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1 author:

Noveen Nico Alexandra Ng

Universiti Malaysia Pahang

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DESIGN AND DEVELOPMENT OF ION PROBE TESTING ON FOUR STROKE ENGINE MODEL

N.N.A.Ng*, A.A.A.Ahmad Shamsuddin, M.M.Hasin, N.S.Mazlan, M.L.Mohd Isnin

Faculty of Mechanical Engineering, University Malaysia Pahang,

26600 Pekan, Pahang, Malaysia

Phone: 012 5449846

*E-mail: noveen93@gmail.com

ABSTRACT

This paper carried out the study on an ion probe testing on four stroke engine model. The testing probe was installed inside the engine combustion chamber with specific distance, when the fuel is supply to the engine and the spark plug light up the fuel, it will produce an ionization flame, at the same time, when the flame touch the probe, it will generate a signal. The probe is connected to a circuit, when the signal is generated, the circuit will process the signal. The coding for the process is written inside a chip that installed in the circuit. A user interface was created to display the result. Besides that, a camera will use to catch the flame to compare with the result.

Keywords: Ion Probe Testing, Engine Combustion Chamber, Ionization Flame

INTRODUCTION

Internal combustion engines have been a major power source throughout the history of ground vehicles. [1] Since the oil crisis in the 1970's the focus for engine developers have moved to fuel economy and emission reduction. The introductions of electronic ignition and fuel injection systems in the 1980's have given the engineers far more capability of engine control than before.[2] The limitation in engine control development lies in the available information about the controlled process; the combustion.[1, 3]

Fuel economy drives the development of efficiency of the engine. This includes optimal ignition timing and fuel amount for a given operating condition.[4] Emission reduction drives the development of air-fuel ratio control, misfire detection and purge control.[5] Oxygen sensors mounted in the exhaust pipe provide a possibility for closed loop air-fuel ratio control and piezo-electric knock sensors mounted on the engine block, for closed loop knock control, but the need for supervising the combustion process itself increases constantly. Three methods exist for combustion monitoring;

• Cylinder pressure sensing
• Ionization current sensing

- Optical instrument

Ionization is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes. Ionization can result from the loss of an electron after collisions with sub atomic particles, collisions with other atoms, molecules and ions, or through the interaction with light.[6, 7]

This project is to identify and measure quantitatively the turbulent flame propagation speed of gaseous fuels, and suggest a feedback system to the engine ECU. The outcome is a system which can be used by many automotive companies.[8, 9]

Ionization flame probe is widely use in oversea country such as America, German and etc. The main aim of this project is to develop a simple probe and measure the speed of flame in different fuel flow direction. To measure the speed of flame a simple circuit is needed to connect with the probe, in the circuit a chip with coding is use to operate it and the signal will connect to the oscilloscope(screen).[8, 10]

IONIZATION FLAME

Ionization flame happened is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes.[11, 12] Ionization can result from the loss of an electron after collisions with sub atomic particles, collisions with other atoms, molecules and ions, or through the interaction with light. Heterolytic bond cleavage and heterolytic substitution reactions can result in the formation of ion pairs. Ionization can occur through radioactive decay by the internal conversion process, in which an excited nucleus transfers its energy to one of the inner-shell electrons causing it to be ejected.[12, 13]

To measure the ionization flame, a probe need to put inside the combustion chamber, and the ground of the circuit will connect to the engine, when the flame touch the probe, the circuit will become complete, and a signal will generate.[10, 12]

THERMAL PASTE (CERAMIC)

To install the probe into the combustion chamber, an insulate material is need to be use guarantee the surface of the probe not connected to the engine surface. Besides that, inside the combustion chamber, the temperature is around 700°C or more for 4 stroke gasoline engines and the pressure is around 25.1 bar for compress ratio 10:1. To support the probe, the material must have 3 properties, which are insulation, high heat resistance and high pressure resistance.[1, 12, 14]

Ceramic is an inorganic, non-metallic solid material comprising metal, non-metal or metalloid atoms primarily held in ionic and covalent bonds.[15] The crystalline of ceramic materials ranges from highly oriented to semi-crystalline, and often completely amorphous.[14, 15] Varying crystalline and electron consumption in the ionic and covalent bonds cause most

ceramic materials to be good thermal and electrical insulators and extensively researched in ceramic engineering. Besides that, ceramic materials are brittle, hard, and strong in compression, weak in shearing and tension. With that reason, ceramic is the most suitable material to be use in this project.[16, 17]

