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Research Article

Performance Evaluation of an IC Engine in the Presence of a C-D Nozzle in the Air Intake Manifold

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Abstract

The present day energy crisis and ever increasing demands of energy in addition to global pollution brought us into a situation where there is an urgent need for energy conservation, efficient utilization and eco-friendly techniques to be implemented in day to day use. These needs lead us to an idea of modified design in a CI engine without any additional energy requirement and with no complicated variations in design. There are various other methods to improve the efficiency of engine such as super charging, turbo charging, varying stroke length, varying injection pressure, fuel to air ratio, additional strokes per cycle and so on. Many of them require additional design (stroke length, injection pressure etc.,) and some of them load to increase environmental effect. Here in this project affords were made to increase the velocity (physical parameter) of air entering the inlet manifold of the engine by inserting a convergent divergent nozzle at the inlet manifold. There by increasing the mixture quality of air & fuel in the combustion chamber before the initialization of ignition. The engine load tests were carried out at different loads, variation of different parameters with load was plotted. The nozzle setup was installed and then again load test were carried out at different loads and the values were plotted in comparison to former values. The emissions from the engine were also tested before and after the setup installation to estimate the environmental effects. The comparative results were also plotted.

Keywords: *I.C Engine, diesel engine, Performance characteristics, Emission control.*

1. Introduction

A diesel engine (also known as a compression-ignition engine) is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel that has been injected into the combustion chamber. The diesel engine has the highest thermal efficiency of any regular internal or external combustion engine due to its very high compression ratio. Low-speed diesel engines (as used in ships and other applications where overall engine weight is relatively unimportant) can have a thermal efficiency that exceeds 50%. Diesel engines are manufactured in two-stroke and four-stroke versions. They were originally used as a more efficient replacement for stationary steam engines. Since the 1910s they have been used in submarines and ships. Use in locomotives, trucks, heavy equipment and electric generating plants followed later. In the 1930s, they slowly began to be used in a few automobiles. Since the 1970s, the use of diesel engines in larger on road and off-road vehicles in the USA increased. As of 2007, about 50% of all new car sales in Europe are diesel.

As of 2013, many common rail and unit injection systems already employ new injectors using stacked piezoelectric wafers in lieu of a solenoid, giving finer control of the injection event (M.chandramouli *et al*, 2009). Variable geometry turbochargers have flexible vanes, which move and let more air into the engine depending on load. This technology increases both performance and fuel economy. Boost lag is reduced as turbo impeller inertia is compensated for. Accelerometer pilot control (APC) uses an accelerometer to provide feedback on the engine's level of noise and vibration and thus instruct the ECU to inject the minimum amount of fuel that will produce quiet combustion and still provide the required power (especially while idling). The next generation of common rail diesels is expected to use variable injection geometry, which allows the amount of fuel injected to be varied over a wider range (Mohan raj *et al*, 2009), and variable valve timing (see Mitsubishi's 4N13 diesel engine) similar to that on petrol engines. Particularly in the United States, coming tougher emissions regulations present a considerable challenge to diesel engine manufacturers. Ford's HyTrans Project has developed a system which starts the ignition in 400 ms, saving a significant amount of fuel on city routes, and there are other methods to achieve even more efficient combustion, such as homogeneous charge compression ignition, being studied. Japanese and Swedish vehicle manufacturers are also developing diesel engines that run

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on dimethyl ether (DME) (Asad *et al*, 2009). Some recent diesel engine models utilize a copper alloy heat exchanger technology to take advantage of benefits in terms of thermal performance, heat transfer efficiency, strength/durability, corrosion resistance, and reduced emissions from higher operating temperatures. M.Chandramouli *et al*. (M.chandramouli *et al*, 2009) selected a four stroke compression ignition engine with power 9 H.P and rated speed 1500 rpm to investigate the performance characteristics. The swirl motion of the air is an important parameter in optimizing the performance of the engine. In order to increase the air velocity in the inlet manifold a convergent-divergent nozzle is used. The rise in velocity with the use of nozzle generates turbulence at the exit of the manifold which facilitates for better combustion of injected fuel. The Performance characteristics were calculated with nozzle and without nozzle in the inlet manifold and compared (V.CVS Phaneendra *et al*, 2009).

