Experimental Investigation and Performance of Diffuser Type Exhaust Manifold in Single Cylinder CI Engine with Various Injection Pressure

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ABSTRACT

The combustion process in the internal combustion engine is varying cycle to cycle while changing load, speed, etc. It is difficult to achieve better fuel economy and reduce pollution emissions. Literature shows that a taper, straight and lower thermal inertia exhaust manifold gives better mass conservation, fuel economy and engine efficiency.Optimum injection pressure will reduce exhaust pollution and gives better fuel economy. Back pressure and injection pressure on engine having a strong influence on engine performance .Back pressure need to be minimized by using divergent shape exhaust manifold and optimum injection pressure can be achieved by experimentally .Therefore one of the operating parameters affecting the performance and emissions of a Diesel engine is the fuel injection pressure also. Most of the injection pressure studies have been performed with direct injection (DI) Diesel engines. However, the injection pressure in indirect injection (IDI) Diesel engines also affects the emissions, especially CO_2 and smoke.

Keyword: *- Diffuser Shape Exhaust Manifold, Injection Pressure, Smoke, Performance, Emissions*

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1. INTRODUCTION

In automotive engineering, an exhaust manifold collects the exhaust gases from multiple cylinders into one pipe. Exhaust manifolds are generally made from simple cast iron or stainless steel units which collect engine exhaust gas from multiple cylinders and deliver it to the exhaust pipe. [2]

Great care must be taken while selecting the length and diameter of the exhaust pipe. Exhaust pipe are too large will cause the exhaust gas to expand and slow down, decreasing the scavenging effect. Exhaust pipes are too small will create exhaust flow resistance which utilize engine work to expel the exhaust gas from the chamber, it means reducing power and leaving exhaust in the chamber to dilute the incoming intake charge. [2]

The high pressure head is created by the large pressure difference between the exhaust in the combustion chamber and the atmospheric pressure outside of the exhaust system. This relatively low pressure in exhaust manifold helps to extract all the combustion products from the cylinder and induct the intake charge during the overlap period when both intake and exhaust valves are partially open. The effect is known as 'scavenging'. Length, Cross sectional area, and shaping of the exhaust ports and pipe works influences the degree of scavenging effect. [2]

1.1 A New Concept of Exhaust Manifold

The usual configuration for a converging diverging nozzle in which Gas flows through the nozzle from a region of high pressure (referred as the chamber) to one of low pressure (referred as the ambient). The chamber is usually big enough so that any flow velocities here are negligible. The pressure here is denoted by the symbol *pc*. Gas flows from the chamber into the converging portion of the nozzle, past the throat, through the diverging portion and then exhausts into the ambient as a jet. The flow accelerates out of the chamber through the converging section, reaching its maximum speed at the throat. The flow becomes decelerate through the diverging section and exhausts into environment. [3]

2. DESIGN OF DIFFUSER SHAPE EXHAUST MANIFOLD

The rate of area increase in a diffuser has a direct effect on the behavior of flow in the diffuser. If the rate of area increase is greater than that needed to keep the boundary layer energized and attached, the flow may be characterized by unsteady zone of stall. The turbulent mixing is no longer able to overcome the pressure force at all points in the flow and local separation occurs at some point. If the diffuser walls diverge rapidly, the flow will separate completely. The rate of area increase without stall for a diffuser depends on the characteristics of the flow at the entrance and on the length of the divergent section. [21]

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The ratio of length of diffuser and inlet diameter is $\frac{L}{D_{inlet}}$= 3 at 10° half cone angle without flow separation of gas. D_{inlet}= 28 mm, then, L = 84 mm. [21]The ratio of length of diffuser and inlet diameter is $\frac{L}{D_{inlet}}$ = 2 at 12.5° half cone angle without flow separation of gas. D_{inlet}= 28 mm, then, L = 56 mm. [21]

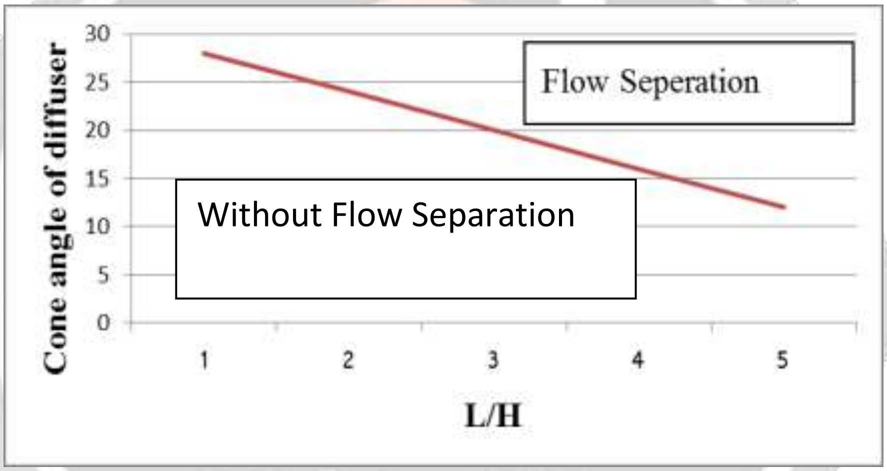

Fig1: Cone angles of Diffuser Vs L/H[21]

