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# Effect of intake swirl on the performance of single cylinder direct injection diesel engine

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**Abstract:** In the present work, the effect of inlet manifold geometry and swirl intensity on the direct injection (DI) diesel engine performance was investigated experimentally. Modifications in inlet manifold geometry have been suggested to achieve optimized swirl for the better mixing of fuel with air. The intake swirl intensities of modified cylinder head were measured in swirl test rig at different valve lifts. Later, the overall performance of 435 CC DI diesel engine was measured using modified cylinder head. In addition, the performance of engine was compared for both modified and old cylinder head. For same operating conditions, the brake power and brake specific fuel consumption was improved by 6% and 7% respectively with modified cylinder head compared to old cylinder head. The maximum brake power of 9 HP was achieved for modified cylinder head. The results revealed that the intake swirl has great influence on engine performance.

## 1. Introduction

Diesel engines are mostly used for industrial application and vehicular power sources. There are two types of diesel engine in use in automotive sector, direct injection and indirect injection. One of them is Direct Injection diesel engine, long used in larger size engines, is now entering the smaller size market. Here fuel is injected directly into the main chamber into a deep bowl in piston, within which a highly swirling air has been created during suction and compression stroke. By which rapid mixing between fuel and air has been achieved [1].

Swirl is usually defined as organized rotation of the charge about the cylinder axis. Swirl can be created by bringing the intake flow into the cylinder with an initial angular momentum [2]. It is well known that the in-cylinder air motion strongly affects the combustion process and consequently their performance. In fact, the Swirl intensity increases the velocity of the air entraining into the fuel jet, which means an acceleration of the mixing process. Also, excess swirl might cause the overlap of the sprays and increase in unburned hydrocarbon emission [3]. Swirl increases the ratio of ignitable mixture at the ignition point and reducing the soot generation [4].

There are three motions inside the engine cylinder from which the engine flow pattern is formed. The first motion is the large re-circulating motion, which has a toroidal vortex structure and its axis of rotation at a right angle to the cylinder axis. This motion created as a result of the deflection of the induced jet from the inlet valve on the cylinder wall and the piston face. The second motion is the swirling flow that takes the form of a forced vortex around the cylinder axis. It is usually created as a result of a tangentially approaching inlet manifold. Also masking off or shrouding part of the peripheral of the inlet valve open area creates a swirling motion during the suction stroke. The third



motion is the squish flow, which is only created during the compression stroke. It is generated in the form of a radial inward or transverse gas motion that occurs near the end of compression stroke due to presence of a cup in the piston or cylinder head with wedge shape [5].

The combustion system of an internal combustion engine is usually designed for a certain working condition, the engine load or speed changes, then the designed parameters will not match better any more. For example, the combustion system of a diesel engine is designed basically on full load condition; the engine's fuel economy will be poorer. A variable swirl system can change the situation and meet the combustion's need of swirl in broader operating conditions. If a variable swirl system is applied, when the engine works under full load condition the inlet swirl will be decreased so that the charging efficiency is increased, and under the opposite condition of partial load, the inlet swirl will be enhanced at a little expense of charge. In this way, engine combustion is thus improved. So, variable swirl can improve engine performance.

Combustion and emissions of diesel engine are largely depend upon geometry of combustion chamber as well as fuel spray and mixing process [6]. The performance of engine with biodiesel has been investigated for collective effect of injection pressure, timing and geometry of combustion chamber by Jaichandar and co-workers [7, 8], the baseline engine and toroidal re-entrant combustion chamber was compared and observed that brake thermal efficiency was improved whereas brake specific fuel consumption decreased in case of toroidal re-entrant combustion chamber as compare to baseline engine. CFD software was used by Feng and co-workers [9] to match the conical spray with swirl-chamber scheme for small single-cylinder diesel engines and reported that in prototype engine; fuel economy can be improve with the application of the conical spray.

