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# Flame ionization testing in an internal combustion engine to measure the speed of the flame for gaseous fuels

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**Abstract.** The study was carried for combustion ionization flame testing on a K3-VE engine cylinder head. The main purpose of this experiment is to measure the speed of flame by using multiple ionization (ION) probe systems. The aim is to determine the feedback from the probe for engine control systems. The fuel that is use in this experiment is Liquified Petroleum Gas (LPG), because LPG gas causes a lot misfire during combustion due to its gaseous state and mixing. The testing probe was installed inside the engine combustion chamber with specific distance for the ION Probe. When the fuel is supplied in to the engine and the spark plug lights up the fuel, it produces a flame which is ionised, at the same time, when this flame touches the probe, it will generate a signal before quenching. The probe is connected to a circuit, when the signal is generated by the flame, the circuit will process the signal. A user interface was created to display the result of the experiment. Also, a camera was used to catch the flame to validate with the result. By using calculation, the speed of the flame can be determined to 20.60 m/s. The signal of the flame can be further used to improve the efficiency of the engine by adding a chip to the circuit to convert the signal and send to the vehicle Electronic Control Unit (ECU) to control the ignition time for better engine performance.

## 1. Introduction

Ionization probe contain signals that obtained in autoignition zone and in burned gas at different amplitude. Obtained probe current-voltage characteristics showed that in autoignition area the current to probe is formed by the drift of positive or negative ions, depending on the polarity of bias voltage. Evaluation of probe current at these conditions allowed prediction of relative variation of probe current with pressure in burned gas area [1]. Ion probe also used to detect the flame existence and stop the gas supply when the flame is extinction [2]. Alternative methods have therefore been investigated, such as techniques based on gas ionization analysis: the spark plug can be used as an Ionization probe, by measuring the corresponding current, in order to detect abnormal combustion phenomena through the sharp increase in ionization [3]. The voltage bias placed between the Ionization probe and the engine block keeps the probe voltage substantially constant thereby substantially reducing the capacitive effect of the cable and improving the speed of response of the Ionization probe [4]. In the case of laminar flames, the surface might be associated with the boundary of either unburned or completely burned gas[5], or with some location between these two, as described previously[6], where the reference surface is within the reaction zone. When turbulence is present, the flame front is no longer smooth and the reaction zone is thicker than that in the laminar case. In addition, the flame speed, when turbulence is present, is several times the laminar value depending on the intensity of turbulence [7]. These complexities are further compounded in turbulent combustion because of the influence of turbulence



parameters and the resulting, comparatively thick, flame brush [8]. As with laminar combustion, for all but one-dimensional systems, definitions of burning velocities have been in terms of either the entrainment of cold reactants or the formation of hot products [9]. A further complication is that in explosions, the effective spectrum of turbulence to which the flame is subjected is continually broadening during the flame development [10].

The focus here is to get a general overview of the ionization flame is an internal combustion engine. Flame ionization probe is widely uses in other country such as American, German, Japan and etc. the major function of this probe is to increase the efficiency of the engine, control the air fuel ratio and detect miss fire in the combustion chamber. With this probe, engine control unit (ECU) can detect the problem of the internal combustion and solve the problem by control the air fuel ratio, ignition timing and others.

