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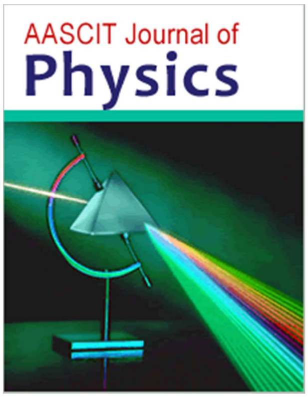

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Analysis of Internal Combustion Engines Using Laser Induced Fluorescence Spectroscopy

T. K. Subramaniam

Department of Physics, Sri Sairam Engineering College, Chennai, India

Email address
subramaniam.phy@sairam.edu.in

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Abstract
There are a number of laser related techniques to study combustion processes, namely, laser induced fluorescence (LIF), Raman Spectroscopy, and Rayleigh scattering. Use of lasers for combustion research has mainly focused on gasoline (petrol) and diesel engines. The aim and scope of this paper is to bring out the methods to improve combustion efficiency and to reduce thereby the emission of pollutants by the automobiles into the atmosphere, causing vehicular pollution. Internal Combustion (IC) engines have to be modified with the inclusion of glass windows that will permit laser photons to enter and exit the combustion chamber. Three factors, have been identified and studied here, namely, a)Fuel and Air mixing ratio, b)Spatial and temporal variations of temperature inside the combustion chamber and c)Chemical intermediates concentration that rapidly change with time. Excimer lasers (or) excited exciplex lasers are used, notably, ArF (193 nm) (or) XeCl (308 nm) are generally used to study fuel-air mixing process. [1] .Studying nitrous oxide (NO) distribution inside the combustion chamber leads to a better understanding of the NO_x formation mechanisms and this will ultimately help to improve the efficiency of the IC engine and reduction of the NO_x emissions. Imaging of hydroxide (OH) radicals inside the combustion chamber will give details of the structure of the flame , which in turn, provides qualitative measure of the combustion efficiency .Only liquid fuel oils are discussed in this paper.

1. Introduction

Figure 1. *Nikolaus Otto-IC engine inventor.*

Air pollution due to automobile exhaust is the single largest source of many gaseous pollutants. The various gases emitted through these automobile engines, their relative concentrations are closely linked to efficiency of the combustion process and the overall health of the engine. In 1876, a German Engineer Nikolaus August Otto built a successful internal combustion engine (IC engine) that allowed all basic processes like intake, compression, combustion, expansion (power) and exhaust within a piston-cylinder arrangement. [2-4].The internal combustion engine is a major contributor to the global warming, though there are many uses of it. Carbon–di-oxide is the most damaging gases among other gases that are pollutants in the category of Greenhouse gases. The depletion of the ozone layer that is seen in the Antarctic region is mainly because of CFC (Chlorofluorocarbons) though hydrocarbons and nitric oxide generated by the IC engines are also a factor for it. The Table I below shows the summary of the impact of several types of engines on the environment.

Table I. *Contribution to pollution by different categories of IC engines.*

Type of pollution	Engine Source						
	Carbon-di-oxide	**Carbon monoxide**	**Nitric oxide**	**Sulphur dioxide**	**Diesel exhaust**	**Anti-Knock component**	**Unburned hydrocarbons**
Global warming	Yes						
Acid rain		Yes	Yes	Yes			Yes
Carcinogens					Yes		
Lead						Yes	
Ozone depletion			Yes				Yes
Photochemical Smog		Yes	Yes	Yes			Yes

The advantages of using optical techniques, such as lasers are that it provides information on the IC engine characteristics with a high degree of temporal and spatial resolution. The cost involved may be higher and the IC engines design has to be modified in order to make the laser beam access to the flame.

2. Laser Induced Fluorescence (LIF)

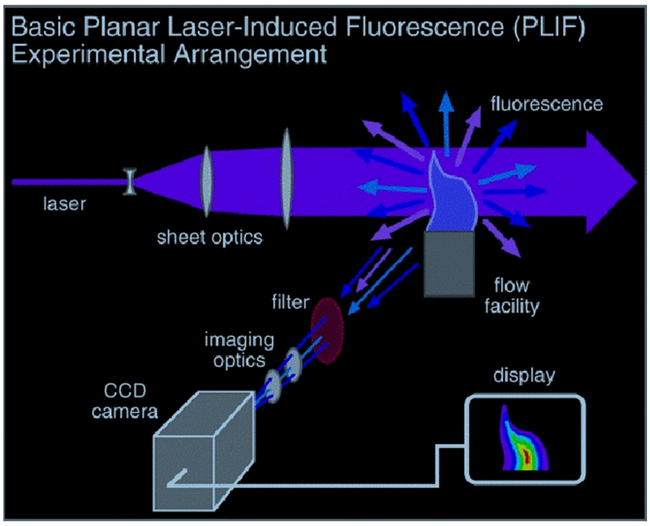

Figure 2. *Laser Induced Fluorescence set-up (Courtesy- Velocimetry& Wikipedia).*