In some recent researches it is reported that favourable fuel air equivalence ratio distribution can be possible with special piston cavity that guides the airflow [6]. Geometric arrangement for the new natural gas DI engine and the influence of mixing of air-fuel inside cylinder with combustion chamber geometry, injection parameters, type of injector and cylinder head shape on has been discussed by Yadollahi and Boroomand [10]. The air-fuel mixing and combustion both are governed by in-cylinder air motion for diesel engines and generally characterized by swirl and turbulence [11]. The intake port design plays the major roll for swirl motion and hence improved combustion can be achieved by good intake port design [12]. The re-entrant combustion chamber geometries have been observed with complex turbulent flow field at the end of compression due to swirl-squish interaction [13, 14].

It was observed from the literature that the intake swirl significantly affected the engine performance. Therefore, in the present study, cylinder head of an existing DI diesel engine (435 CC and 7 HP rated power) was modified to achieve optimized intake swirl in order to enhance its performance. Also, the performance of diesel engine with old head and modified head was compared for different operating conditions.

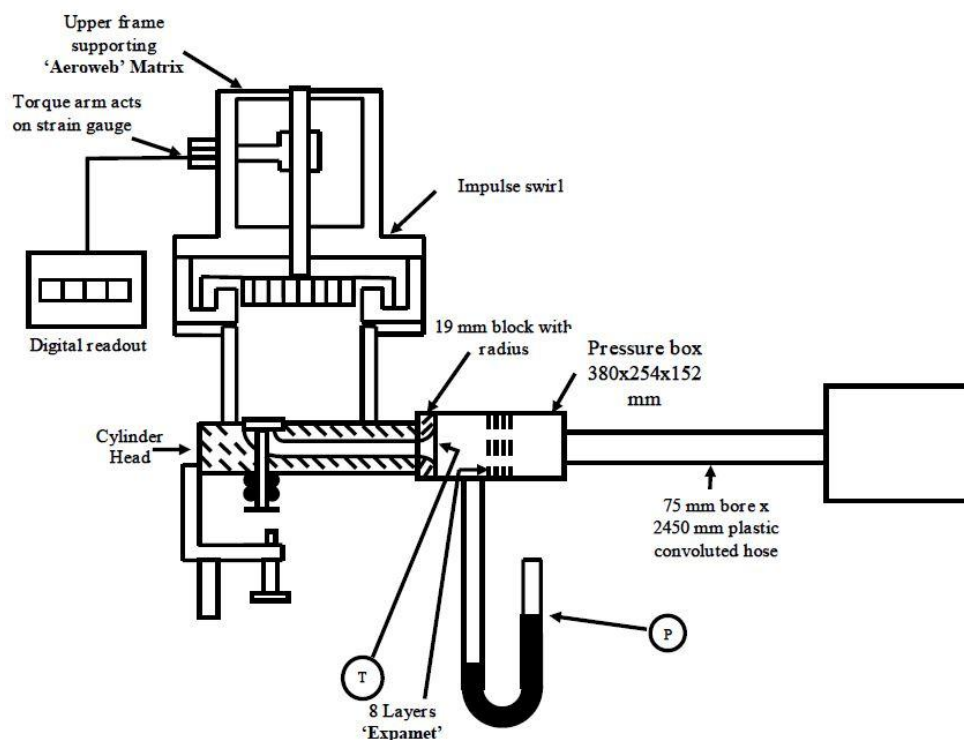
## 2. Experimental details

Engine test setup consists of DI diesel engines, eddy current dynamometer, control panel, smoke meter and Nox analyzer. The specification of engine is as follows. Number of cylinders = 1, Bore  $\times$  Stroke = 86 mm  $\times$  75 mm, Swept volume = 435 CC, Compression ratio = 18:1, Rated power = 7.5 HP @ 3600 rpm, Maximum torque = 18 Nm @ 2400 rpm, Low idle engine speed = 1150 $\pm$ 50 rpm, High idle engine speed = 3850 $\pm$ 50 rpm. The engine was coupled with the dynamometer along with the well-instrumented test bed and control panel. Engine performance has been taken over the rage of 1600 to 3600 rpm and various performance parameters have been recorded during full throttle performance test. Engine testing was conducted with different fuel injection (fuel supply) to study the effect of fuel supply on engine performance. In addition, engine testing was conducted for different power output.