CHEMICAL REACTION

$$4\ C_{12}H_{23} + 71\ O_2 \longrightarrow 48\ CO_2 + 46\ H_2O$$
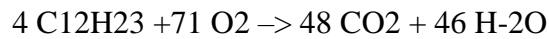
Diesel engines convert the chemical energy in fuel to mechanical energy. Energy is released in a series of combustions as fuel reacts with oxygen from the air. Combustion reactions are spontaneous yielding a $-\Delta G$. The reaction goes from 71 moles of O_2 gas to 48 moles of CO_2 yielding a $-\Delta S$.[18, 19] Combustion reactions break bonds between the molecules signaling an exothermic reaction or $-\Delta H$.

Diesel engines convert the chemical energy in fuel to mechanical energy which moves pistons up and down inside cylinders.[20] The pistons are connected to the engine's crankshaft, which changes their linear motion into the rotary motion needed to propel the vehicle's wheels. Energy is released in a series of small explosions (combustion) as fuel reacts chemically with oxygen from the air.[21, 22] The chemical equation of diesel fuel combustion is as follows, $C_{13}H_{28} + 20O_2 \rightarrow 13CO_2 + 14H_2O$. Combustion reactions are spontaneous yielding a $-\Delta G$.[3, 4] The reaction goes from 20 moles of O_2 gas to 13 moles of CO_2 yielding a $-\Delta S$. Combustion reactions break bonds between the molecules signaling an exothermic reaction or $-\Delta H$.[23, 24]

German engineer Rudolf Diesel theorized that fuel could be made to ignite spontaneously if the air inside an engine's cylinders became hot enough through compression because air heats up when it's compressed. Achieving high temperatures meant producing much greater air compression than occurs in gasoline engines, but Diesel calculated that high compression should lead to high engine efficiency. Part of the reason is that compressing air concentrates fuel-burning oxygen. A fuel that has high energy content per gallon, like diesel fuel, should be able to react with most of the concentrated oxygen to deliver more punch per explosion, if it was injected into an engine's cylinders at exactly the right time. Diesel's calculations were correct. As a result, although diesel engines have seen vast improvements, the basic concept of the four-stroke diesel engine has remained virtually unchanged for over 100 years.[12, 16]

INSULATION

High-temperature insulation wool (HTIW), known as ceramic fiber wool until the 1990s, is one of several types of synthetic mineral wool, generally defined as those resistant to temperatures above 1000°C. The first variety, aluminums silicate fiber, developed in the 1950s, was referred to as refractory ceramic fiber. Due to the costly production, and limited availability

compared to mineral wool, HTIW products are almost only used in high temperature industrial applications and processes.[24, 25]

To ensure safe working with the fire, for melting and working metals (bronze, iron), special refractory materials were needed to enable the handling of liquid or hot metals . To meet the needs of the wide-ranging applications, a large number of shaped, dense materials (refractory bricks, chamotte), shaped heat-insulating materials (lightweight refractory bricks) and unshaped refractory materials (heavy- and lightweight ramming mixes) have been developed, which are used for special high temperature applications. For decades, however, other manmade materials have been used for thermal insulation, woodland rock wool being used in the low-temperature range (around 200 °C to maximum 500 °C).[26]

In the 1960s aluminum-silicate-based "refractory ceramic fiber" was launched on the market in Europe. Due to their high temperature-resistance and good technical properties (i.e. good thermal shock resistance and low thermal conductivity), they quickly became the reference for industrial high temperature insulation. Due to the development of new material types the nomenclature of *high-temperature insulation wool* was redefined in Germany at the end of the 1990s. (VDI 3469.). Although even today the term "ceramic fiber" or "refractory ceramic fiber" is commonly used it is inaccurate in terms of the materials available, their specific properties and limitations.[25, 27]