A de Laval nozzle (or convergent-divergent nozzle, CD nozzle) is a tube that is pinched in the middle, making a carefully balanced, asymmetric hourglass-shape. It is used to accelerate a hot, pressurized gas passing through it to a supersonic speed, and upon expansion, to shape the exhaust flow so that the heat energy propelling the flow is maximally converted into directed kinetic energy. Because of this, the nozzle is widely used in some types of steam turbines, and is used as a rocket engine nozzle. It also sees use in supersonic jet engines (Ganeshan).

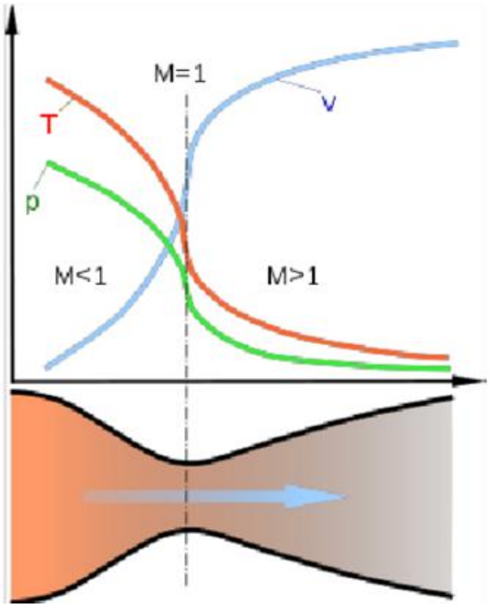

Fig.1 De-laval nozzle showing approximate velocity (v), together with the effect on temperature (T) and pressure (P).

Its operation relies on the different properties of gases flowing at subsonic and supersonic speeds. The speed of a subsonic flow of gas will increase if the pipe carrying it narrows because the mass flow rate is constant. The gas flow through a de Laval nozzle is isentropic (gas entropy is nearly constant). At subsonic flow the gas is compressible; sound, a small pressure wave, will propagate through it. At the throat, where the cross sectional area is a minimum, the gas velocity locally becomes sonic (Mach number = 1.0), a condition called choked flow. As the nozzle cross sectional area increases the gas begins to expand and the gas flow increases to supersonic velocities where a sound wave will not propagate backwards through the gas as viewed in the frame of reference of the nozzle (Mach number > 1.0).

A de Laval nozzle will only choke at the throat if the pressure and mass flow through the nozzle is sufficient to reach sonic speeds, otherwise no supersonic flow is achieved and it will act as a venturi tube; this requires the entry pressure to the nozzle to be significantly above ambient at all times (equivalently, the stagnation pressure of the jet must be above ambient).

2. Analysis of gas flow in De Laval nozzles.

The analysis of gas flow through de Laval nozzles involves a number of concepts and assumptions:

- For simplicity, the gas is assumed to be an ideal gas. The gas flow is isentropic (i.e., at constant entropy). As a result the flow is reversible (frictionless and no dissipative losses), and adiabatic (i.e., there is no heat gained or lost).
- The gas flow is constant (i.e., steady) during the period of the propellant burn.
- The gas flow is along a straight line from gas inlet to exhaust gas exit (i.e., along the nozzle's axis of symmetry)
- The gas flow behavior is compressible since the flow is at very high velocities (Mach number > 0.3).