On the basis of the literature review following methodology has been selected to optimize the performance of the engine for the better performance within the controlled emission. For the enhancement of the performance of the base line engine, present work is more concentrated on the optimization of intake swirl within the cylinder and some modification on the inlet port to increase the volumetric efficiency of the engine.

- Modification on intake manifold geometry and inlet path to enhance the performance.
  - Simulation to predict the performance for the modification suggested.
  - Validation of the simulation result by experimental performance results.
  - Selecting final configuration on the basis of performance comparison.
- The detail of simulation and its validation is given in author's previous article [15].

### 3. Swirl test rig



**Figure 1.** Schematic of swirl test rig

Figure (1) shows the schematic arrangement of the flow rig used by Ricardo for the measurement of swirl. The cylinder head or wooden model is fitted to the outlet of the pressure box usually with a bell mouthed block interposed having the smaller diameter arrange to line up with and match accurately the entry end of the head port. At times an actual inlet manifold may be used instead when its shape is such that it could affect swirl generation. Normally the cylinder head is inverted for convenience, and a cylinder liner of the correct diameter for the engine for which the head has been design clamped to its top and correctly orientated with respect to the valve. The desk liner is made 1.75 times the cylinder bore long. When merely determining flow resistance the impulse swirl meter is removed.

When testing inlet ports, air is blown from pressure box through the port and valve into the cylinder liner. When flowing exhaust valve and port configurations, air is sucked from the cylinder through the valve into the pressure box. Means are provided whereby the valve under test, fitted with a light spring, is lifted in a series of accurately determined lifts from its seat up to the maximum designed lift. At each lift the flow from the fan, or to it for exhaust valves, is adjusted so that the pressure box pressure is maintained at 254 mm of water above atmospheric for an inlet port, and below in case of exhaust valve and port. With the flow steady the air meter pressure drop, downstream pressure and

temperature are measured. Thus the flow is determined. In order to make comparison for different designs and engine sizes these lift/flow figures are often converted into flow coefficients.

### ***Assumptions***

- 1) Flow is adiabatic and incompressible and laminar.
- 2) The moment of momentum is conserved (there are no viscous losses in the cylinder).
- 3) Volumetric efficiency of 100% per cent.
- 4) If a paddle wheel is used, the swirl is a forced vortex.
- 5) If a paddle wheel is used, the axial velocity within the cylinder is uniform.
- 6) The pressure drop across the port is constant during induction.
- 7) Flow only occurs between inlet valve opening and closing, and hence flow rate at any time is dependent only on valve lift.

### **4. Results and discussion**

The circular intake port has been modified by rectangular port with intake port area of 1080 mm<sup>2</sup> as well as the helical angle of the intake path is reduced to optimize the intake swirl. To study the effect of helical inlet manifold with increased area, the swirl testing was conducted for both old cylinder head and modified cylinder head. Tables (1) and (2) shows the swirl measurement parameters for both the cylinder head at different valve lifts. It can be seen from Tables (1) and (2) that the paddle wheel rpm for modified cylinder head is lower than the old cylinder head due to modification in intake swirl which also reduce swirl ratio at each valve lift rather we can say optimized swirl ratio for higher power output.

