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Experimental Validation of Combustion Characteristics of Commercial Diesel Fuel

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Abstract: In current scenario commercially available diesel fuel becomes the primary energy resource of transportation and power production. Diffusion combustion of fuels in compression ignition engines is a very complex phenomenon. Delay period is single most important parameter which controls the performance and emission characteristics of fuels used in CI engines. Present work deals with measurement of ignition delay of commercial diesel fuel in a closed cylindrical camber and a comparison of the obtained results with the Arrhenius equation given by Wolfer and Stringer in 1959 is carried out. The comparison is done at different ambient air pressure from 10 to 25 bar and air temperature from 350^0C to 450^0C. It is found that, experimental results shows more consistant trends with the arrhenius equation, when fuel is injected at high injection pressure of 300bar.

Keywords: cylindrical combustion chamber, ignition delay, variation of injection pressure.

NOMENCLATURE

τ_{id} = Ignition Delay in millisecond, P = In-cylinder pressure in Pa, E_A = Apparent activation energy in j/mol, R = Universal gas constant in j/mol-K, T = In-cylinder Temperature in Kelvin, A and n = Constants depends upon type of fuel.

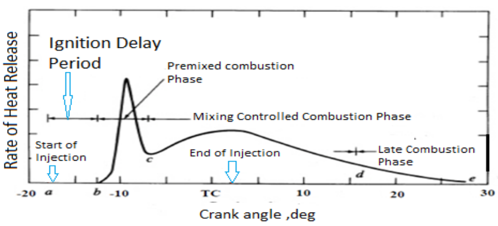
I. INTRODUCTION

Numerous experimental research works all around the world have contributed in the investigations of the various operational characteristics of internal combustion engines. These characteristics are BSFC, peak pressure measurement, thermal efficiency, brake efficiency, emission analysis and the ignition delay measurement.

With the advancement of technology it becomes easier to develop the test fascility for such measurements. Since the diesel engine combustion process is heterogeneous its spontaneous combustion ignition process is even more complex. Though ignition occurs in vapor phase regions, oxidation equations can proceed in liquid phase as well between the fuel molecules and the oxygen dissolved in the fuel droplets also , cracking of large hydrocarbon to smaller molecules is occuring.

These processes depends on the chemical composition othe fuel and the cylinder charge temperature and pressure as well as the ignition delay [1]. A shorter ignition delay period means buring of a lower fraction of fuelburned during premixed cmbustion phase which decreases engine.Therefore ignition delay prediction through analytical methods and measurement through experimental methods play a vital role in comparing the performance and emission characteristics of the various fuels which can be used in CI engines.

II. COMPRESSION IGNITION COMBUSTION PROCESS



Compression ignition combustion can be studied under following phases [2]

A. *Ignition Delay (ab)*

The duration between the start of fuel injection into the combustion chamber and the start of combustion as shown, determine from the change in slope on the p-θ diagram.

B. *Premixed Combustion Phase (bc)*

Combustion of the fuel which has mixed with air within flammability limits during ignition delay period occurs rapidly in a few crank angle degrees, high heat release characteristics in this phase.

C. *Controlled Combustion Phase (cd)*

Once the fuel and air which is pre-mixed during the ignition delay is consumed, the burning rate (heat release rate) is controlled by the rate at which mixture becomes available for burning. The rate of burning in this phase is mainly controlled by the mixing process of fuel vapor and air. Liquid fuel atomization, vaporization, pre-flame chemical reactions also affect the rate of heat release.

I. IGNITION DELAY

When the charge (fuel air mixture) is ignited making contact with hot compressed gases (in case of CI Engines), it does not get burned immediately, rather there is a time lag between the two stages known as ignition delay of the fuel. During the delay period, the injected fuel undergoes complex physical and chemical processes such as atomization, evaporation, mixing and preliminary chemical reactions. It consists of two parts physical delay and chemical delay.

A. Physical delay period

It is the time period to perform the physical process like; atomization of the liquid fuel jet, vaporization of the fuel droplets, mixing of the fuel vapor with air as shown in Figure 2.

B. Chemical Delay

It is the time period to complete the chemical processes like; the pre-combustion reactions of the fuel, air and residual gas mixture which lead to auto-ignition as shown in Figure 3. Both physical and chemical processes must take place before a significant fraction of the chemical energy of the injected liquid fuel is released.

II. THEORETICAL DETERMINATION OF IGNITION DELAY

Basic studies in the constant-volume combustion chamber, in steady flow reactors, and in RCM (rapid compression machines) have been used to study the

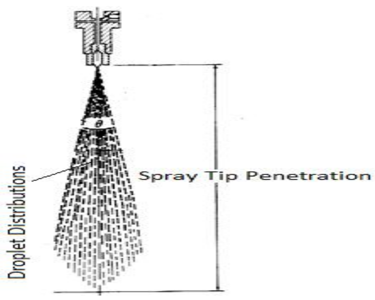


Figure 2 Atomization and Vaporization of fuel in the cylinder [1]

auto ignition characteristics of the fuel air mixture under controlled conditions. In some of these studies the fuel and air are premixed; in some, fuel injection was used [3]. Studies with fuel injection into constant temperature and pressure environment have shown that the temperature and pressure of the hot air are the most important parameters for a given fuel composition. Ignition delay data from these experiments have usually been correlated by Arrhenius equation given below.