2.1 Exhaust gas velocity

As the gas enters a nozzle, it is traveling at subsonic velocities. As the throat contracts down the gas is forced to accelerate until at the nozzle throat, where the cross sectional area is the smallest, the linear velocity becomes sonic. From the throat the cross sectional area then increases, the gas expands and the linear velocity becomes progressively more supersonic. The linear velocity of the exiting exhaust gases can be calculated using the following equation

$$\upsilon = \sqrt{\frac{TR}{M}\frac{2\gamma}{\gamma-1}[1-\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}}]}$$

Where

υ = Exhaust velocity at nozzle exit m/s

T= absolute temperature of inlet gas, K

R= Universal gas law constant=8314.5 j/(kmol-k)

M= the gas molecular mass, kg/kmol

γ = isentropic expansion factor

C_p= specific heat of the gas at constant pressure

C_v= specific heat of the gas at constant volume

P= absolute pressure of exhaust gas at nozzle exit, Pa

3. Design of the nozzle

$h_{water\ column} = 3\ cm = 0.03\ m$
$h_{air\ column} = 3\ cm\ \times 862 = 0.03\ \times 862\ m$
$P_1 = 1.013\ bar = 1\ atm, D_1 = 42\ mm, T_1 = 300K$
$Q_1 = \frac{P_1}{RT_1} = \frac{1.013\ \times 10^2}{0.287 \times 300} = 1.176\ kg/m^3$
$A_1 = A = \frac{\pi}{4}(0.048)^2 = 1.385442 \times 10^{-3} m^2$
$C_1 = \sqrt{2gh1} = \sqrt{2 \times 9.81 \times 862 \times 0.03} = 22.524\ m/s$
To obtain a velocity say 300 m/sec, we considered for throat velocity & design the throat Area Consider C_2=300 m/sec
$C_1{}^2 - C_2{}^2 = 2000(h1 - h2) = 2000Cp(T1 - T2)$

$T_2 = 255.25\ K$
$we\ know\ that (\frac{T_1}{T_2}) = (\frac{P_1}{P_2})^{\frac{\gamma-1}{\gamma}}$
$P_2 = 0.5737\ bar$
$Q_2 = \frac{P_2}{RT_2} = \frac{0.5737\ \times 10^2}{0.287 \times 255.25} = 0.78313 \frac{kg}{m^3}$
According to law of conservation of mass,
Max flow rate $m_1 = Q_1 A_1 C_1 = 0.036697 \frac{kg}{s}$
$m_2 = Q_2 A_2 C_2 = 0.78313\ \times A_2 \times 300 \frac{kg}{s}$
$A_2 = 1.562\ \times 10^{-4} m^2$
$D_2 = 14.10\ mm$
Due to machining problems D_2 is taken as 15 mm. therefore velocity is reduces by 1.1317 times.

4. Experimental Set up

In Direct injection diesel engines fuel is injected directly onto the compressed air and gets mixed depending upon the motion of the air in the chamber.

Fig.2 Experimental set up test rig.

Air is directed into the cylinder through the inlet manifold and this air flow is one of the important factors controlling the combustion process. It governs the fuel-air mixing and burning rates in diesel engines. Air enters the combustion chamber of an I.C engine through the intake manifold with high velocity. Then the kinetic energy of the fluid results in turbulence and causes rapid mixing of fuel and air, if the fuel is injected directly into the cylinder. The increased turbulence causes better cooling of the cylinder surfaces thereby reducing the heat loss to the surroundings. The heat from the cylinder walls gets absorbed by the air supplied during suction and used for reducing the delay period thereby increasing the thermal efficiency of the engine.

Engine specifications are as shown.