**Table 1.** Swirl test on old cylinder head

Valve Lift Mm	L/D	Tank Pr. Drop Pa	Paddle Speed RPM	Swirl Ratio	Flow	Discharge	Flow l/s
8	0.2424	2500	3110	2.11	0.371	0.483	21.56
7	0.2121	2500	3120	2.21	0.357	0.537	20.71
6	0.1818	2500	2910	2.15	0.341	0.609	19.83
5	0.1515	2500	2478	2.02	0.309	0.67	17.94
4	0.1212	6000	2850	1.67	0.276	0.76	25.34
3	0.0909	6000	2292	1.71	0.216	0.804	19.8
2	0.0606	6000	1786	1.48	0.196	1.107	17.91
1	0.0303	6000	0	0	0.16	1.835	14.62
<b>Rated Engine RPM</b>		<b>Valve Seat Dia.</b>	<b>Ambient Temp.</b>	<b>Bore</b>	<b>Stroke</b>		<b>Max. Valve lift</b>
<b>3600</b>		<b>33 mm</b>	<b>230°C</b>	<b>86 mm</b>	<b>75 mm</b>		<b>7.7 mm</b>

It is reported by Payri et al. [3] that the better performance not always results from higher swirl intensity. In addition, the excessive swirl causes the overlap of the spray and an increase in unburned hydrocarbon emission. The very-high speed intake air may also cause reduction in volumetric efficiency. Therefore, an optimized swirl intensity may be required for the improvement of engine performance [3]. Since, higher as well as lower swirl reduces engine power output. It was also observed that the swirl ratio is reduced by around 30% in the higher valve lift with the modified cylinder head, which is good for the engine to achieve higher brake power. In addition, it was also observed that the flow coefficient

increased by 30% with modified cylinder head. The increment is due to the greater flow through the inlet valve, which is due the increased port area. It shows that the filling and discharge of the modified cylinder head is more compared to old cylinder head. Also, swirl speed of modified cylinder head is lower, which is good for the engine performance. Since it increases the volumetric efficiency. The swirl ratio with lower valve lifts does not influence the engine performance because engine performance should be taken only with the maximum valve lift.

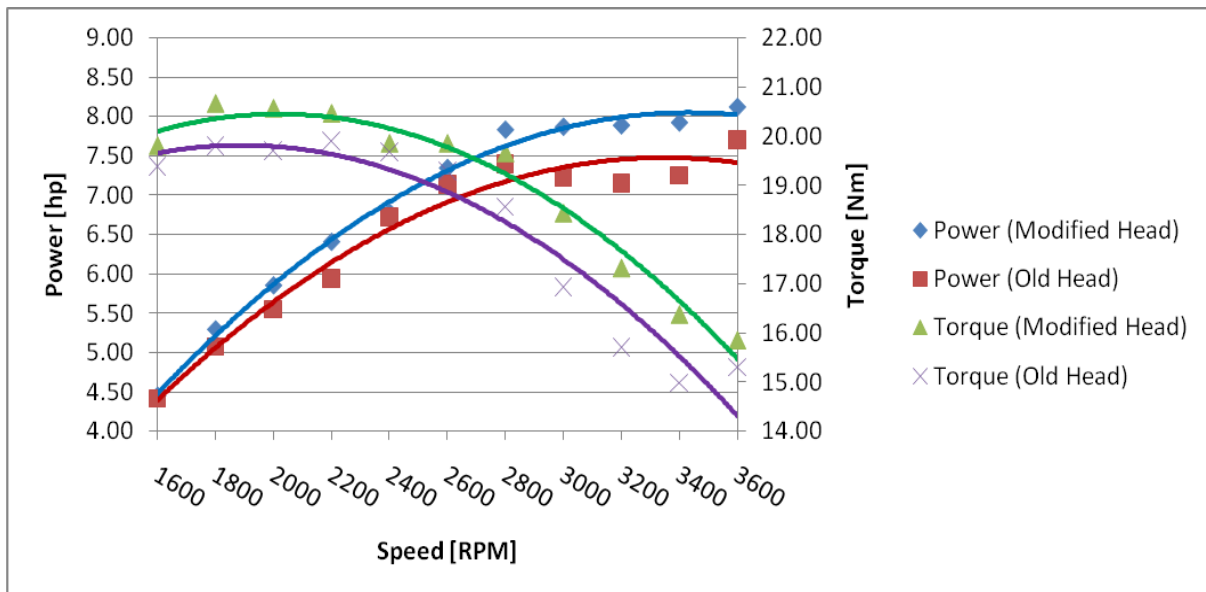
**Table 2.** Swirl test on modified cylinder head.

