products of combustion. On turbulent or molecular scale, the time taken to complete the reaction after ignition is almost negligible because most of the chemical reactions in flames are very fast at elevated temperature according to the Arrhenius equation. The end of the second stage is usually the point of maximum pressure in the indicator diagram. However, combustion does not terminate at this point in practical combustor of piston engines, and after burning continues for some time and to the walls of the chamber and behind the turbulent flame front.

**Engine Speed:**
The higher the engine speed, the higher is the turbulence intensity and hence the greater the speed of flame propagation in the chamber. From this observation, the flame speed increases almost linearly with engine speed. Thus, if the engine speed is doubled or halved, the time in milliseconds required for the flame to traverse the combustion chamber is consequently halved or doubled respectively but at the same number of crank angles degrees. An important characteristic of piston engine operation is therefore that the number of crank angle degrees required for the flame propagation, which is the main stage of combustion will remain almost constant at all engine speeds. Engines are classified according to speed and fall, in general, into three categories, especially in marine propulsion namely: slow speed, medium speed and high speed. As a general rule, slow speed engines are two-stroke cycle engines. Medium speed and high-speed engines are available as both two and four-stroke engines. Also, slow and medium-speed engines operate on heavy fuel oils, whereas, high-speed engines operate on the lighter distillates. High-speed engines are normally cranked and started by starter motors which may be electrical, hydraulic, or pneumatic whilst medium and slow-speed engines of high powers are started by injecting compressed air directly into their cylinders to crank the engine. The power of a diesel engine is higher than that of the petrol engine because of the higher compression ratio which is 1: 20 and above in diesel and 1: 11 in petrol.

**Factors that influence normal combustion in Engines are:**

(i) **Induction pressure** – delay period increases as pressure reduces and ignition must therefore be earlier at low pressures.

(ii) **Speed of the Engine** – As rotational speed rises, the time delay period requires more crank angle, hence ignition should be earlier.

(iii) **Ignition time** – if ignition is too early the maximum pressure will occur too early and hence, the engine loses power. If ignition is too late the peak pressure will be low and the engine also loses power out put.

(iv) **Mixture strength** – The mixture of Air and fuel is always made slightly richer than stoichiometric for maximum power production by the engine.

(v) **Compression Ratio** – An increase in compression ratio increases the maximum pressure and hence the indicated mean effective pressure and this leads to increase in engine power.

(vi) **Combustion chamber** – The combustion chamber should be designed to promote optimum turbulence and enhance a brisk short flame path to avoid engine knock.

(vii) **Fuel choice** – The ignition delay period of the fuel should be low to reduce the ignition delay. Also, the calorific value of the fuel if high will affect the power and temperature achieved.

**INCREDIBLE POWERS OF ENGINES**

The incredible power of the internal combustion engine is determined during the expansion stroke in a reciprocating engine. For a four-stroke cycle engine, power is produced once in two revolutions of the crankshaft, whilst in two-stroke cycle engine, power is also produced once but in one revolution the crankshaft. This arrangement makes the two-stroke cycle engine more powerful than the four-stroke counterpart. The two-stroke engine may however not be more efficient than the four stroke engine as its fuel consumption may be more.
This incredible power is measured as the product of the force the cylinder charge exerts on the piston top and the stroke of the engine per unit time. However, frictional effects reduce this power by about 10%. Other prevailing conditions further reduce the power.

On the contrary, the incredible power of the gas or steam turbine engine is measured by the degree of expansion of the charges in the turbines which is expressed as enthalpy change across the turbine per unit mass flow rate of the charge. Also, irreversibilities due to friction resulting in entropy increase, reduce this power. For the reciprocating engines, the power ranges from about 0.75KW as obtained in some single cylinder two stroke petrol engines to about 2MW as obtained in some Multi-cylinder two or four-stroke diesel engines.