## 2. Gaseous Fuels

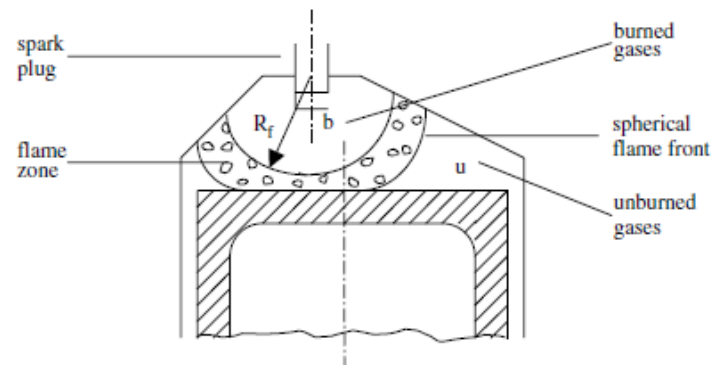
The environmental problems caused by vehicle exhaust emissions become more severe, exhaust gas emission regulations and fuel economy standards become more stringent [11, 12]. Thus, an alternative-fuel engine technology is needed to cope with the new requirements and regulations. Among clean fuels such as LPG, Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), DME (dimethyl-ether) is one of the best candidates for an alternative fuel because it can be liquefied in a low-pressure range of 0.7–0.8 MPa at atmospheric temperature, and it has a sufficient supply infrastructure. The main advantages lies in LPG as the fuel also has a higher heating value compared with other fuels [13]. Some disadvantage is LPG engine has lower power than a gasoline engine because the fuel is supplied into cylinder as a vapour creating much combustion unsteadiness. The price of LPG is cheaper than gasoline thus, it is more economical for the consumer, It is also less harmful as emissions are lower than in gasoline engines due to simplified carbon chains [12]. If the properties of propane main LPG constituents, are compared with those of gasoline and alcohols, the following benefits and/or shortcomings can be expected when it is used as the SI engine fuel. Propane has lower density and stoichiometric fuel–air ratio than gasoline, and thus, it could reduce the specific fuel consumption and exhaust emissions [12]. If a propane fuelled SI engine operates at the same equivalence ratio as a similar gasoline fuelled engine, higher effective power could be expected due to the higher calorific value of propane. However, as will be explained below, this advantage may be balanced by decreasing volumetric efficiency. On the other hand, propane can be used at higher compression ratios due to its higher octane number, and as a consequence of this property, engine performance, that is engine power and thermal efficiency, would be improved [11].

**Table 1:** A comparison of some physical properties of propane and other engine fuels

Property	Propane	Methanol	Ethanol	Gasoline
Molecular formula	$C_3H_8$	$CH_3OH$	$C_2H_5OH$	$C_7H_{17}$
Molecular weight, kg/kmol	44.10	32.04	46.07	101.213
Density at 15 °C, kg/m <sup>3</sup>	507	792	785	690
Lower heating value, MJ/kg	46.40	20	26.90	44
Heat vapor, MJ/kg	0.426	1.103	0.840	0.33
Stoichiometric fuel–air ratio	0.0638	0.155	0.111	0.0659
Research octane number	112	106	107	91

The above-mentioned properties of propane make it an attractive alternative fuel for spark ignition engines. The most important drawback of this fuel is that it reduces the engine volumetric efficiency and consequently the fresh charge mass, which is mainly due to its rising inlet temperature and it's

entering the intake system in the gaseous state [14]. This problem can be removed by cooling, i.e. offsetting the heat in the inlet manifold.