Cylinder	: 2 line
Bore	: 87.5 mm
Stroke	: 110 mm
RPM	: 1500
BHP	: 10 HP
Fuel	: HS Diesel
Sp.GR	: 0.833
Cal.Value	:10,833 k.cal/kg

In the present work the intake manifold of the CI Engine was modified by using nozzle with a throat. The Performance characteristics and the emission levels were verified by using manifolds with nozzle. The time taken to fill the chamber would indeed depend on the inlet dimensions. There is enough time in each inlet stroke to allow the cylinder charge and atmosphere to gain a state of equilibrium, setting aside inlet rarefactions due to inlet obstacles, or compressions due the valve for 1 second might let some air in, but (depending on the opening, and a couple of other things), the vacuum would be decreased. The amount by which the vacuum decreases will depend on how much air got back into the inlet valve open longer, having denser air or large ports will allow more air into the cylinder

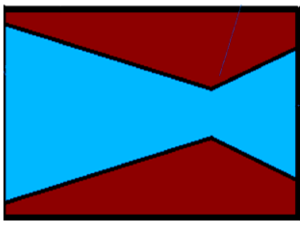

Fig.3 Schematic diagram of nozzle

Fig.4 Inlet manifold showing nozzle.

The throat of the nozzle is 15mm, length of convergent section is 80mm and the length of the divergent section is 42mm and the outlet diameter of the nozzle is 28mm. The nozzle is manufactured by using nylon as material.

5. Results

The results shown in table 1 are obtained by conducting load test here the test is carried by increasing the load on the twin cylinder diesel engine it follows a trend that as the load on the engine increases the fuel consumption increases and the exhaust temperature also increases as the load on the engine increases and this trend is tabulated above in table 1. With the help of above tabulated results all the terms are calculated and they are tabulated in the table 2.

Table.1 Results with normal manifold

Voltage (volts)	Current (amp)	Time for 10 cc of fuel consumption(s)	Temperature(^{0}C)					
			T_1	T_2	T_3	T_4	T_5	T_6
204	0	39	28	38	28	39	90	75
216	5	26	28	38	27	39	127	109
218	7	24'89	28	39	28	39	133	114
221	9	23'41	28	39	29	38	141	120
224	11	22'40	28	39	28	39	147	126
227	13	20'88	28	39	28	39	153	131
229	15	20'59	28	40	28	39	158	135
230	17	18'31	28	40	28	38	165	141
232	19	17'59	28	41	28	39	174	147

Table.2 Performance characteristics of diesel engine with normal manifold

S.No	Item	Units	Loads %					
			0	20	40	60	80	100
1	Brake power	KW	--	1.35	2.48	4.29	5.51	6.7
2	Indicated power	KW	1.2	2.55	3.68	5.49	6.71	7.9
3	Total fuel consumption	KW/H	0.768	1.153	1.28	1.49	1.7	1.8
4	Brake specific fuel consumption	Kg/KWH	--	0.854	0.516	0.339	0.309	0.286
5	Air fuel ratio		59.4	39.62	36.28	31.48	26.8	21.8
6	Brake thermal efficiency	%	0	9.29	15.63	23.46	25.68	27.1
7	Mechanical efficiency	%	0	52.94	67.39	78.14	82.11	84.3

Latter the experimentation is carried out with inserting a nozzle in the air in let manifold of the twin cylinder diesel engine and again the load test is carried on the same engine and the obtained values are tabulated in the table.3 and are as follows:

Table.3 Results with nozzle in the manifold

Voltage (volts)	Current (amp)	Time for 10 cc of fuel consumption(s)	Temperature(^{0}C)					
			T_1	T_2	T_3	T_4	T_5	T_6
210	0	36.75	28	37	28	32	92	80
217	5	28.13	28	39	28	32	128	111
220	7	26.5	28	41	28	32	135	116
225	9	24.25	28	41	28	32	145	125
227	11	22.47	28	42	28	32	150	128
228	13	20.78	28	43	28	33	156	132
229	15	19.5	28	44	28	33	163	139
230	17	18.09	28	44	28	33	173	144
231	19	18	28	45	28	33	183	152