However, in gas or steam turbine engines for either aircraft propulsion, electricity generation or marine propulsion or traction generally, power production ranges from about 1MW to about 500MW and above. As energy costs continue to increase, industrial gas turbine plants are being upgraded to reduce their fuel consumption. Simple cycle gas turbine engines have become favoured by users seeking high reliability, low installation costs and low level of exhaust emissions. In spite of these advantages, gas turbines are generally less fuel efficient than reciprocating engines of the same power capacities. However, a combined cycle gas turbine engine with waste heat recovery, can capture the turbine exhaust energy, which is normally wasted, and produce about 35% additional useful shaft power without necessarily increasing the fuel consumption rate. Using a combined cycle plant with a high performance gas turbine engine (for driving compressors, pumps, alternators and in oil and gas pipeline services) is the most fuel efficient prime mover arrangement presently available.

A combined cycle plant is a combination of two separate thermodynamic cycles. The cycles being combined are the joule/Brayton cycle the bases on which the gas turbine plant is designed and the Rankine cycle, the bases on which the steam power plant is design. Steam is generated in the steam plant by utilizing a counter flow heat exchanger to regenerate a large portion of the energy contained in the gas turbine engine exhaust. Hence, the combined plant can convert the turbine exhaust heat to useful shaft power thereby resulting in a system which is more efficient than either the gas turbine plant or the steam turbine plant. Incredible shaft power output from this type of combined power plant may be as high as 500MW.

### Power Stations, and the National Grid:

At one time in this country, the grid system connected power stations and local areas so that they could help one another during difficult periods and exchange power when the need arose and when it was economical to do so. Later, the grid changed from an area to a national facility and electricity is now being transmitted over long distances in what is called the national Grid. This electricity is generated in the power stations using mainly high powered steam and gas turbine plants of hundreds of Megawatts ratings. The fuel consumption annually runs into several million standard cubic metre of fuel. Therefore, economic sense requires that this huge demand be met from the country's most productive oil fields and that such stations should be sited as rear as possible to the oil or gas sources. Nigeria's population and industrialization are increasing somehow rapidly and there is a consequential sharp rise in electricity demand. The answer therefore is to install oil or gas burning steam or gas turbines plants close to the oil or gas fields and to transmit the generated electric power of several thousands Megawatts by overhead supergrid transmission lines.

These requirements can be met by the provision of combined power plants or installation of several steam or gas turbine plants of the 200 to 500MW ratings.

In conclusion to the above, the incredible power of an engine is supposed to be limitless but for the metallurgical limit of the engine components materials and the adiabatic flame temperature of the combustion fuels which place a limit to the maximum possible temperature attainable in a combustion process. This, notwithstanding, some supersonic turbo-jet engines like those powering the concord supersonic airliners and some military war planes have their turbines running at over 30,000 revs per min, producing several megawatts of power to drive their compressors while cruising at over Mach 3, that is, three time the speed of sound.
in atmospheric medium. Some high speed railways are now powered by gas turbine engines of several Megawatts rating that move the trains at speeds close to the sonic threshold.

Pollution from Engines
The need to avoid air pollution has long been foremost in the design requirements of modern internal and external combustion engines. In the case of external combustion engine like the steam power plant the flue gases are carried high into the atmosphere. Some single, multi-flue chimney can be as high as 230m. In industrial applications and in transport vehicles, the effluent gases are constantly monitored and advanced control systems ensure that where there is danger of harmful emission, immediate remedial action is taken.

As a consequence of pollution and the limited availability of fossil fuels on earth, engine designers have shifted, somewhat belatedly, concerns from engine power output to exhaust emissions and fuel consumption. The high power output engines operating with over-rich mixtures have the consequence of exhaust emissions of carbon monoxide CO, unburnt hydrocarbons (UHC), and oxides of Nitrogen (NOx). An increase in air-fuel ratio (lean burning) can lead to reductions in both fuel consumption and emissions of CO and UHC, although at the expense of some loss of power. Further increase in the ratio results in a decrease in NOx emission. Eventually, as the lean misfire limit is approached, fuel consumption increases markedly as do emissions of CO and UHC. Improvement on the emission characteristics of internal combustion engines therefore necessitates a trend towards leaner mixtures. A number of emission control techniques have been devised in an attempt to reduce emissions of the three pollutants viz UHC, CO and NOx from internal and external combustion engines. Amongst the devices are stratified charge combustion, prechamber combustion (as discussed earlier), catalytic converters and exhaust gas recirculation (EGR).

