International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

Swirl Induction with Dimpled Cylinder Head and its Effect on Exhaust Emission of Diesel Engine

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Abstract: ***This paper aims at studying the effect of in-cylinder air turbulence generated by oval shape dimpled cylinder head on engine performance as well as on its exhaust emissions. In view this, experimental investigation has been carried out to find the effect of swirl on the performance characteristics of the engine as well as on its exhaust emissions , by inducing swirl in cylinder with different configurations of cylinder head i.e. in the order of number of oval shape dimples 1& 3. This intensification of the swirl is done by making in order to enhance performance characteristics of the engine. It is inferred that, engine with dimpled cylinder head optimized the performance of engine and yields less exhaust emission as compared to the engine with conventional cylinder head. This is because dimpled cylinder head achieved a higher swirl coefficient and swirl ratio as compared with conventional cylinder head. The increase in swirl intensity by dimpled cylinder head resulted in better mixing of air- fuel mixture which improves the combustion rate resulted in reduction of exhaust emissions.***

Keywords: Diesel engine, Dimpled cylinder head, Swirl enhancement, Exhaust emissions.

1. Introduction

Diesel engines have an excellent reputation for their low fuel consumption, reliability, and durability characteristics. In-cylinder flow field structure in an internal combustion engine has a major influence on the combustion, emission and performance characteristics. Fluid flows into the combustion chamber of an I.C engine through the intake manifold with high velocity. Then the kinetic energy of the fluid resulting in turbulence causes rapid mixing of fuel and air, if the fuel is injected directly into the cylinder. With optimal turbulence, better mixing of fuel and air is possible which leads to effective combustion. A good knowledge of the flow field inside the cylinder of an I.C engine is very much essential for optimization of the design of the combustion chamber for better performance [1].

Two general approaches are used to create swirl during the induction process. In first approach, swirl is created by discharging the flow into the cylinder tangentially towards the cylinder wall (helical port) and in the second approach, the swirl is generated in the manifold runner so that the flow rotates about the valve axis before it enters the cylinder. Several research studies related to swirl enhancement in IC engines reported that swirl facilitates the mixing of the air fuel mixture and increases the combustion rate.

S.L.V. Prasad et al. [2] conducted series of experiments by making straight grooves in the cylinder head. In this work three different configurations of cylinder heads i.e. in the order of number of grooves 1, 3, 6 were used to intensify the swirl for better mixing of fuel and air and to enhance the performance of the engine. Tests showed that the brake thermal efficiency of CH3 was increased by about 6.9% when compared to normal engine at 3/4 of the rated load.

The experimental work of Sihun Lee *et al.*, [3] showed that both swirl and tumbling motions enhanced the fuel vaporization and fuel-air mixing and results in better cold start performance. Another advantage that was reported was ability to retard ignition timing as it has faster burning, which gives enough time for fuel vaporization and fuel-air mixing before being ignited.

Taehoon Kim *et al.*, [4] improved the lean misfire limit by the introduction of swirl and tumble motion. Three types of ports with an IACV (Intake Air Control Valve) have been developed to obtain sufficient swirl and tumble motion to improve combustion and still keep high volumetric efficiency. Tests showed that the combustion duration was shortened and consequently lean misfire limit and EGR tolerance were improved with considerable reduction in the level of NOx.

Abdul Rahim Ismail *et al.*, [5] in their experiment investigated air flow and coefficient of discharge desirable for inflow (reverse flow) through the exhaust port using super flow bench. The experimental results show that the air flow and coefficient of discharge in the intake port and exhaust port of the four stroke diesel engine provided the best at 0.25 L / D and in highest test pressure. Increasing the valve lift and test pressure can increase the air flow, valve air flow and coefficient of discharge in intake manifold system or in exhaust manifold system, but after the maximum valve lift per diameter 0.25L / D, the air flow, valve air flow and coefficient of discharge is stable and did not increase.
Tomonori Urushihara *et al.*, [6] studied the flow measurements for various types of intake systems that generated several different combinations of swirl and tumble ratios using laser doppler velocimetry and visualization of in-cylinder fuel vapour motion by laser induced fluorescence. It was concluded that a low tumble ratio is a necessary

condition for obtaining axial mixture stratification in the cylinder and Strong swirl, which has been considered to be necessary for axial mixture stratification, is not always effective in stratifying the mixture.

According to Al- Rousan [7] swirl is generated in the inlet manifold by inserting a loop inside the intake manifolds to increase the swirling in the air during induction. Rasul and Glasgow [8] prepared a convergent-divergent induction nozzle and is tested in order to increase the airflow into the engine, which may increase the overall performance.