Valve Lift Mm	L/D	Tank Pr. Drop Pa	Paddle Speed RPM	Swirl Ratio	Flow	Discharge	Flow l/s
8	0.2424	2500	2880	1.701	0.4435	0.46	24.1
7	0.2121	2500	2750	1.721	0.4175	0.5	22.7
6	0.1818	2500	2480	1.681	0.3863	0.54	21
5	0.1515	2500	2370	1.852	0.3348	0.57	18.2
4	0.1212	6000	2100	1.694	0.3164	0.59	17.2
3	0.0909	6000	1850	1.7	0.2777	0.62	15.1
2	0.0606	6000	1860	2.099	0.2262	0.54	12.3
1	0.0303	6000	1930	2.35	0.2097	0.36	11.4
<b>Rated Engine RPM 3600</b>		<b>Valve Seat Dia. 33 mm</b>	<b>Ambient Temp. 230°C</b>	<b>Bore 86 mm</b>	<b>Stroke 75 mm</b>	<b>Max. Valve lift 7.7 mm</b>	

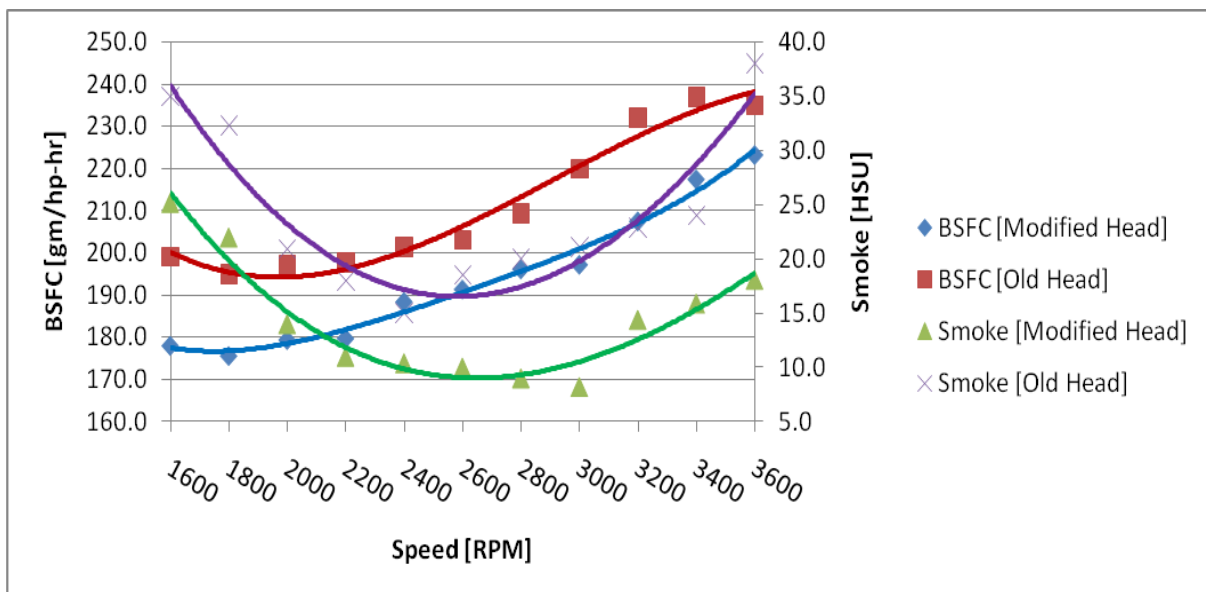
Figure (2) shows the performance of diesel engine with modified and old cylinder heads for some operating condition (no change in fuel injection). First, the performance of engine was recorded with old cylinder head for its rated power of 7.5 HP. Later, the performance of engine was recorded with modified cylinder head at the same operating conditions. Brake power and torque was observed to increase by 6% with modified cylinder head under same fuel injection. Results show that the modification in inlet manifold geometry i.e. increased in port area and optimized swirl, increases the volumetric efficiency and improves the combustion consequently improve performance output. With optimized swirl the complete burning of the fuel may takes place which ultimately improves the combustion process and overall heat release pattern will be best at this point so the maximum cylinder pressure will be highest ultimately increases the bmep which ultimately increases the Torque.

