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Experimental and mathematical modeling in a DICI engine with various combustion chambers

S.Arumugam*, K.Pitchandi, P.Karthik Selvan
Department of Mechanical Engineering, Sri Venkateswara College of Engineering, Pennalur, Sriperumbudur Taluk–602 117, Tamil Nadu, India
***Corresponding author: E-Mail: arumugam@svce.ac.in**

ABSTRACT

The present work investigates the experimental and mathematical modeling in a DICI Engine. The two combustion chambers namely Spherical combustion chamber (SCC) and Toroidal combustion chamber (TCC) were fitted in a constant speed single cylinder direct injection compression ignition (DICI) engine maintaining constant compression ratio. The experiments were performed at different loads from zero to maximum load corresponding to rated power. The influences of the combustion chamber geometry characteristics on combustion, performance and emissions characteristics have been investigated. In mathematical modeling**,** regression analysis is used to generate an equation and minitab software is to solve the statically illustrate the relations between dependent variable and independent variables. However, there was a reduction of HC, CO, CO_2, NO_X emissions. Regressive square value is more than 90 is the minimum of errors is obtained and predictor variable is less than 90 is obtained for both spherical and toroidal combustion chambers.

KEY WORDS: Compression ignition, Direct injection, Combustion chambers, Mathematical model, Regression, Emission.

1. INTRODUCTION

There are many advantages on diesel engine, such as high thermal efficiency and low fuel consumption. However, due to the characteristic of diffusion combustion, the rate of air fuel mixture process does a great contribution to power, economical efficiency and emission performance. The piston bowl geometry design affects the air–fuel mixing and the subsequent combustion and pollutant formation processes in a DI CI engine an attempt has been made here to investigate the effects of combustion chamber geometry (Chandrashekhara, 2012).

The fuel spray is typically aimed at the bowl lip. This design has been used for its high swirl and strong squish flows, which tend to promote sufficient mixing, especially at high engine speeds. Some researchers have found that when modern high-pressure injection systems are used along with sufficiently small bowl throat diameter chambers, liquid impingement may occur on the piston at certain operating conditions. They contend that the traditional small diameter bowl may be inappropriate when used with modern high-pressure injection systems (Dehong and Hill, 1996).

The directing flows of air while its entry to the cylinder known as induction swirl. This method is used in open combustion chamber. By forcing air through a tangential passage into a separate swirl chamber during the compression stroke, known as Combustion swirl (Heywood, 1988).

The regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed (Jaichandar and Annamalai, 2012).

Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables that is, the average value of the dependent variable when the independent variables are fixed. Less commonly, the focus is on a quartile, or other location parameter of the conditional distribution of the dependent variable given the independent variables. In all cases, the estimation target is a function of the independent variables called the regression function. In regression analysis, it is also of interest to characterize the variation of the dependent variable around the regression function which can be described by a probability distribution (Luo Maji, 2011; Marcin and Andrzej, 2007; Asif, 1996).

Regression analysis is widely used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. Many techniques for carrying out regression analysis have been developed. Familiar methods such as linear regression and ordinary least squares regression are parametric, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data. Nonparametric regression refers to techniques that allow the regression function to lie in a specified set of functions, which may be infinite-dimensional (Brand, 1979).

The addition of turbulence to the incoming air charge is important to mixing the air and fuel in the cylinder to obtain good emission characteristics. In direct injection combustion chambers, a swirl is imparted to the air as it enters the chamber. A radial swirl is imparted as air enters the cylinder and a rotational turbulence from the radius bowl of the piston on the piston up-stroke. When the piston compresses the turbulent mass, hundreds of smaller more violent miniature tornadoes are created. Diesel fuel injected into the chamber continues to mix and remix. Correct matching of spray patterns from injector nozzles are required to obtain optimum mixing (Middlemiss, 1978; Mobasheri and Peng, 2012).