Yasar et al and Stansfield et al [9] have conducted PIV measurements on various engines and reported that the flow structure changes substantially along the cylinder length due to the geometry of the intake valve port and the tumble motion was generated during induction process. Also, reported that the increase in the air flow rate at higher engine speed causes the vortex center to move right-upwards compared to the lower engine speeds.

In general, the presence of a swirl in the cylinder of an internal combustion engine improves the homogenization of the air - fuel mixture, and consequently, enhances fuel combustion. The aim of this work is to investigate the effect of the swirl on the exhaust emission of the engine, by inducing swirl in cylinder with different configurations of cylinder head i.e. in the order of number of oval shape dimples 1& 3.

2. Experimental Work

In the present work the effect of the swirl on the performance characteristics as well as on its exhaust emissions of the engine, by inducing swirl in cylinder with different configurations of cylinder head i.e. in the order of number of oval shape dimples 1& 3. Oval shape dimples are made on the cylinder head with a relative pitch of S/D=1.21 and relative depth of δ/D=0.16.

The experiments are conducted on a single cylinder Kirloskar make direct injection four stroke cycle diesel engine. The general specifications of the engine are given in Table-1. Water cooled eddy current dynamometer is used for the tests. The engine is equipped with electro-magnetic pick up, piezo-type cylinder pressure sensor, thermocouples to measure the temperature of water, air and gas, rotameter to measure the water flow rate and manometer to measure air flow and fuel flow rates.

Table 1: Specifications of Engine used for Experimentation

S. No.	*Engine Parameters*	*Specifications*
1	Engine Type	TV1. Kirloskar, Vertical, Four stroke diesel engine
2	Software used	ICEngineSoft version 8.0
3	Number of cylinders	Single cylinder
4	Bore Diameter	80mm
5	Stroke Length	110mm
6	Rated Power	3.68 kW (5 HP)
7	Rated Speed	1500 RPM
8	Compression Ratio	16.5:1

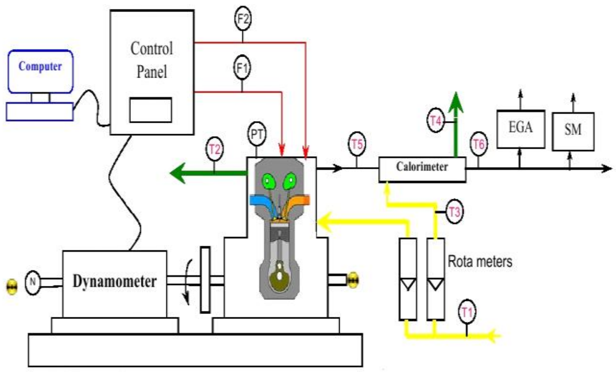

Figure 1: Schematic Diagram of the Engine Set-up used for Experimentation

T1, T3 - nlet Water Temperature, T2 - Outlet Engine Jacket Water Temperature, T4 - Outlet Calorimeter Water Temperature, T5 -Exhaust Gas Temperature before Calorimeter,T6-Exhaust Gas Temperature after Calorimeter,F1- Fuel Flow DP (Differential Pressure) unit, F2- Air Intake DP unit, PT - Pressure Transducer, N - RPM Decoder, EGA AVL Di-Gas Analyzer (5 gas) , SM - AVL Smoke meter

Figure 2: Conventional cylinder head and Cylinder head with oval shape dimples

3. Results and Discussions

3.1 Brake Thermal Efficiency

The brake thermal efficiency Vs load for diesel engine with different configurations of cylinder head i.e. in the order of number of oval shape dimples 1& 3 is compared with the engine with normal cylinder head and is shown in fig.3. From Fig, it is inferred that the brake thermal efficiencies are increasing with an increase in load for all configurations that are under consideration. The brake thermal efficiency of engine with normal cylinder head at 3/4 of rated load is 28.2%. It can be observed that the engine with cylinder head having one and three oval shape dimples give thermal efficiencies of 28.7% and 29.5%, respectively, at 3/4 of rated load. It is observed that there is a gain of 4.6% with three oval shape dimples on cylinder head compared to engine with normal cylinder head. This is because cylinder head having one and three oval shape dimples achieved a higher swirl coefficient and swirl ratio compared with normal cylinder head.