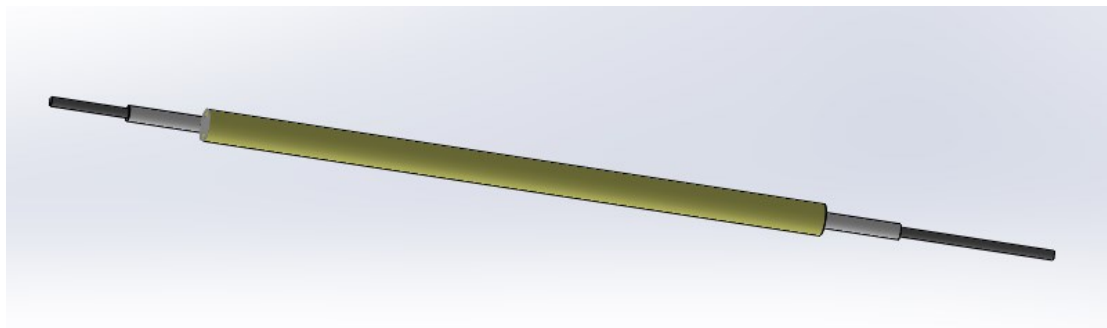


**Figure 1.** Internal Combustion of an Engine

Figure 1 above shows the internal combustion engine. In the thermodynamic model, throughout the combustion period, it is assumed that the cylinder charge consists of unburned and burned gas zones that are separated by an infinitesimally thin spherical flame front, whereas for burn rate model, it is assumed that burned, unburned and burning zones exist in the cylinder [13]. A schematic representation of the engine cylinder contents during combustion is shown in Figure 1. During the combustion happened, the mixture of LPG and Oxygen will compress by the piston and the spark will light up the mixture to produce power, in this process, carbon dioxide and water will occur [13]. Equation below are the chemical reaction of this process:



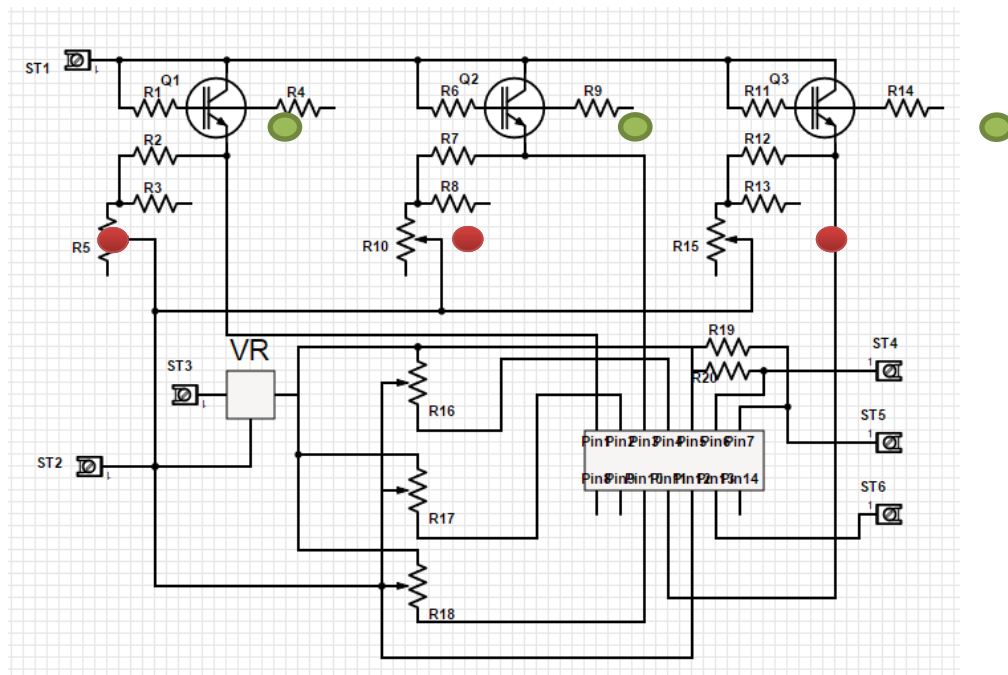
The material that suitable to be used as probe is tungsten wire, because tungsten wire has high melting point, high electron emissivity and high strength. Firstly, use Computer aided design (CAD) to design the probe, the probe should have 2 layers, first is insulation layer and second is ceramic layer. In Figure 2, the black colour is tungsten wire, the white colour is insulation and the yellow colour is ceramic. The insulation is to prevent short circuit happened during experiment. The ceramic is used as adhesive to stick the probe into the engine block so that heat from the engine is not transferred to the probes.



**Figure 2.** Design of Probe Wire

Based on circuit in Figure 3, the circuit is designed by including resistors and transistors as per table 2. The main function of the circuit is to make a 90 V bias between the probe end and the engine ground.

The bias is detected by the transistor circuit to detect the closing of the circuit due to ion created from the combustion process.