Experimental investigations had been carried out in the Department of Mechanical Engineering, University of Lagos by the author on the effect of exhaust gas recirculation on NOx formation in petrol and diesel engines as an emission reduction technique in respect of other varying engine performance characteristics. A fraction of the engine exhaust (not more than 15%) was recycled and mixed with the intake fresh charges. A reduction in NOx formation was observed. Akindele et al (1998) Dilution of the intake mixture with some combustion products decreased combustion temperature, because they act as heat sink. Since high combustion temperature is responsible for the formation of NOx, a reduction in NOx formation was therefore obtained with reduced temperature caused by recycling of some exhaust products of combustion. Elevated temperature may result from the following:
(i) Poor cooling system in engines.
(ii) Overheating of the engine in traffic jams
(iii) Increased engine speed
(iv) Reduced cooling water flow rate.

The effective control of these emissions therefore requires Government policy on pollution in which emphasis are placed on installation of pollution control devices on automobile, aircraft and industrial engines.

NIGERIA NATURAL GASES AS ALTERNATE FUELS FOR AUTOMOBILE ENGINES

It is an established fact that the development or rapid progress of a country does not only depend on an endowment of natural and human resources, but also much more on the capability to harness such resources for the benefit of the entire society. Among the countries of the world endowed with fossil fuels, Nigeria stands out as one with abundant combination of resources including crude oil, natural gas, petroleum gas, coal, hydro, solar and even wind. Failure to utilize these resources to provide our energy needs adequately would be blamed on our deficiencies in planning, execution, management of our socio/political and economic problems.

A first step should be to diversify our energy resources and be less dependent on crude oil that has been our main source of foreign exchange earning. The economic prospects of our abundant natural gas is worth looking into and a step in the right direction. The natural gas had been discovered in large quantities and more gas wells are yet to be discovered. As a result, many natural gas (NG)
projects have been conceptualized giving rise to diverse shades of illusions. The Nigerian public now sees the NG projects as viable and as the panacea of Nigerian foreign exchange earning.

The global utilization of natural gas as a source of energy has experienced tremendous growth over the last three decades. Energy derived from burning of natural/petroleum gases have almost completely revolutionized the industries, keeping the lead. Since 1960, global consumption was about 32 million tons and by 1970s, consumption had doubled. Petroleum gases have become a favoured source of fuel over other fuels and a study in Britain has shown that by the year 2020 gas alone shall account for over 50% of electrical energy generated.

Natural gases comprise two types of gases, namely: Associated Gas (AG), that is, associated with crude oil during its retrieval from the earth and Non-Associated Gas (NAG), in pure gas wells and produced independent of crude oil. Until recently, all AG had been flared at production sites while the crude oil was being produced, whilst all NAG wells are either flared or reinjected or sealed. Nigeria’s gas reserves is about 13 trillion standard cubic feet and monthly production is about 115 billion standard cubic feet.

Since the beginning of the last decade, there has been a dramatic increase in the use of Natural gas in Nigeria. Natural gases are utilized mainly as energy sources for petrochemical industries, fertilizer manufacture, electric power generation (steam and Gas turbine plants), Furnaces firing fuels, cement industries and glass manufacturers. However, little or no utilization has been observed in the automotive industries. It is envisaged that natural gas is perhaps a better alternative fuel for automobile engines than the widely used and conventional premium motor spirit (PMS) namely petrol or gasoline and if developed may reduce the current over dependence on the use of PMS. Hydrocarbon fuels obtained from wells in gaseous forms are commonly petroleum gas (PG) and natural gas (NG). When compressed at low temperatures to high pressures, they are liquefied and stored in these condition as liquefied petroleum gas (LPG) and liquefied natural gas (LNG). LPG is basically a mixture of propane and butane, whilst LNG is basically methane. Currently in Nigeria a daily production of 8000 barrels of LPG is obtained from about 180 million standard cubic feet of NG. This production rate is expected to increase tremendously in the early part of this millennium giving rise to a promising future on the use of LNG and LPG in automobiles and other transport industries in General.