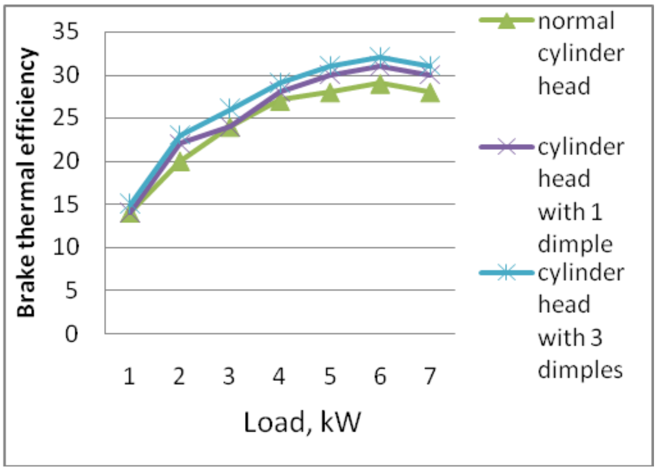

Figure 3: Brake thermal efficiency Vs Load

3.2 Exhaust Gas Temperature

Figure.4 depicts the variation of exhaust gas temperature for engine with different configurations of cylinder head i.e. in the order of number of oval shape dimples 1& 3 is compared with the engine with normal cylinder head. The exhaust gas temperature is lower for diesel engine with one and three oval shape dimples on cylinder head compared to engine with normal cylinder head at a given load. At various load conditions it is observed that the exhaust gas temperature increases with load because more fuel is burnt to meet the power requirement. It can be seen that in the case of the engine with normal cylinder head exhaust gas temperature is 247^{0}C at 2.5kW load. For diesel engine with one and three oval shape dimples on cylinder head are exhaust gas temperature marginally decreases to 239 and 235^{0}C respectively. Lower exhaust gas temperature for engine with one and three oval shape dimples can be attributed due to low operating temperature in the combustion chamber resulted by the swirl created in the combustion chamber.

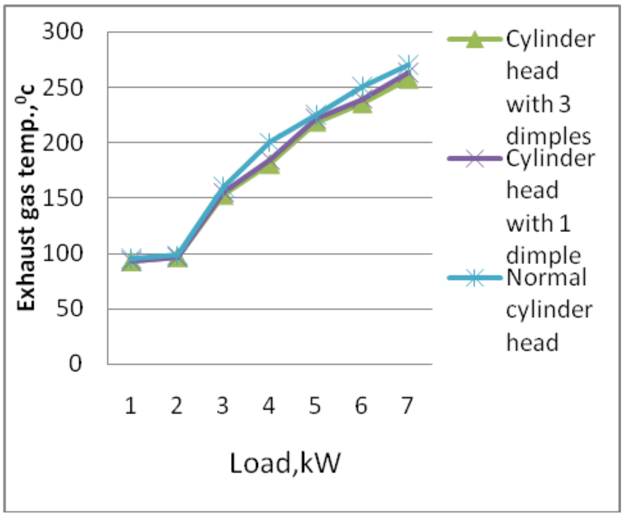

Figure 4: Exhaust gas temperature Vs Load

3.3 HC Emission

The comparison of Hydrocarbon emission in the exhaust is shown in Figure 5. Unburnt hydrocarbon emission is the direct result of incomplete combustion. It is apparent that the hydrocarbon emission is decreasing with the increase in the turbulence which results in complete combustion. It is observed that for diesel engine with one and three oval shape dimples on cylinder head reduction in HC levels is about 3.11% and 5.32 % by volume at 3/4 of rated load when compared to engine with normal cylinder head.

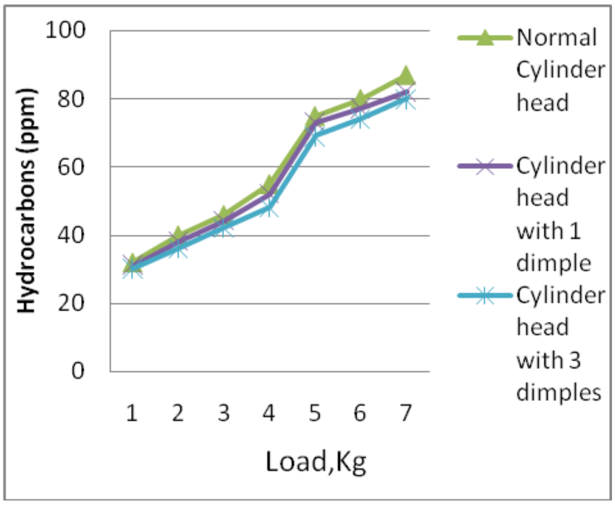

Figure 5: Load Vs Hydro carbons

3.4 CO Emission

Fig. 6 shows the comparison of Carbon monoxide emission with Load for diesel engine with one and three oval shape dimples on cylinder head is compared with the engine with normal cylinder head. Generally, C.I engines operate with lean mixtures and hence the CO emission would be low. With the higher air turbulence having one and three oval shape dimples on cylinder head, the oxidation of carbon monoxide in the engine is improved and which reduces the CO emissions. It is observed that for diesel engine with one and three oval shape dimples on cylinder head reduction in CO levels is about 4.87% and 2.65% by volume at 3/4 of rated load when compared to engine with normal cylinder head.