**Figure 3.** Circuit Diagram

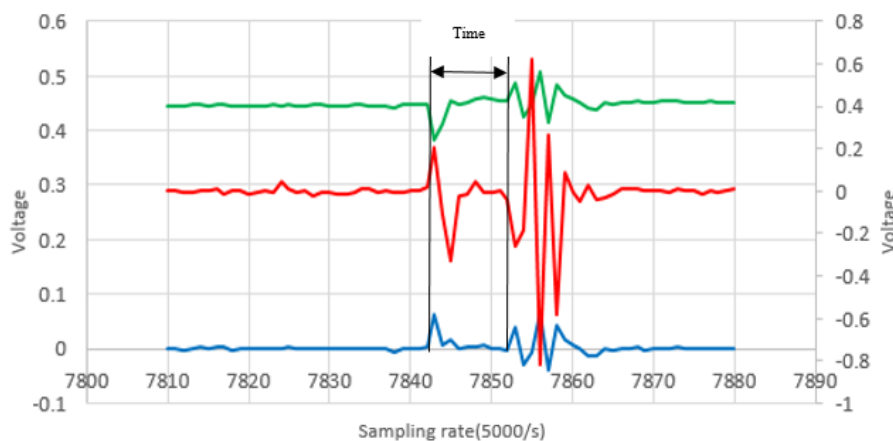
**Table 2.** Component and Descriptions

Component	Description
R1, R6, R11	Resistor 1 M $\Omega$ $\pm$ 5%
R2, R7, R12	Resistor 150 K $\Omega$ $\pm$ 5%
R3, R8, R13	Resistor 10 K $\Omega$ $\pm$ 5%
R4, R9, R14	Resistor 100 K $\Omega$ $\pm$ 5%
R19, R20	Resistor 3.3 K $\Omega$ $\pm$ 5%
Q1, Q2, Q3	Transistor 2N 5401
R5, R10, R15, R16, R17, R18	Potential Meter 103
ST1, ST3	+ 90 V
ST2	GND
ST4, ST5, ST6	Digital signal output
VR	Voltage regulator L7805CV
14 pin IC	IC LM339N
●	Voltage signal output to DAQ
●	Probe 1, Probe 2, Probe 3

Multiple ionization probe was connected to a 4 channel DAQ to obtain the signal produced when the Tungsten wire is burned inside combustion chamber. The obtained signal will be used to retrieve the time taken from one peak of signal to another peak signal. The retrieved time is needed to calculate the flame speed during combustion of an engine during combustion stroke. The diameter of the cylinder is taken from engine bore of 72 mm, the spark plug is located at the centre of the cylinder. The distance of the tungsten wire to the centre of spark plug is 35 mm. The distance of the multiple probe is 5 mm distance from each other.