Alternatively, if LNG or LPG is used in an automobile engine, the burning is clean and can be precisely controlled because it vaporizes at atmospheric pressure and temperatures. One noticeable difference between LPG and gasoline is that the former enters the engine as vapour only and entirely, whereas, gasoline enters as tiny droplets of liquid and vapour, whether through carburettor or injector. Some other advantages derivable from burning LPG in engines are smoothness of combustion and hence better performance of engine, reduced emissions of NOx and CO and increased power as observed from experiments conducted in our laboratory here by Akindele et al (1999). LPG is clean, sulphur free and lead free and hence does not tend to corrode valves, piston rings, pistons, cylinder walls as does gasoline. Also, being completely gaseous in the engine cylinders LPG has little or no tendency towards diluting the lubricating oil which is possible with gasoline due to condensing fuel droplets especially on cylinder walls. This therefore results in a much longer lubricant life and reduced lubricating oil consumption.

All the above culminate in a lower fuel consumption rate and hence greater power output in an LPG engine if well controlled, than in a gasoline engine. From many tests conducted over the past few years, a switch from gasoline to LPG had brought reductions in the emissions of carbon monoxide, unburnt hydrocarbons, oxides of sulphur and oxides of nitrogen without the use of converters or stratification. However, more researches and experimental studies are presently being conducted by the author on LPG and LNG alternative fuels for automotive engines in the Department of Mechanical Engineering, University of Lagos. Fig 20.

The use of LNG or LPG in automobiles in Nigeria should be encouraged so that by the early years of this millennium, gas fired engines would be common and well understood. This will reduce our absolute dependence on gasoline and hence extend
the depletion period of the crude oil. The country tends to benefit from the following advantages of LNG/LPG over Gasoline:

1. Acquisition of another technology;
2. Reduction in transportation fuel cost;
3. Cleaner environment as a result of reduction in poisonous emissions with LNG or LPG;
4. Easy handling resulting in higher safety level;
5. Reduction in maintenance cost of engines resulting from purer lubrication oil; and
6. Abundance of natural gas in Nigeria wells should provide some impact on the transportation industries in Nigeria if utilized for this purpose.

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**CO₂ Emissions**

![CO₂ Emissions Graph](image)

**NOₓ Emissions**

![NOₓ Emissions Graph](image)

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**Fig. 20**

**Fig. 21**

**Fig. 22**
PROPOSED NIGERIA'S TECHNOLOGICAL DEVELOPMENT PLANS AND STRATEGIES

Nigeria is very much endowed with abundant natural and human resources, and therefore, the national objectives of transforming her from a poor and technologically backward country into a prosperous, self-reliant, and modern nation, and no more vulnerable to foreign exploitations is a move in the right direction. For this reason, the national resources should be carefully planned and geared towards the provisions of basic infrastructure such as water, comfortable shelters, food, education, health, industries and realistic capital projects.

For every nation, availability of human and natural resources is a gateway to industrialization if properly planned. Industrialization on the other hand is a gateway to prosperity and high standard of living.

Once the resources have been assessed in a quantitative a fashion as is possible, scientists, engineers and technologists are required to suggest what uses, modifications, and extensions of techniques can be made to achieve these set objectives most readily. Technology is a complete range of methods for transforming resources into goods and services, but mostly one finds hybrids, depending on the needs of the nation. Any quantitative appraisal of resources must, from its start, assume a given state of techniques and also a given set of needs. Technology does not always require sophistication but a technique for solving a given environmental problem, which in the process of solving that environmental problem will provide adequate employment as well as knowledge and skill for the citizens. The modern technology with all its automation available in the advanced countries is not suitable for Nigeria. In a country like ours where the economy is impeded by large labour surplus and scarce capital, high degree of automation in technology will create idleness and high capital investment and the ultimate result is unemployment, hence, such version of technology will not constitute a solution to our problem of appropriate technologies for our small and medium size industries. A low capital investment, less automated technology where a considerable part of the operation could be done manually should be envisaged.