Thermal insulation with HTIW enabled a more lightweight construction of industrial furnaces and other technical equipment (heating systems, automobiles), resulting in many economic and ecological benefits. Consequences are smaller wall thicknesses and considerably lower lining masses.[28]
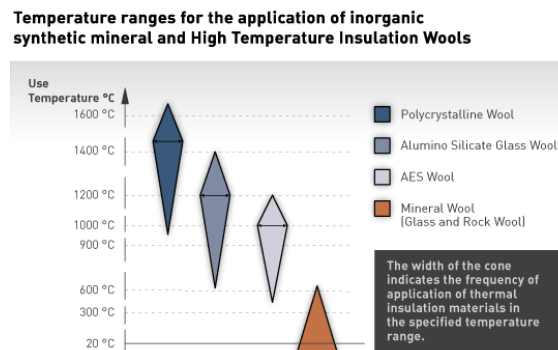

Figure 1: Temperature Ranges For Application Insulation Wools

Sources: https://en.wikipedia.org/wiki/High-temperature_insulation_wool

GASEOUS FLAME

Color and temperature of a flame are dependent on the type of fuel involved in the combustion, as, for example, when a lighter is held to a candle. The applied heat causes the fuel molecules in the candle wax to vaporize. In this state they can then readily react with oxygen in the air, which gives off enough heat in the subsequent exothermic reaction to vaporize yet more fuel, thus sustaining a consistent flame. The high temperature of the flame causes the vaporized fuel molecules to decompose, forming various incomplete combustion products and free radicals, and these products then react with each other and with the oxidizer involved in the reaction. Sufficient energy in the flame will excite the electrons in some of the transient reaction intermediates such as CH and C_2, which results in the emission of visible light as these substances release their excess energy (see spectrum below for an explanation of which specific radical species produce which specific colors). As the combustion temperature of a flame increases (if the flame contains small particles of unburnt carbon or other material), so does the average energy of the electromagnetic radiation given off by the flame.[29, 30]
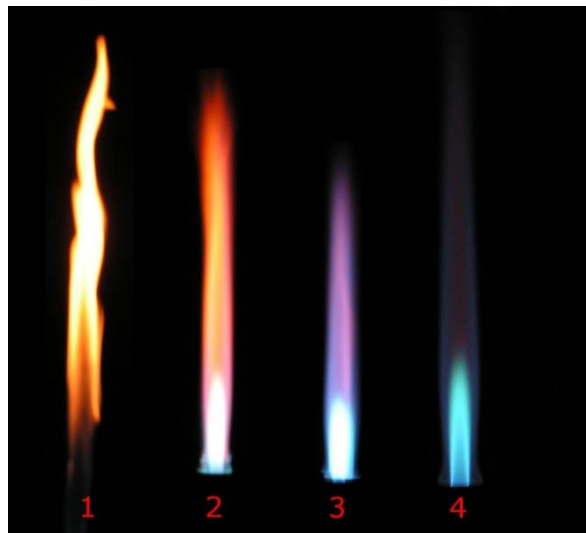
Figure 2: Different Color of Flame
Source: https://en.wikipedia.org/wiki/Flame

Other oxidizers besides oxygen can be used to produce a flame. Hydrogen burning in chlorine produces a flame and in the process emits gaseous hydrogen chloride (HCl) as the combustion product.[2] Another of many possible chemical combinations is hydrazine and nitrogen tetroxide which is hypergolic and commonly used in rocket engines. Fluoropolymers can be used to supply fluorine as an oxidizer of metallic fuels, e.g. in the magnesium/teflon/viton composition.[31]

The chemical kinetics occurring in the flame is very complex and involves typically a large number of chemical reactions and intermediate species, most of them radicals. For instance, a well-known chemical kinetics scheme, GRI-Mech, uses 53 species and 325 elementary reactions to describe combustion of biogas.[32, 33]

There are different methods of distributing the required components of combustion to a flame. In a diffusion flame, oxygen and fuel diffuse into each other; where they meet the flame occurs. In a premixed flame, the oxygen and fuel are premixed beforehand, which results in a different type of flame. Candle flames (a diffusion flame) operate through evaporation of the fuel which rises in a laminar flow of hot gas which then mixes with surrounding oxygen and combusts.[34, 35]