Table.4 Performance characteristics of diesel engine with nozzle in the manifold

S.No	Item	Units	Loads %					
			0	20	40	60	80	100
1	Brake power	KW	--	1.35	2.53	4.29	5.48	6.43
2	Indicated power	KW	1.3	2.65	4.42	5.59	6.78	7.7
3	Total fuel consumption	KW/H	0.715	1.065	1.236	1.43	1.61	1.76
4	Brake specific fuel consumption	Kg/KWH	--	0.788	0.488	0.32	0.304	0.286
5	Air fuel ratio		59.4	39.62	36.28	31.48	26.8	23.4
6	Brake thermal efficiency	%	0	10.09	16.2	24.1	25.77	27.7
7	Mechanical efficiency	%	0	50.9	66.05	76.74	80.8	84.3

After conducting the load test on the twin cylinder diesel engine by applying the electric loading system following results are obtained as followed.

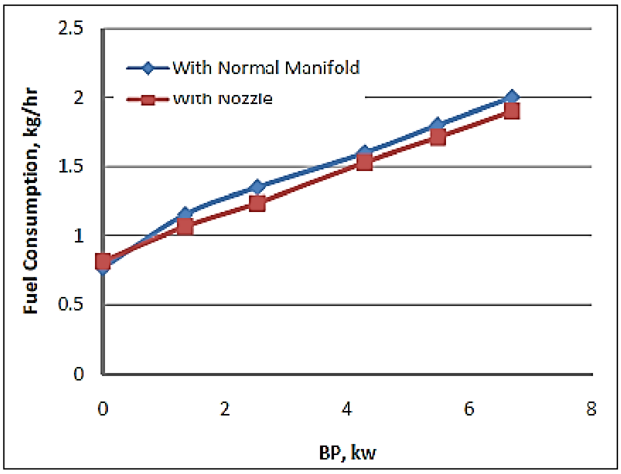

Fig.5 Brake power vs Fuel consumption.

Fig.5 shows the graph drawn in between Break power v/s Fuel consumption which shows the variations with normal manifold and with the nozzle. As the break power increases the fuel consumption increases at no load condition the fuel consumption is almost same in both the cases but as the load increases the fuel consumption increases and the variation can be observed in the above graph.

Fig.6 shows the graph which is drawn in between the Break power v/s Break specific fuel consumption (BSFC) which shows a better trend with normal manifold and with the nozzle at the manifold. From the observations from the graph it is observed that at lower loads the difference in BSFC with nozzle and without nozzle is more but as the load increases the BSFC is almost equal in both the cases.

Fig.7 shows the graph which is drawn in between the break power and thermal efficiency by comparing the results of that of the normal manifold and to that of the nozzle in the inlet manifold. On comparing the above graph it is observed that the thermal efficiency increases with inserting the nozzle in the inlet manifold.

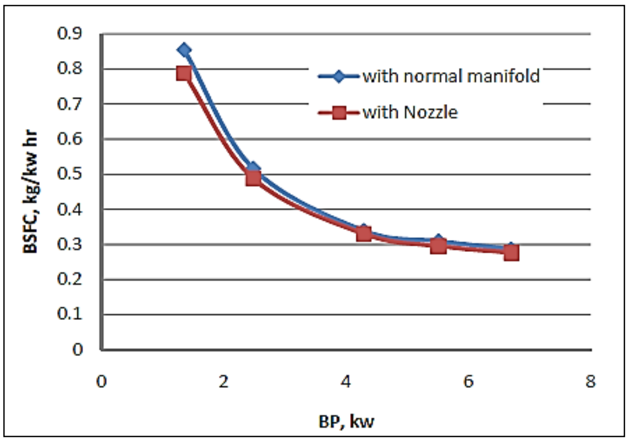

Fig. 6 Brake power vs specific fuel consumption.