The second step in our development strategy should focus on the establishment of small and medium size industries by private entrepreneurs and government, supported by the appropriate level of technologies previously determined by the level of education and technological training in the country. Education and technological training do not really constitute the problem because the various universities, polytechnics, trade centres and some private and government firms with well established, In-Plant training Programmes for their engineers and technologists have achieved much as far as education and training are concerned. All over the world small-scale industries are involved in consumer goods, trading and manufacture, examples of which are, department stores, garment and shoe shops, bakery, pottery, printing, engineering workshops to name a few. Some of these, especially the engineering workshops for fabrication had metamorphosed into medium and large-scale industries in Europe and America. The peugeot of France, Rolls-Royce engine division of Britain are examples.

Government Roles:
The roles the government has to play are:
(i) Provide the necessary manpower to run the proposed industries;
(2) Place special low import duties on machine tools and other engineering instruments and devices that are useful in engineering systems design and construction. Such machine tools should include among others, machines for production, workshop tools, electronics and electrical components. The present prices of such tools are so exorbitant, if at all they are available, in the market.

No industry whether small, medium or large can operate without the means of production. The means of production are machines manually or automatically operated. Availability of these tools would create opportunities for the engineers and the technologists to design and produce simple marketable products for the needs of the society.

The only government owned machine tool company in Nigeria today is located in Oshogbo. Since the inception of this “golden” industry,
serious production of machine tools is yet to commence, forty years
after independence. Nigeria cannot claim to have a single
functioning machine tool industry, yet, she possesses several
vehicle assembly plants which time has proved to be unnecessary
for our technological development. With the present number of
steel plants and rolling mills in the country, five additional machine
tool industries in the least should be set-up immediately. The
continued existence of all the vehicle assembly plants should be
reconsidered by the government, and if possible, some of them
should be closed down or be replaced or converted to designing
and manufacturing firms for constructing engineering tools,
components and engines.

One of the incentives you can give to an engineer, technologist
and a scientist to function effectively in his chosen profession is to
provide him with the appropriate tools to transform his brilliant
designs to realities at reasonable costs.

It might interest you to know that there are only five functional
foundry shops in the country today. All are very poorly equipped. Foundries
do not require too sophisticated equipment to run. It can reasonably
be regarded as a small scale industry. Foundry technology involves,
in addition to others, the use of molten metals in the casting of any
complicated machine component that cannot be possibly machined
or whose production may be too expensive and time consuming in
a machine shop, an example is an engine block. Some of the raw
materials useful in this shop are scrap metals. Scrap metals could
be melted and used in a casting equipment for reforming these
complicated shapes.

Thousands of machine components are imported into the country
yearly. If we encourage the establishment of adequate number of
small-scale foundries using the scrap metals readily available in
the country as raw materials, a large percentage of the foreign
exchange spent on these imports could be conserved. Apart from
savings in foreign exchange, the country will move a step further
in her desire for technological progress and employment
opportunities.

CONCLUSION
We have in this inaugural lecture reviewed the exciting technological
history of man and his environment. Therefore, over the centuries,
technological advancement had been the major proof of man's
intelligence and innovative capabilities, the attributes that make
him the captain of the universe. No doubt, the Mechanical Engineer
has played tremendous roles in this technological development from
backwardness and primitiveness to industrialisation and civilization
of the globe. For man to retain his ingenuity he must continue
to probe deeper into the mysteries of nature.

Government should therefore encourage more scientific research.
This can be made possible by providing the necessary equipment
in the science and engineering laboratories to facilitate research
work. Scientific and technological knowledge is acquired through
research and innovative designs or imparted. The research should
however be geared towards the solutions of basic local problems.
Such research findings and innovative designs should be published
in local journals so as to facilitate their commercialization or use in
setting up small scale enterprises by government and enthusiastic
entrepreneurs. By now Nigeria should be able to build an engine.

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