This technique is a well established one to detect atoms or molecules in specific quantum states. When an atom or a molecule is excited by an incoming laser beam, the atom or the molecule goes into the excited state .The excited atom stays there for a certain period of time called as the 'lifetime' of the excited state and then it has to return to the ground state or the equilibrium state by giving away the extra energy that it had obtained while going up. Besides other processes of emission of energy in the form of a light photon, an atom or a molecule can undergo spontaneous emission and reaches a state other than the ground state giving a light photon and which is called as 'fluorescence'. The energy is quantized and transitions can occur only for fixed amounts of it.

In the case of a molecule undergoing a transition, vibrational and rotational transitions or relaxations causes absorption and fluorescence. The fluorescence lifetime is for one tenth of a nanosecond and the fluorescence rate, that is the number of photons emitted per unit volume per second, is dependent on the number density, saturation intensity, number of atoms or molecules that were there in the ground state, laser parameters, and other molecular constants. [5-9]

3. IC Engine

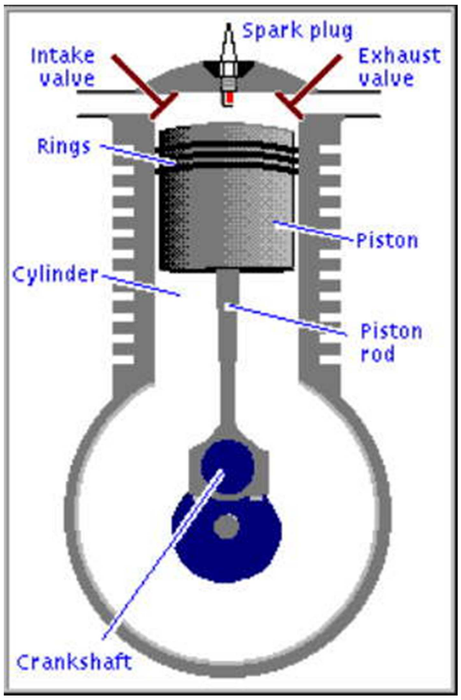

Figure 3. *Basic IC engine diagram (Courtesy Wikipedia).*

The basic definitions of the parts of an IC engine are given here.

l= rod length (distance between piston pin and crank pin)

r = crank radius (distance between crank pin and crank center, i.e. half stroke)

A = crank angle (from cylinder bore centerline at TDC.

x = piston pin position (upward from crank center along cylinder bore centerline)

v = piston pin velocity (upward from crank center along cylinder bore centerline)

a = piston pin acceleration (upward from crank center along cylinder bore centerline)

ω = crank angular velocity in radians/sec.

4. Air/Fuel Ratio (λ)

An important factor is the air /fuel ratio (λ) of any combustion mixture in an IC engine. This ratio affects the relative emission of gases. When $\lambda < 1$, the air/fuel mixture is said to be rich; for example,-when an engine is in a start-up condition, then the exhaust gas contained will be CO (Carbon Monoxide) and unburned hydrocarbons. When $\lambda > 1$, the air/fuel mixture is said to be low and therefore CO and other unburned hydrocarbon emissions will be low. When $\lambda = 1$, all the emission gases are at a minimum and a stoichiometric mixture of all gases is obtained. [10].A stoichiometric ratio is one in which there is theoretically just sufficient oxygen to burn all the combustible elements in the fuel completely. Some of the automobiles are fitted with "catalytic converters" which enables to adjust the air/fuel ratio λ and allows air/fuel mixture to optimize while the engine is in running condition. Thereby CO and hydrocarbons are minimized. However, Nitrogen oxides and the nitrogen compounds NO_x are not related to their air/fuel mixing ratio and therefore require some other technique to control them. The detection of NO by laser-induced fluorescence (LIF) can be achieved by using excimer laser ArF (193 nm) (or) XeCl (308 nm) wavelengths. Exciting the NO by ArF or XeClexcimer laser will give rise to fluorescence from the molecular states, such as, $A^2\Sigma^+$, $B^2\pi$ and $D^2\Sigma^+$ states. This method is used for directly or indirectly injected diesel engines. However, there may be a restriction on the data collected due to late stages of combustion stroke and exhaust stroke in diesel engines. To overcome this, we can use KrF laser (248 nm) which excites the NO and produces $A^2\Sigma^+$ state. This molecular state shifts the fluorescence signal from the main excitation wavelength (248 nm) and hence signals can be achieved easily in the high temperature regions of combustion, thus leading to a better understanding of the nitrous oxides formation. Another important factor is the "crank angle". It is defined as, "The angle of rotation of a crank shaft measured from the position in which the piston is at its highest point known as top dead center TDC.