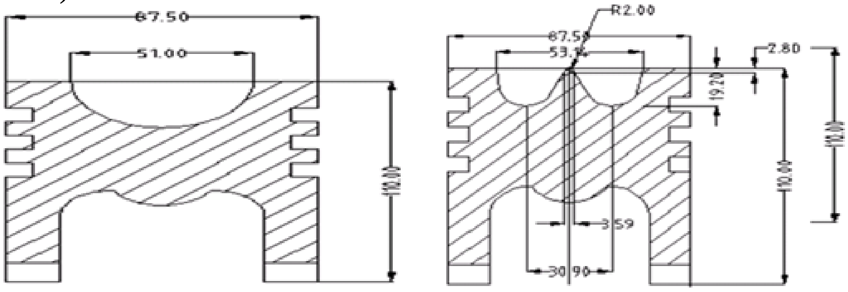

Fig.1. Combustion chambers

2. Result and Discussions

Combustion Characteristics: Fig.2 shows the variation of cylinder pressure with crank angle at maximum load. The peak pressure of spherical chamber is higher than the toroidal chamber. This is due to the more air swirl present in the spherical chamber lead to enhance the complete combustion of the diesel fuel, resulting in higher peak pressure.

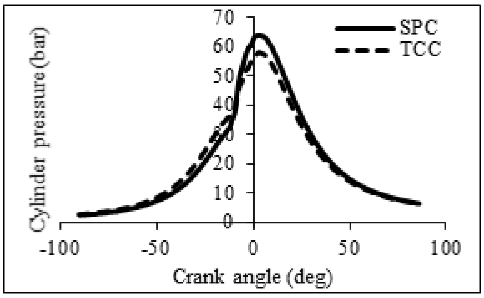

Fig.2. Variation of cylinder pressure with crank angle

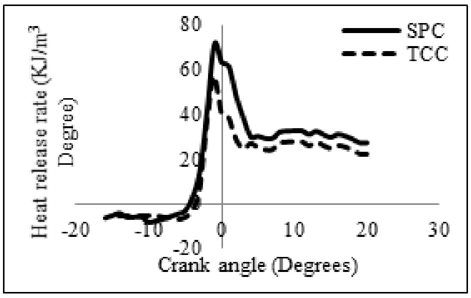

Fig.3. Variation of heat release rate with crank angle

Fig.3 shows the variation of heat release rate with crank angle at maximum load. Typical heat release rate curve for DICI engine has two peaks for spherical and toroidal combustion chamber. First peak occurs during premixed combustion due to rapid combustion of part of fuel injected during delay period. Height of the first peak depends on the injection rate and the length of the delay period. The second peak occurs during mixing controlled combustion. Heat release period depends on the injection duration. This mainly due to spherical chamber having capable of proper mixing fuel with high pressure air and swirl and squish created by the incoming air. The intensity of pre combustion phase and turbulence of the compressed air with atomized fuel droplets are more thus resulting in higher heat release in spherical chamber compared to toroidal chamber.

Fig.4 shows the variation of actual air fuel ratio with brake power. The actual air fuel ratio in a DICI engine varies from $18 \leq A/F \geq 70$. The toroidal chamber having lower air fuel ratio compared to spherical chamber at all loads because of toroidal chamber accumulate more non evaporated fuel and lead to rich mixture. This is due to the energy input to the engine comes in the form of chemical energy of fuel, which is known as heat of combustion. Both the flow of fuel and air are measured and these must be within the well-defined proportion for good condition for the premixed combustion engines.

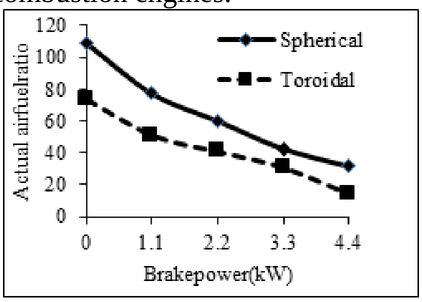

Fig.4. Variation of actual air fuel ratio with brake power

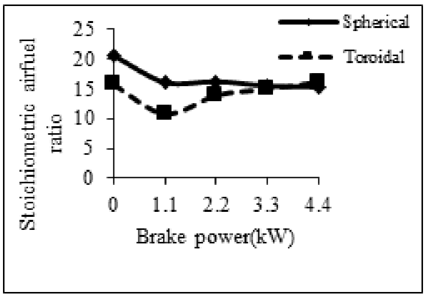

Fig.5. Variation of stoichimetric air fuel ratio with brake power

Fig.5 shows the variation of stoichimetric air fuel ratio with brake power for spherical and toroidal combustion chambers. Stoichiometric air fuel ratio for 15.3 in spherical chamber compared to toroidal combustion chamber. More amount of air reached through the inlet manifold is to provide complete burning of fuel in the spherical chamber. This is due to the chemically correct air fuel ratio for complete combustion of a fuel depends on its chemical composition.