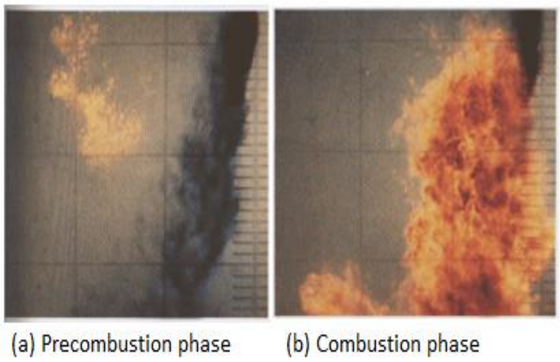


Figure 3 Combustion Phases in Combustion Chamber [1]

$$\tau_{id}(ms) = A * P^{-n} * \exp\left(\frac{E_A}{RT}\right) \ldots\ldots\ldots\ldots\ldots [3]$$

Several investigators gave the constant for the Arrhenius equation. Table 1 summarizes the value of these constants given by Wolfer and Stringer [7]. For the purpose of comparison we calculate the ignition delay times for the diesel fuel using Wolfer and Stringer formula, for the given condition of our study (Pressure=10 bar to 25 bar , temperature range = 623-723 K) and the results are summarized.

III. EXPERIMENTAL SETUP AND TEST PROCEDURE

A cylindrical combustion chamber with hot surface exposed to the incoming jet of fuel is established. the injection pressure is fixed by the mechanical arrangement attached on the fuel injector. Injection pressure ranges from 100bar to 300 bar. The ambient air inside the chamber is maintained at 10 to 25 bar by the compressed air supplied from the Nimpra NPHPC-30 model air compressor. Chamber temperature is maintained at 350^0C to 450^0C by electric heater attached inside the chamber.

A pressure transducer is attached to the fuel line from Bosch single barrel type fuel pump [4] to the fuel injector, when fuel is pumped into chamber it is detected by the transducer and the ignition of fuel inside the chamber is detected by the photo sensor attached inside the chamber. The difference between these two instant is taken as the ignition delay and it is display on the screen of the Fluke Digital Storage two channels Oscilloscope as shown in the figure 5.

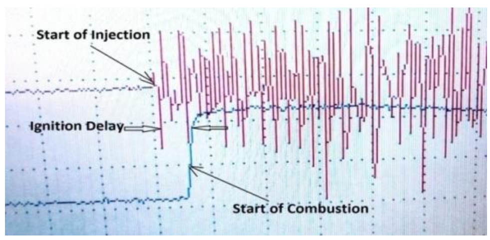


Figure 5 Display of Digital Oscilloscope

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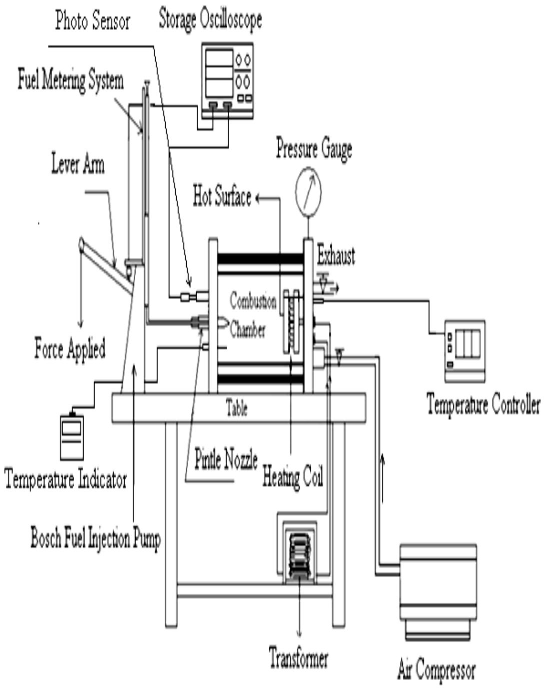

TABLE 1
CONSTANTS FOR ARRHENIUS EQUATION FOR IGNITION DELAY [3]

Investigator	Apparatus	Fuel	P (Atm)	T (K)	n	a	E_A/R (K)
Wolfer	Constant Volume Bomb	Fuel With 45-50 cetane number	8-48	590-782	1.19	0.144	4650
Stringer	Steady flow	Diesel 45-50 cetane Number	30-60	770-980	0.757	0.0405	5473

TABLE 2
SPECIFICATION OF DIESEL FUEL TESTED

Properties	API Gravity at 15°C (degree)	Cetane No
HS Diesel (Bharat Stage III)	830 (Kg/m^3)	54

TABLE 3
SPECIFICATIONS OF COMBUSTION CHAMBER

Dimensions	Diameter =9.3 cm, Height=22.3 cm, Wall thickness=8mm
Maximum pressure Design	200 bar
Maximum temperature Design	800 °C
Material	Stainless Steel
Nozzle	Pintle Nozzle
Temperature Indicator	Digital Temperature Indicator (Cromel / alumel type)
Sensor	Photo Sensor

V. RESULTS

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AND DISCUSSION

Commercial diesel fuel injected at different injection pressure and at different ambient conditions into the combustion chamber displays the ignition delay on screen of the oscilloscope and this is done five times at each condition and averaged value is ploted, the ignition delay calculated by arrhenius equation [3] is also ploted on the same graph for the comparison purposes.