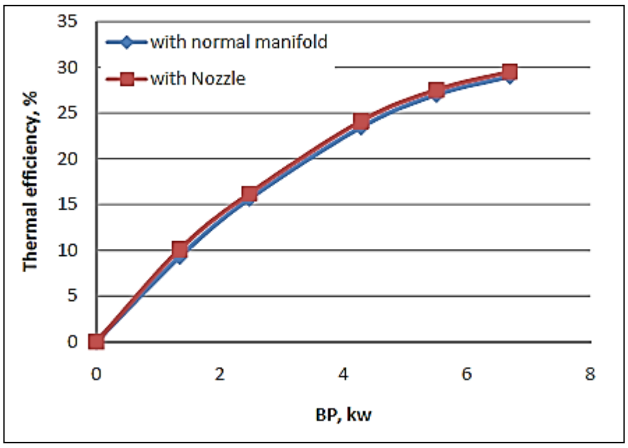

Fig.7. Brake power vs Thermal efficiency

Fig.8.shows the graph which is drawn in between the break power and exhaust gas temperature by comparing the results of hat of the normal manifold and to that of the nozzle in the inlet manifold. On comparing the above

graph it is observed that for nozzle the exhaust gas temperature is more.

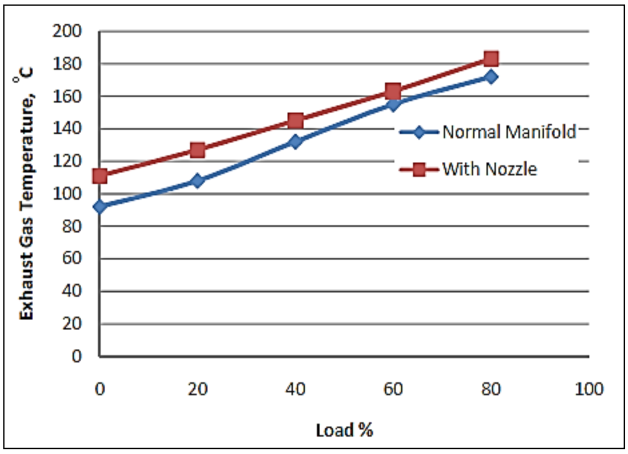

Fig.8. Load vs Exhaust gas temperature

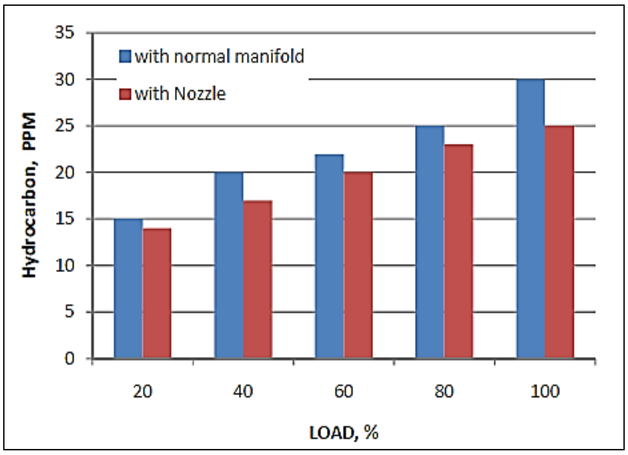

Fig. 9 Load vs Hydrocarbon emissions

Fig.9 shows the graph drawn between the load and the hydro carbon emissions from the twin cylinder diesel engine which is tested with that of the nozzle and to that of that of the normal manifold. It is observed from the graph that the emissions are decreased by inserting the nozzle in the air inlet manifold.

6. Conclusions

By comparing the various observations before and after the insertion of nozzle at the inlet manifold, we concluded that there is an increase in thermal efficiency, decrease in specific fuel consumption and also considerable decrease in environmental effecting gases that are releasing from the CI engines which leads to better environment. Evaluation of performance characteristics at all loads was done in the present work and the engine showed better performance at 60% load.

- Specific fuel consumption is reduced by 5.6%
- Exhaust gas temperature is increased by 3.16%
- Break thermal efficiency is increased by 2.72%
- Mechanical efficiency is reduced by 1.79%
- CO emissions are reduced by 0.5%
- Hydro carbon emissions are reduced by 10%

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