FLAME SPEED

A premixed flame is self-sustaining propagation of a localized combustion zone at subsonic velocities. We use the term deflagration in gas dynamics to define a premixed flame travelling at subsonic velocities. Consider a premixed flammable mixture in a long tube, open at both ends, ignited from one end. A combustion wave will travel down the tube starting from the ignition point. A flame is caused by a self-propagating exothermic reaction which is accompanied by a reaction zone. It will propagate through a stationary gas mixture at a characteristic velocity (burning velocity). For most hydrocarbon-air stoichiometric mixtures, this velocity is about 0.4 to 0.6 m/s. For hydrogen-air mixtures, this velocity is several meters per second. The velocity of this wave is controlled by the diffusion of heat and active radicals. For a flame burning in a mixture of gases of known pressure and composition, two characteristic properties may be defined and measured, the burning velocity and the flame temperature. Flame temperature can be predicted from thermodynamic data, if we invoke the assumption of chemical equilibrium. Various flame theories attempt to predict the laminar flame progation from physical and chemical properties; however, a closed form solution which is universal and accurate has not been possible.[36-38]

FACTOR EFFECTING AREA OF SURFACE

The study of factors that affects the speed of flame propagation is important since the velocity of flame influences the rate of pressure rise inside the cylinder, flame speed also influences the quality of combustion (complete combustion or incomplete combustion) and consequently it affects on the engine performance. There are several factors which affect the flame speed, so let's discuss together these factors. The 1ˢᵗ is the mixture ratio of the system. The A/F ratio has a very significant influence on the flame speed. The highest flame speed (minimum time for complete combustion) are obtained with richer mixture and the lowest flame speed (maximum time for complete combustion) are obtained with leaner mixture. This sketch shows the relation between the mixture ratio and flame speed. You can conclude that in leaner or richer mixture, the flame speed decreases. When the mixture is lean or very rich, the combustion is incomplete because of

less thermal energy which resulting in lower flame speed. The 2nd is the turbulence of the system: the flame speed increases with increasing turbulence. This is mainly due to increasing the surface area of the flame which leads to increasing in the rate of reaction.[28, 30, 39] Excessive turbulence may extinguish the flame resulting in rough and noisy operation of the engine. The 3rd is Compression ratio (Vc+Vs)/Vc of the system. A higher compression ratio increases the pressure and temperature of the working mixture inside the cylinder. Increased compression ratio reduced the clearance volume and therefore increases the density of the cylinder gases during burning. This increases the peak pressure and temperature and the total combustion duration decreases. Thus engines having higher compression ratio, have higher flame speed. The 4th is temperature and pressure inside the system. Flame speed increases with an increase in intake temperature and pressure. A higher initial pressure and temperature may help to form homogenous air and fuel mixture which helps in increasing the flame speed. This is possible because of an overall increase in the density of the charge. The 5th is engine speed (rpm) of the engine system. The flame speed increases almost linearly with the engine speed since the increase in engine speed increases the turbulence. The 6th is engine size. The size of the engine doesn't have much effect on the rate of flame propagation. In large engines, the time required for complete combustion is more because the flame has to travel long distance. This requires increased crank angle duration during the combustion. This is one of the reasons why the large sized engines are designed to operate at low speed. The last is molecular structure of the fuel system. Molecular structure of the fuel used in the engine affects on the flame speed. When the number of carbon atoms decreases, the effect of compounds on the flame speed increases, but when the carbon atoms increase, the flame speed is almost constant for all compounds.[24, 25, 40]

EXPERIMENT MATERIAL

MATERIAL

Resistor

Tungsten Wire

Wire

Crocodile Clips

Temperature Sensor

ELECTRIC EQUIPMENT

Digital Oscilloscope

Soldering Equipment

EXPERIMENT PROCEDURE

The circuit is designed first with the aid of schematic diagram. Electric components used include are resistors, transistor, IC, AC to DC powers supply. The AC to DC power supply used is 90V.