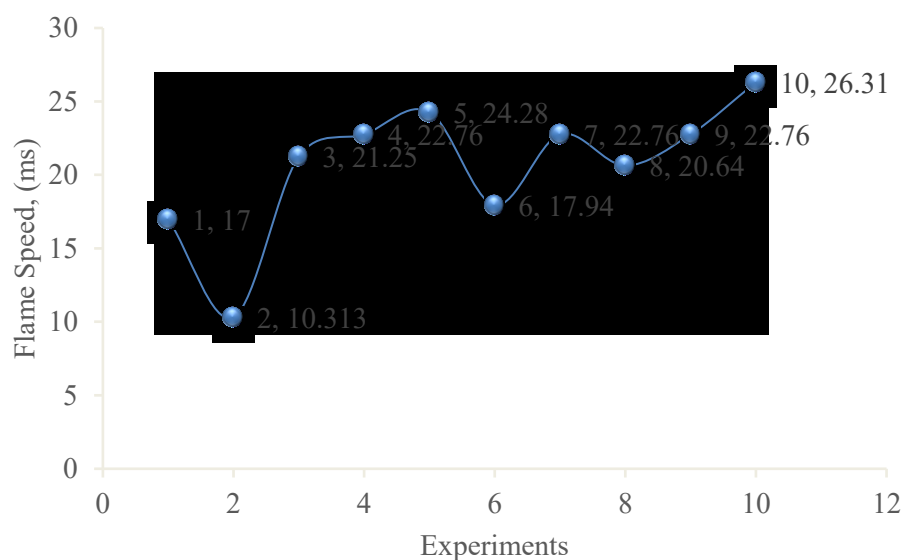
### 3. Results and Discussion

Figure 4 displays a signal produced when flame completes the circuit. The flame speed can be calculated by retrieving the time between three peak signals. The signal produced was perfect because the heat intensity from the flame was balanced and stable. The blue colour line graph shows the spark signal, the red colour shows the ion probe 1 and the green colour show ion probe 2. To calculate the flame speed, the time of start from spark ignition to the starting of the probe is used as reference in the blue line. The speed of the flame will fluctuate with each spark. As such, to get more accurate answer, 10 random sparks will be selected to calculate the speed of flame, from the result of 10 different experiments, the average of flame speed is used for the analysis.

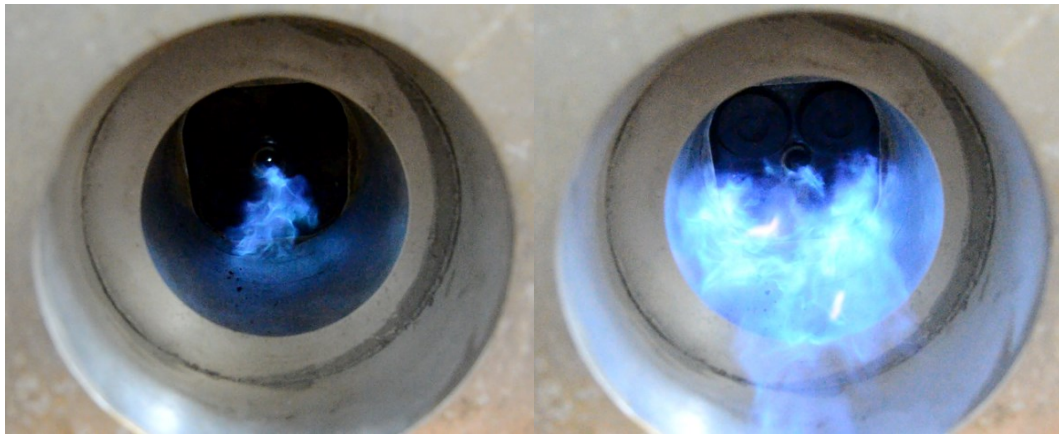


**Figure 4.** Data for Single Spark

The reading from the triggering of the spark and expansion of combustion moving to the wall before quenching is taken to determine the flame speed. The experiment is repeated as in Figure 5. The flame is unsteady however, the probe managed to find the average speed from each experiment. The fluctuations are occurring due to air fuel mixture at the vicinity is difficult to predict as findings by Heywood [15]. The average speed of flame is determined at 20.60 m/s. The flame and spark is visualised in Figure 6.



**Figure 5.** All flame speed obtained from the test rig experiments.



**Figure 6.** Flame Propagation captured from camera spark to reaching to the wall.

#### 4. Conclusion

The Ionization probe is designed to measure the flame speed of engine. The objectives to design an Ionization probe and measure the speed of flame has achieved with LPG fuel at 20.60 m/s. The distance between the spark plug and Tungsten wire fixture to the engine body divided by the time between two peaks signals to obtain the flame speed. The application of this probe can be used inside of the combustion engine to measure the flame speed when the spark ignites the air-fuel mixture. The data can be further used to improve the performance of the engine by control the air-fuel mixture. Increase the ratio of fuel in the mixture can reduce the misfire happened during the combustion. The current work establishes that LPG mixture flames are turbulent and will cause misfires in engine ECU. The feedback from the ion probe may reduce the misfires by maintaining the coefficient of variations (COV) at below 10 % [15].

#### 5. Acknowledgement

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