Fig.6 shows the variation of relative air fuel ratio with brake power for spherical and toroidal combustion chambers. From this experiment the relative air fuel ratio decreases with increases in brake power the higher value of lambda denotes that the mixture is lean whereas the lower value of lambda significance that the air fuel mixture is rich, this trend discloses that the mixture strength is getting richer with increases in brake power. So the toroidal chamber has lower value of 1.447 compare to spherical chamber.

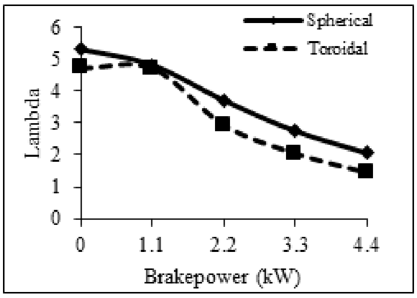

Fig.6. Variation of relative air fuel ratio with brake power

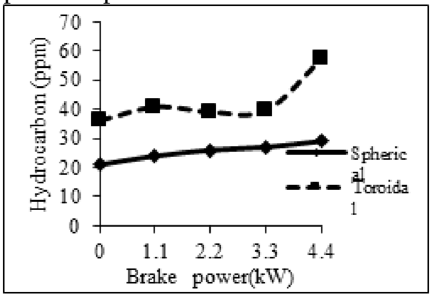

Fig.7. Variation of hydrocarbon with brake power

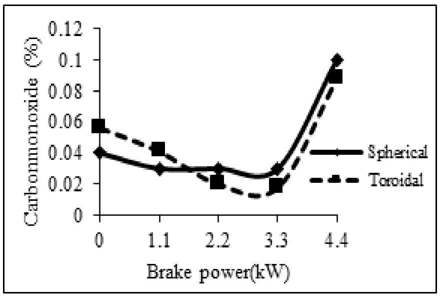

Fig.8. Shows the variation of carbon monoxide with brake power

Emission Characteristics: Fig.7 shows the variation of hydrocarbon with brake power for spherical and toroidal combustion chambers. It is evidently proved from plot that the hydrocarbon emission decreases with increases in brake power in toroidal chamber and increases linearly in spherical chamber. At maximum load condition toroidal combustion chamber is having slightly higher hydrocarbon emission than spherical chamber. This is primarily due to increases in cylinder temperature with increases in brake power.

Fig.8 shows the variation of carbon monoxide with brake power for spherical and toroidal combustion chambers. The carbon monoxide emission is the product of incomplete combustion which can be combust to supply addition thermal energy. At maximum load condition toroidal combustion chamber produces lower carbon monoxide emission than spherical chamber due to better squish and swirl in case of toroidal combustion chamber.

Regression Analysis for Spherical and Toroidal Chambers: Fig.9 shows the variation of regression analysis for hydrocarbon with spherical and toroidal combustion chambers. Spherical chamber the constant coefficient is 32.2800 and standard equation co efficient is 0.9736. By the percentage of load have 0.18160 and standard equation coefficient is 0.01590.Standard deviation has 3.9782. R-square is the regressive square of co efficient of determination R-sq=73.1% and R-sq (adj) =72.5%. Toroidal chamber the constant coefficient is 31.0800 and standard equation co efficient is 0.8936. By the percentage of load have 0.17160 and standard equation coefficient is 0.01590.Standard deviation has 3.9782. R-square is the regressive square of co efficient of determination R-sq=71.081% and R-sq (adj) =74.32%.