The ready soldered circuit then will be tested with the real flame. The probes are placed near the source of flame. The ignition of the flame will be detected by the probe and as the ionization occurs, the signal is transferred to the oscilloscope. Data from the graph shown on the oscilloscope monitor then is recorded and analyzed.

```
                    ┌─────────────┐
                    │    Start    │
                    └─────────────┘
                           │
                           ▼
         ┌──────────────────────────────────┐
         │   Identify the problem statement  │
         └──────────────────────────────────┘
                           │
                           ▼
         ┌──────────────────────────────────┐
         │  Preparing and designing the circuit │
         │    • Power Supply (Ac-Dc)         │
         │    • Electronic Component         │
         └──────────────────────────────────┘
                           │
                           ▼
         ┌──────────────────────────────────┐
         │ Fabricate the circuit (Ionization probe test) │◄──┐
         └──────────────────────────────────┘              │
                           │                                │
                           ▼                                │
         ┌──────────────────────────────────┐              │
         │     Testing with the engine block  │              │
         └──────────────────────────────────┘              │
                           │                                │
                           ▼                                │
              ◇ Obtained the reading ◇─────────────────────┘
                           │
                           ▼
         ┌──────────────────────────────────┐
         │        Data is obtained           │
         └──────────────────────────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │     END     │
                    └─────────────┘
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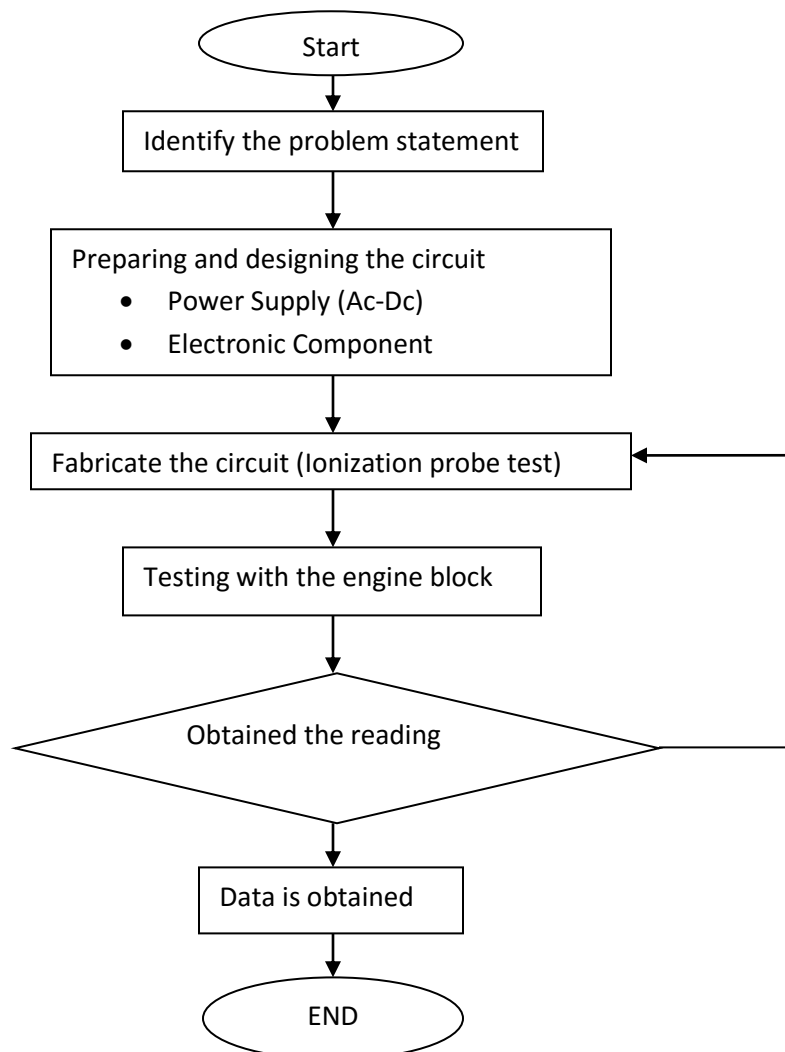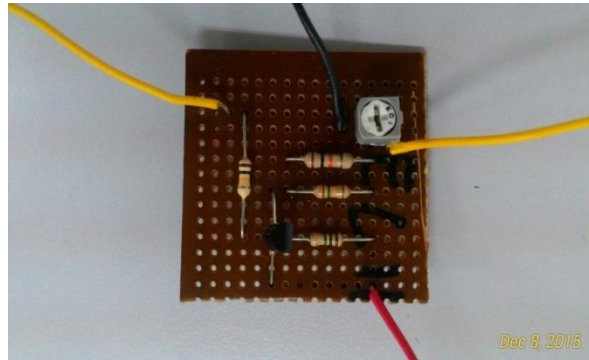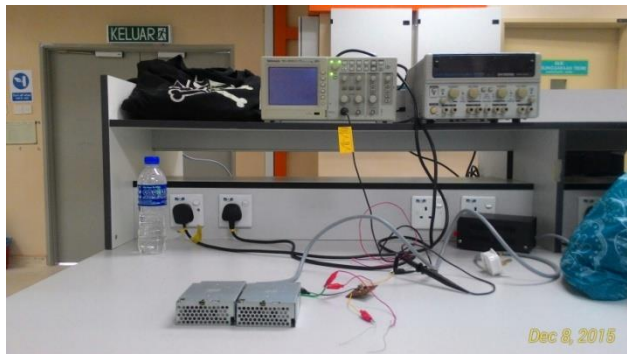
MATHEMATICAL MODELLING

Laminar flame speed is a property of a combustible mixture. It is the speed at which an un stretched laminar flame will propagate through a quiescent mixture of unburned reactants.[21, 41, 42] Laminar flame speed is given the symbol s_L. According to the thermal flame theory of Mallard and Le Chatelier, the un-stretched laminar flame speed is dependent on only three properties of a chemical mixture: the thermal diffusivity of the mixture, the reaction rate of the mixture and the temperature through the flame zone:

$$s_L^\circ = \sqrt{\alpha \dot{\omega} \left(\frac{T_b - T_i}{T_i - T_u} \right)}$$

α is thermal diffusivity.
$\dot{\omega}$ is reaction rate.
And the temperature subscript u is for unburned; b is for burned and is for ignition temperature.
Laminar flame speed is a property of the mixture (fuel structure, stoichiometry) and thermodynamic conditions upon mixture ignition (pressure, temperature). Turbulent flame speed is a function of the aforementioned parameters, but also heavily depends on the flow field. As flow velocity increases and turbulence is introduced, a flame will begin to wrinkle, then corrugate and eventually the flame front will be broken and transport properties will be enhanced by turbulent eddies in the flame zone. As a result, the flame front of a turbulent flame will propagate at a speed that is not only a function of the mixture's chemical and transport properties but also properties of the flow and turbulence.[22, 24, 25, 30]

RESULT AND DISCUSSION

Number of Reading	Frequency (Hz)
1	17.86
2	10.30
3	20.36
4	9.86
5	8.96

Table 1: Frequency of the Flame

Frequency of The Flame

Figure 4: Frequency of the Flame

Number of Reading Versus Frequency
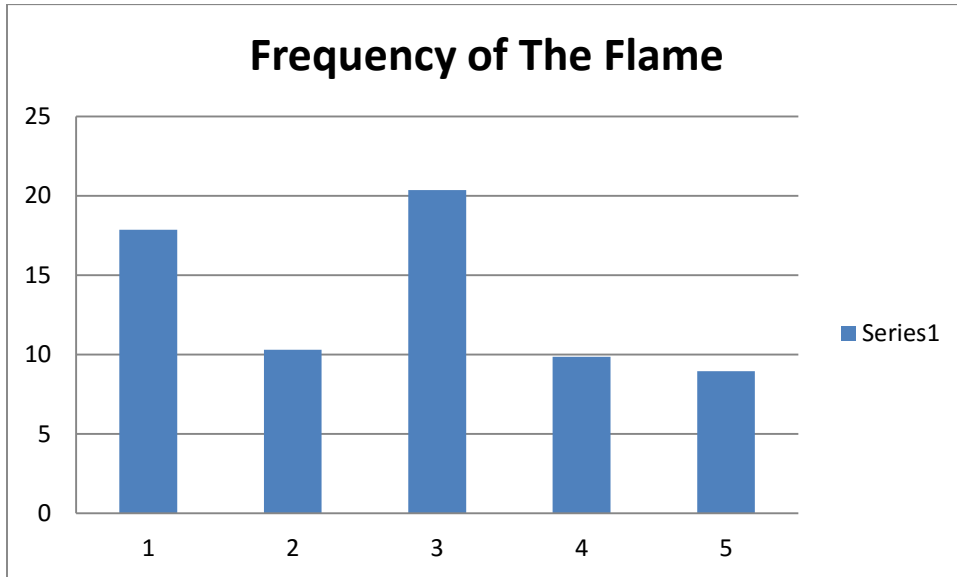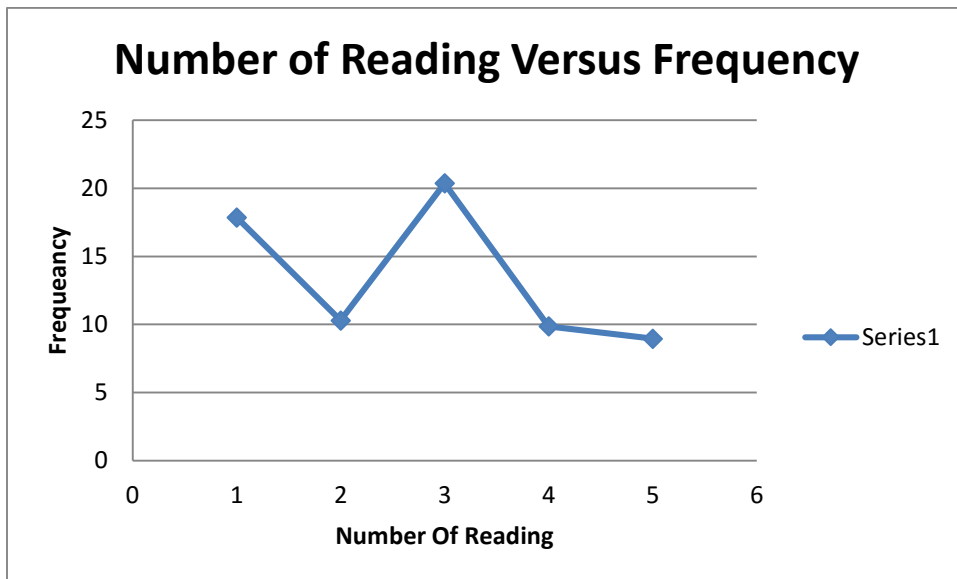
Figure 5: Number of reading with the frequency

A lot of performance promises have been made since the advent of the internal combustion engine more than a century ago: miracle lubricants, gasoline additives, new-fangled carburetors, fire-injector spark plugs, and a host of other miracle paths to power, each with its own disappointments. Synthetic lubricants create better lubrication between moving parts than conventional oils do.[19, 41] They don't break down in high-heat, high-stress situations, which is

why you see them used a lot in performance applications. They also offer excellent cold weather performance and extreme temperature protection. For example, Mobil 1 synthetic oil is engineered to be more robust in terms of low-temperature pumpability, high-temperature stability and protection against deposits.The fact remains, car maintenance still should include ignition systems. And spark