Table 1 Specification of exhaust manifold

Exhaust manifold	Conventional manifold	Diffuser shape manifold	
Material	Cast iron	Stainless steel	Stainless steel
Inlet diameter	28 mm	28 mm	28 mm
Outlet diameter	28 mm	57.50 mm	53 mm
Length	62.5 mm	84 mm	56 mm
Thickness	5 mm	5 mm	5 mm
Half cone angle	0°	10°	12.5°

2.1 Manufacturing of Exhaust manifold

Taper turning is a material removal process used for generating internal and external taper in circular bar. The cutting tool is rotated and moved vertically upward or downward and parallel or inclined to the job axis. Taper turning can be done on the interior surface of the internally boring part and also in exterior surface.

Fig2 : VMC taper turning operation

3. EXPERIMENTAL SETUP

The main aim of the experimentation is to check performance and emission characteristics of CI engine fuelled with diesel with small engine modification. The experimental work under this project consists of two phases, initial phase is experimental work to find out the effect of different engine loads, injection pressure on engine performance and emission from IC Engine. In second phase, engine exhaust manifold replace to the different angles diffuser type exhaust manifold and take the experiment with diesel.

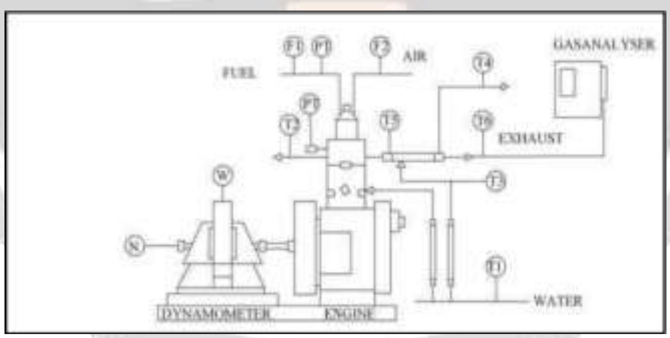

Fig3 : Schematic diagram of experimental setup[IC Engine Manual]

Table 2 List of sensors used in IC engine

Symbol	Sensors Name
F1 & F2	Flow sensor for fuel and air
W	Load sensor
N	Engine speed sensor
PT	Cylinder pressure & Injection pressure sensor
T 1-6	Temperature sensors

Schematic diagram of experimental setup is as shown in fig.3.1 The setup consists of single cylinder, four stroke, research engine, and this engine is connected to eddy-current type dynamometer for loading. The mode of operation in this engine can be changed from diesel to Petrol or from Petrol to Diesel with some needed changes. Different other instruments are provided to interface are airflow, fuel flow, temperatures and load measurement devices shown in table 2. For cooling water and calorimeter water flow measurement Rota meter is provided. For auto start of engine a battery, starter and battery charger is provided. Analysis software Engine-soft is provided for on line performance evaluation and lab view based Engine Performance. The test engine used in this experiment is as shown in fig.3.2

Fig4 : Experimental setup of CI engine

3.1 Engine Setup Specifications

The specifications of the single cylinder four stroke CI engine used in this experiment is as shown in table 3.

Table 3: Engine setup specifications

Engine manufacturer	Apex Innovations (Research Engine test set up)
Software	Engine soft Engine performance analysis software
Engine type	Single cylinder four stroke multi fuel research engine
No. of cylinder	1
Type of cooling	Water cooled
Rated Power	3.5 kW @ 1500 rpm
Cylinder diameter	87.5 mm
Orifice diameter	20 mm
Stroke length	110 mm
Connecting rod length	234 mm
Dynamometer	Type: eddy current, water cooled, with loading unit

3.2 Exhaust Gas Analyzer Specifications

The level of pollutants in the exhaust of the car is being measured with the help of Exhaust gas analyzer. The Exhaust gas analyzer used is as shown in fig 5. Exhaust gas analyzer is also used to tune an engine for optimized mileage, And also applicable to measure the function of catalytic converters. Exhaust gas analyzer is used in various governments authorized test centers. Here we used a five gas analyzer for measuring of CO, CO_2, NO_X, O_2 and HC Emissions. The specifications / working range of this five gas analyzer is as shown in table 4.