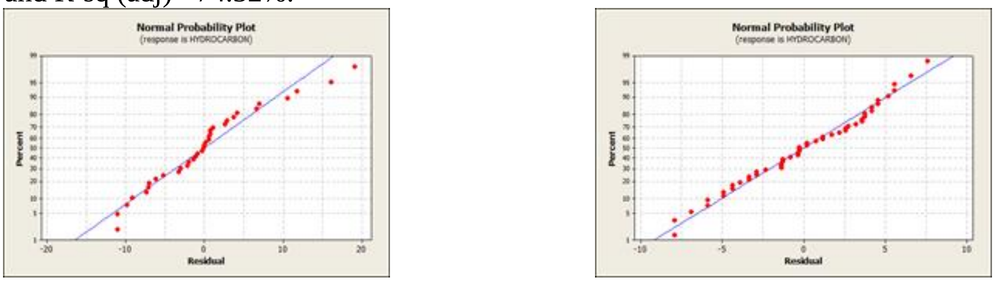

Fig.9. Regression analysis for hydrocarbon with spherical and toroidal combustion chambers

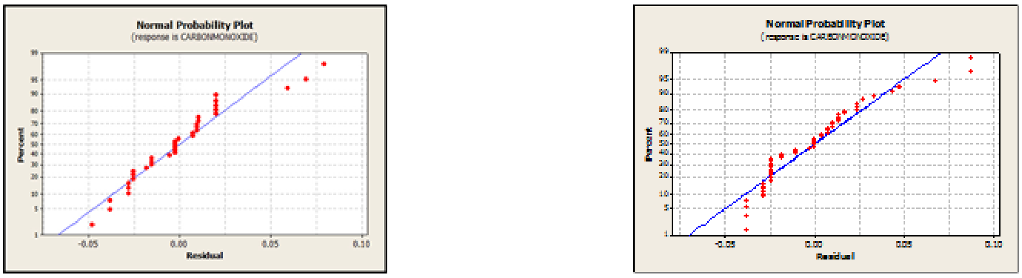

Fig.10. Regression analysis for carbon monoxide with spherical and toroidal combustion chambers

Fig.10 shows the variation of regression analysis for carbon monoxide with spherical and toroidal combustion chambers. Spherical chamber the constant coefficient is 161.371 and standard equation 4.587. By the percentage of load have 2.99943 and standard equation coefficient is 0.07491.Standard deviation has 15.668. R-square is the regressive square of co efficient of determination R-sq=98.0% and R-sq (adj) =97.9%. Toroidal chamber the constant coefficient is 0.03400 and standard equation co efficient is 0.007497. By the percentage of load have 0.0001640 and standard equation coefficient is 0.0001224.Standard deviation has 0.0306054. R-square is the regressive square of co efficient of determination R-sq=73.6% and R-sq (adj) =71.5%.

3. CONCLUSION

In this experimental study the combustion, performance and emissions for DICI engine fitted with spherical and toroidal chambers. The peak pressure of spherical chamber is higher than the toroidal chamber. This is due to the more air swirl present in the spherical chamber lead to enhance the complete combustion of the diesel fuel, resulting in higher peak pressure. Spherical chamber having higher heat release rate is to capable of proper mixing fuel with high pressure air and swirl and squish created by the incoming air. The intensity of pre combustion phase and turbulence of the compressed air with atomized fuel droplets are more thus resulting in higher heat release in spherical chamber compared to toroidal chamber.

The actual air fuel ratio is 14:1 for toroidal combustion chamber when compared to spherical chamber. So toroidal combustion chamber is has rich mixture to release more heat of combustion. The Stoichiometric air fuel ratio is 15.3 in spherical combustion chamber when compared to toroidal chamber have 16.5. Due to the enough air is accumulate is to complete burn the fuel in spherical chamber. In lambda toroidal chamber has lower value of 1.447 compare to the spherical chamber reason is due to relative air fuel ratio decreases with increases in break power. The higher value of lambda denotes that the mixture is lean.

Using the regression analysis it generates an equation to describe the statically relations between one or more predictor variables and the response variables. The use of minitab statically software is to fit the regression model and verified by checking the residual plots. In regression analysis linear regression model is used for spherical and toroidal combustion chamber. Using the linear regression model errors is to be find out for emission characteristics like HC,CO,CO_2 and NO_X for all the emissions characteristics must be R-sq(adj) value is more than 90 is the minimum of errors is obtained and if more predictor variable is<90 errors obtained higher.

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