plugs still need to be changed periodically. Original equipment grade is your best approach or high-end aftermarket parts like MSD. The reason: precision ignition operation means power. A misfire or lackluster light off means lost power, wasted fuel and increased tailpipe emissions. A potent spark from a high-energy ignition system does make a difference in power no matter how small. The lesson here is it all adds up to significant total gains in horsepower. Ignition timing is also a power dynamic you should play with carefully because too much of it can damage your engine. With conventional distributor ignition systems, set total timing at 2500 rpm beginning your efforts at 32 degrees BTDC (Before Top-Dead Center) with a road test or dyno pull. Then, move timing one degree at a time – 33, 34, 35 and so on along with road/dyno testing. Never take total timing beyond 36 degrees BTDC. Some tuners go to 38, 40, and even 42 degrees BTDC, which is foolish. Anything beyond 36 degrees BTDC total represents risks due to detonation. If you have a sudden lean condition coupled with early timing, you can have engine failure in a nanosecond at wide-open throttle. Ignition timing with electronic engine control calls for a professional who knows how to dial in both ignition and fuel maps to where you get power without doing engine damage.[9, 11, 15, 43] A larger high-performance throttle body will deliver more horsepower. Depending on what type of engine you have, you can gain as much as 10-20 more horsepower and comparable torque. There is a catch, however. Go too large and you can lose power. Not every engine is well suited to a larger throttle body, which means you have to do your homework ahead of time. Cruise the Web and learn what others with the same engine are doing and take your lead from them. Also remember that a larger throttle requires higher-flow fuel injectors. Throttle body and injector size are proportional.[1, 5, 18]

CONCLUSION

The fixture of Tungsten wire to the engine block. This fixture was sealed using thermal paste which can withstand temperature as high as 400⁰C. The optimum temperature during an engine operation is around 300⁰C. Thus, the thermal paste will work efficiently during an engine operation. The circuit works effectively when tested using lighter flame and result were collected for tabulation purpose.

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