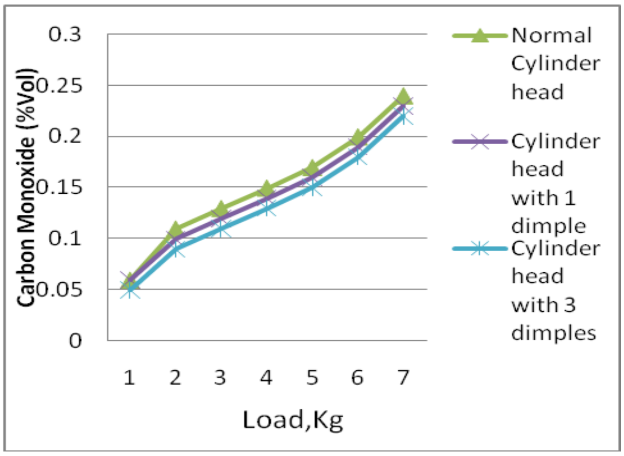

Figure 6: Load Vs Carbon monoxide

3.5 NOx Emission

Fig.7 shows the comparison of NOx emission with Load for diesel engine with one and three oval shape dimples on cylinder head is compared with the engine with normal cylinder head. The NOx emissions for diesel engine with three oval shape dimples on cylinder head is 499 ppm and whereas for engine with normal cylinder head is 516 ppm. NOx emissions are lower for diesel engine with three oval shape dimples on cylinder head when compared to engine with normal cylinder head at 3/4 of rated load. This is due decrease in the operating temperature in the cylinder by the air swirl inside the cylinder and leads to less NOx formation. The decrease in NOx emissions for the engine with one and three oval shape dimples on cylinder head are 1.8 % and 2.9 % at 3/4 of rated load respectively when compared to engine with normal cylinder head.

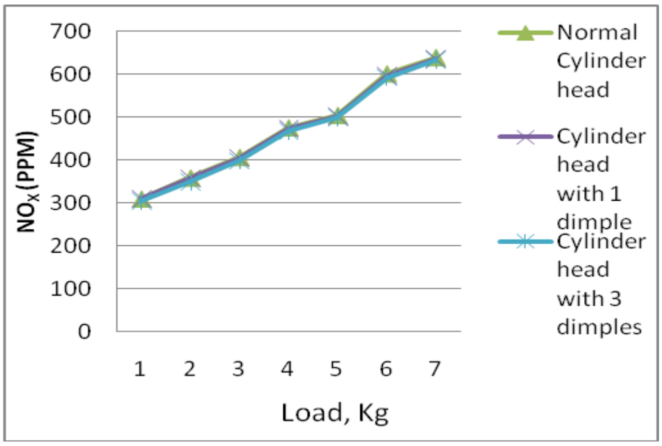

Figure 7: Load Vs NO_X Emissions

4. Conclusion

The Configuration cylinder head with three oval shape dimples enhances the turbulence and hence results in better air-fuel mixing process. As a result, the thermal efficiency is increased and BSFC and exhaust emissions are reduced.

- The maximum enhancement in brake thermal efficiency, volumetric efficiency for engine with three oval shape dimples on cylinder head were found to be 4.6%, 0.91% respectively at 2.5kW load compared to engine with conventional cylinder head.
- It is observed that 6.66% of reduction in bsfc at 2.5kW load engine with three oval shape dimples on cylinder head compared to engine with conventional cylinder head.
- The exhaust gas temperature is lower for diesel engine with one and three oval shape dimples on cylinder head than engine with conventional cylinder head.
- It is observed that 5.32%, 4.87% and 2.9% of reduction in HC, CO and NOx emissions respectively at 2.5kW load for engine with three oval shape dimples on cylinder head compared to engine with conventional cylinder head.

The results indicate that inlet manifold with three oval shape dimples on cylinder head is identified as optimum configuration based on performance as well as exhaust emissions of diesel engine.

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