Figure (3) shows the BSFC and Smoke results for both old and modified cylinder head. BSFC is defined as the amount of fuel required producing unit power. Therefore, it can be concluded with the same quantity of fuel injection, the engine with modified cylinder head gives better performance since BSFC with modified cylinder head is much lesser compared with old cylinder head. This concludes that engine with modified cylinder head requires less quantity of fuel to produce same amount of power. On the other hand, smoke is also very less as compared to the results with old cylinder head due to significant improvement on combustion stability. The highest swirl level produced the lowest SFC, the lowest engine out HC, and consequently highest combustion efficiency.

Figure (4) shows the exhaust temperature for both old and modified cylinder heads. The exhaust temperature for both modified and old cylinder head was also compared. It as observed that the exhaust temperature with modified head was reduced by 30% at rated speed. Which shows that optimized swirl reduces the exhaust temperature of engine. The reduction in exhaust temperature is due to the reason that increasing swirl inevitably increases the convective heat transfer coefficient from the gas to the cylinder wall. This is shown by a reduction in exhaust temperature and an increase in heat transfer coolant. So, with optimized swirl the exhaust temperature can be reduced.

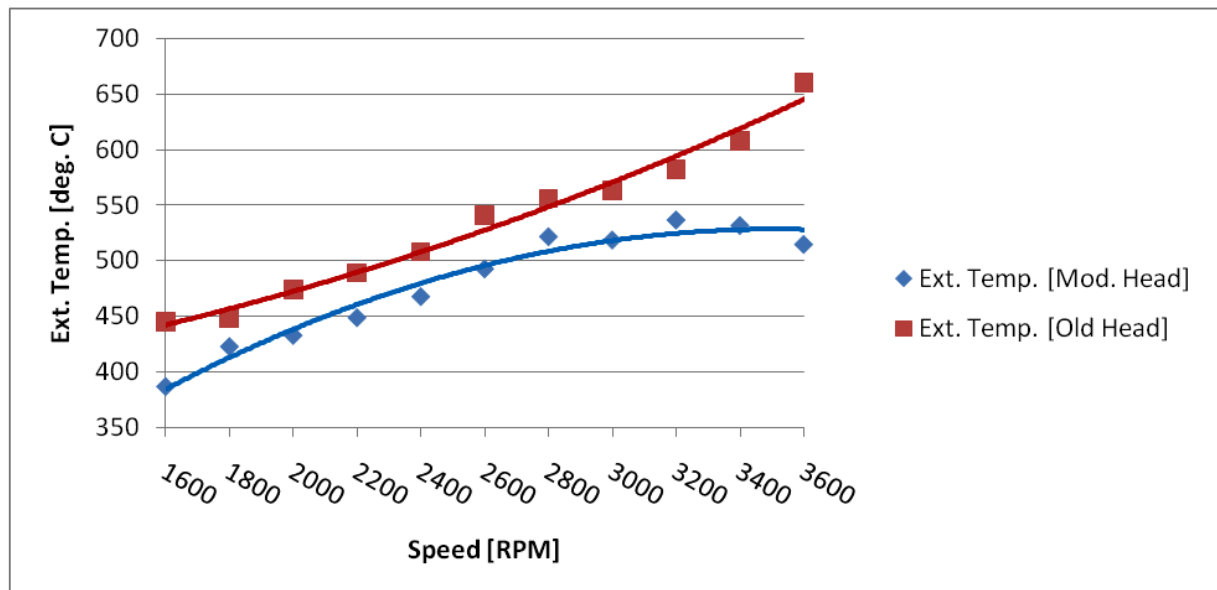


**Figure 2.** Comparison of engine performance

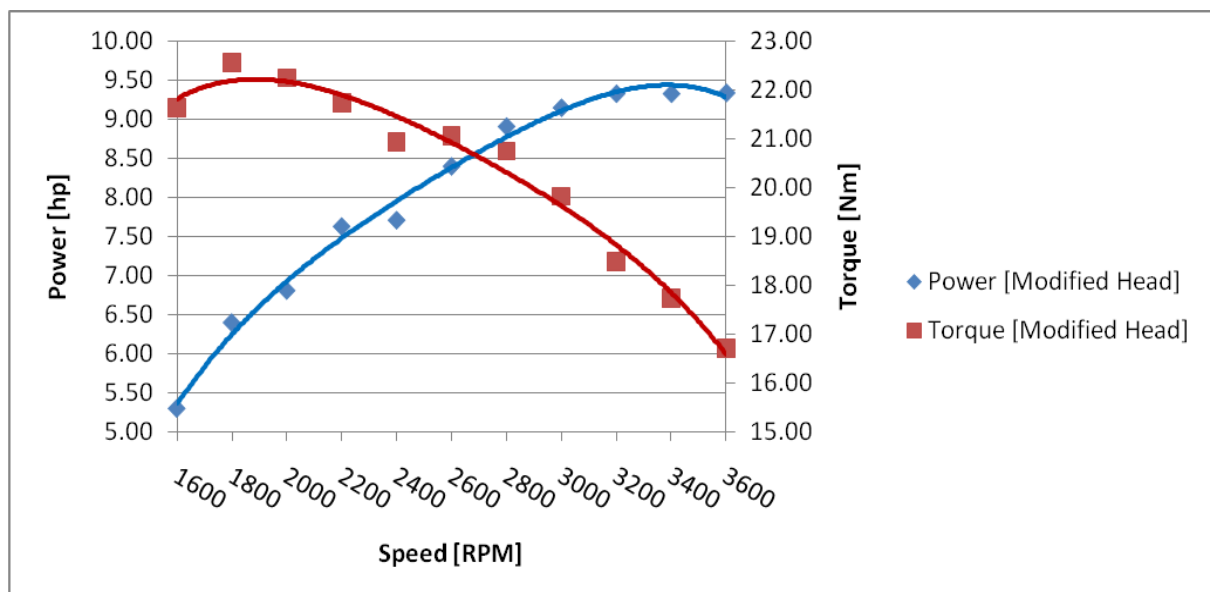