The change in NO concentration as a function of crank angle has been studied by several authors. The change in NO concentration as a function of crank angle (for λ=1.0) stoichiometric ratio compared to (λ = 0.85) gives a better LIF signal intensity as shown by Knapp et al.[11]. We have to design an IC engine with a laser input provision so as to allow the laser beam to penetrate from the input port and reach till the end of the internal combustion engine .A reflecting mirror is kept on a substrate at 45 degree angle so that as and when the laser beam strikes the mirror, the beam gets reflected through an angle of 45 degrees. This would enable LIF studies easy.

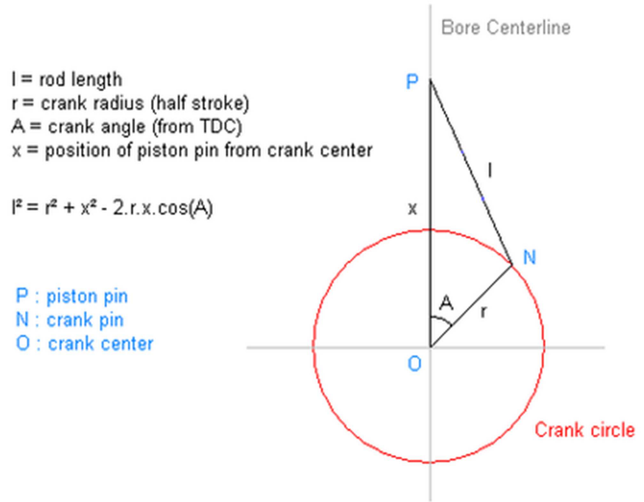

Figure 4. *Crank Angle definitions (Courtesy Wikipedia).*

5. Chemical Intermediates Concentration for Reactions Inside the Combustion Chamber

The rate at which a reaction proceeds inside an IC engine and the stability of the flames inside it are of great importance in the design of an IC engine. Firstly, the combustion process is described here. It is the formulation of chemical equation that shows how the atoms of the reactants are rearranged to form products. Consider the simple chemical equation expressing the complete combustion of carbon and oxygen to carbon-di-oxide.

$$C + O_2 \rightarrow CO_2 .$$

This states that an atom of carbon combines with one molecule of oxygen to give one molecule of carbon-di-oxide. All gases occupy equal volumes per kilo mole when reduced to same pressure and temperature inside the combustion chamber of the IC engine. If any insufficient oxygen is present for all the carbon to burn to CO_2 , some of it will burn to carbon monoxide, such that we get:

$$C + ½\, O_2 \rightarrow CO$$

Carbon monoxide will subsequently burn into CO_2.

$$CO + ½\, O_2 \rightarrow CO_2.$$

Thus a chemical equation is used to predict the analysis of the products of combustion when the composition of the fuel and air/fuel ratio is known and also to determine the stoichiometric ratio.Petroleum oils are complex mixtures of large number of hydrocarbons. [12-17].The analysis of petroleum oils is given in the form of a tabular column below.

Table II. *Analysis of Petroleum Oils.*

Element	Motor Petrol	Vaporizing Oil	Kerosene	Diesel oil	Light fuel oil	Heavy fuel oil
C-Carbon	85.5	86.8	86.3	86.3	86.2	86.1
H-Hydrogen	14.4	12.9	13.6	12.8	12.4	11.8
S-Sulphur	0.1	0.3	0.1	0.9	1.4	2.1

6. Conclusion and Discussion

Quantitative measurement of in-cylinder air-to-fuel ratio is now possible. Calibration of the fluorescence in an efficient manner is possible by choosing a correct choice of tracer and its optimum concentration. Calibration should be done under realistic engine conditions. Laser energy is monitored in an oscilloscope. The error due to energy variation is estimated to be around 10%.The error caused by the collecting optics, namely the image intensifier or the CCD camera is expected to be around 2.5% in measuring the fluorescence count. In spite of all these errors, this method is a good and reliable technique than any other methods to study and reduce the exhaust emission of an IC engine.

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