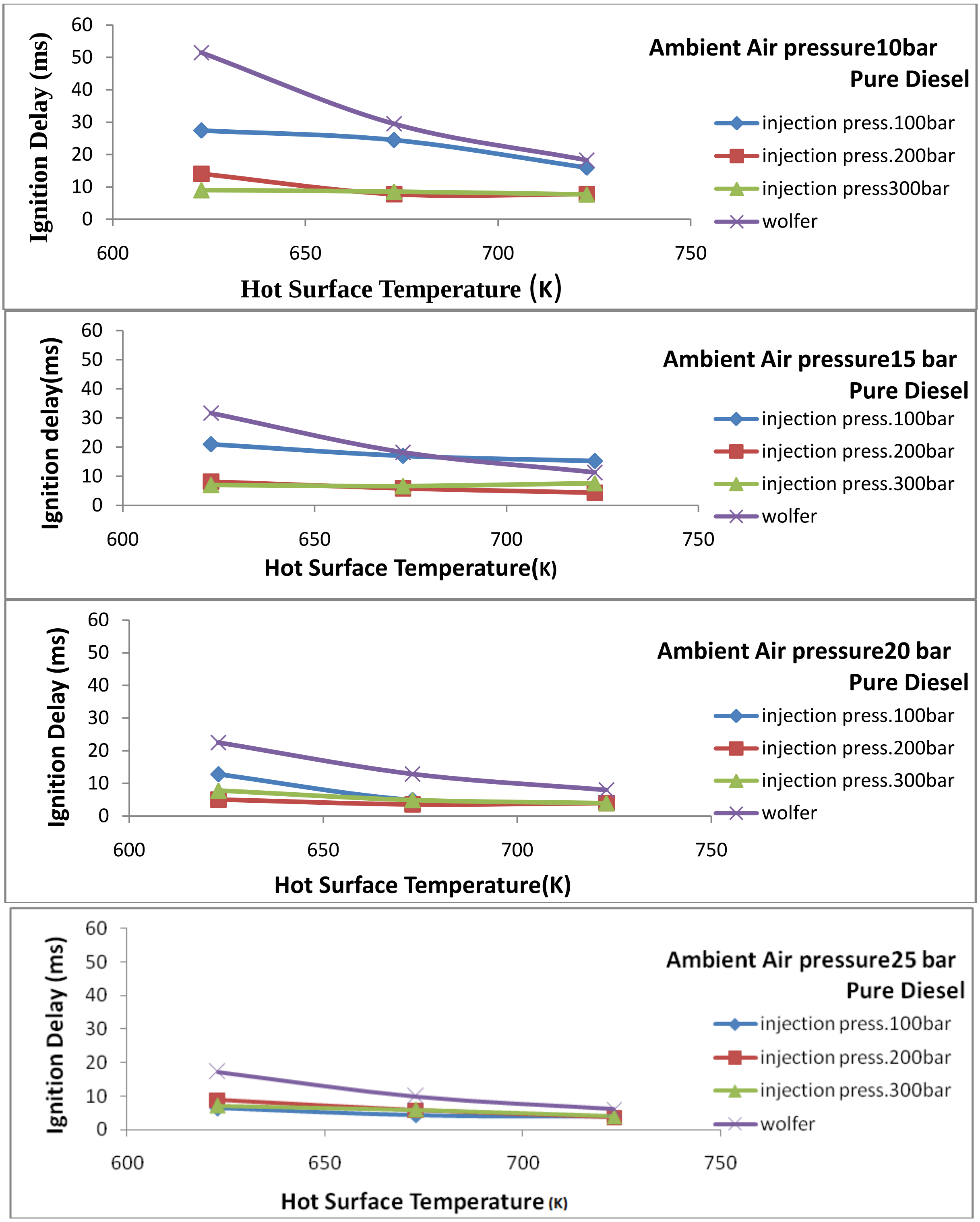

Figure 6 Ignition delay of Diesel fuel at different injection pressure and calculated by Arrhenius equation

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VI. CONCLUSIONS

The experimentally measured values of the ignition delay and the values calculated by Arrhenius equation show a similar trend of decreasing nature at different ambient air pressures between 10 to 25 bar, though values differ when injecton pressure is small. As the injection pressure is increased, the ignition delay is reduced compared to values at lower injection pressure and the experimentally measured values and the calculated values using Arrhenius equation very nearly coincide. At an injection pressure of 300 bar the experimental and measured values were found to be in very close conformity. Therefore, theoretical approach for ignition delay is validated at high injection pressure (about 300 bar and above) and at higher intake air conditions (about 25 bar and 500 ^{0}C) inside the combustion chamber, and a good prediction of ignition delay using Arrhenius equation can be made.

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