**Figure 3.** Comparison of BSFC and smoke

The performance of engine with both old and modified cylinder head with increased fuel injection was already presented in author’s previous article [6]. The engine was tested for power output of 8.5 HP. Figure (5) shows the performance of diesel engine with modified cylinder head for 9 HP power output. It was observed that for 8.5 HP power output [6] with old cylinder head the smoke was very high. It means with old cylinder head, it is not possible to achieve 9 HP with old cylinder head. Whereas with the modified cylinder head, the brake power of 9 HP can be easily achieved. Therefore, the results suggest that with the modified cylinder head the engine performance is very good with better Torque, Power, BSFC and Volumetric Efficiency.



**Figure 4.** Exhaust temperatures for old and modified cylinder heads



**Figure 5.** Engine performance for highest output

## 5. Conclusions

Experimental studies on effect of swirl on diesel engine performance led to the following conclusions:

- Increase in inlet port area increases the flow rate and filling and hence results in higher volumetric efficiency consequently the power output of engine increased.
- Modification in inlet helical path results in optimized intake swirl, which results in good combustion efficiency consequently better BSFC and the BMEP.



- Optimized intake swirl also reduces the exhaust temperature.
- Present study concluded that the intake swirl should not be too low or too fast. The better engine performance necessitates the optimized intake swirl.

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