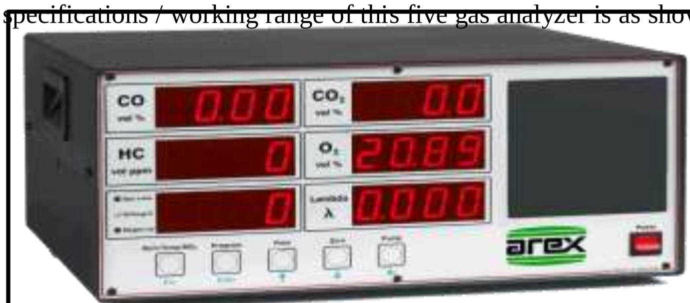

Fig5 : Exhaust gas analyzer

Table 4 Exhaust gas analyzer specifications

	Specified Range	**Accuracy Vol.**	**Accuracy %**	**Resolution**
CO	0-10% ±	0.06 ±	3%	0.01%
HC	0-20000 PPM	± 12 PPM	± 55%	1 PPM
CO_2	0-20%	± 0.4%	± 4.0%	0.1%
O_2	0-21%	± 0.1%	± 3%	0.01%
NO_X	0-5000 PPM	25 PPM	± 5%	1 PPM

Where,

CO = Carbon monoxide % volume measured. HC = Hydrocarbon ppm volume measured

O_2 = Oxygen % volume measure. CO_2 = Carbon dioxide % volume measured

3.3 Experimental Procedure

In this experiment, single cylinder IC Engine is used and attached with the eddy current dynamometer with the help of flywheel shaft, varies the load on the engine or load remain constant. Exhaust Gas analyzer is used to find the emission characteristic of exhaust gas from engine. The reading is taken by varying the load on the engine using the dynamometer.

Fig6 : Engine setup with diffuser.

Different engine performance parameters such as break power, indicated power, specific fuel consumption etc. and emission contents such as CO, CO_2, NO_X and HC are found from the experiments. In this experiment first engine performance and emission is measured by using diesel as a fuel and conventional exhaust manifold, After that the engine performance and emission is measured by diesel with diffuser type exhaust manifold. Than the analysis is being made for which exhaust manifold best optimized performance and emission characteristics is achieved. Experiment set up with diffuser as shown in fig.6

Injection point adjustment to desired point (on line adjustment):-

Fig7 : Pressure variation arrangement

Fig 7 shows pressure variation arrangement. It is presumed that engine is running in diesel mode and on-line diesel injection plot is being displayed on the monitor using software Note the injection point displayed on the monitor. Turn the injection point adjusting nut gradually and note its effect on diesel injection plot. The diesel injection plot shifts horizontally to retard/advance injection point depending upon the direction of rotation. Adjust the nut till desired injection point is obtained.

Load Adjustment:-

Fig 8 shows knob and Eddy current dynamometer for the adjustment of Load. Load Adjustment is done by using the Eddy current Dynamometer. When knob is rotated in clockwise direction at that time electric magnetic force increase. Electric magmatic force produce in opposite direction of engine speed. So that when knob rotates in clockwise direction at that time load is increased and Knob rotate in anti-clockwise at that time load decreased. Load variation shows on the load indicator.

Fig8 : Knob and Eddy Current Dynamometer

3.4 Variable and Measuring Parameters

For this experimental work, we can vary different parameters among their respective range. The variable parameters are engine load, injection pressure etc. The variable parameters used in this experiment are as listed in table 5.

Table 5: Variable Parameters for Experiment

Injection pressure	200,180,160
Load	1 kg, 7 kg, 13 kg

The main parameter used in this experimental work is achieved by varying engine load with different Exhaust manifold. The experiments were carried out with 100% diesel. The measuring parameters are in two categories, performance and emission. In performance parameters BTHE, ITHE, mechanical efficiency, SFC, FC and in emission parameters CO, HC, CO_2 and NO_X are being found out and analyzed.

4. RESULT AND DISCUSSION

In this chapter to find the result and discussion from the result table given in chapter 6 and to find the optimum set of parameter which has best performance Taguchi methods is used.

4.1 Steps in Taguchi Methodology

Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process,

1. Formulation of the problem – the success of any experiment is dependent on a full understanding of the nature of the problem.

2. Identification of the output performance characteristics most relevant to the problem.

3. Identification of control factors, noise factors and signal factors (if any). Control factors are those which can be controlled under normal production conditions. Noise factors are those which are either too difficult or too expensive to control under normal production conditions. Signal factors are those which affect the mean performance of the process.

4. Selection of factor levels, possible interactions and the degrees of freedom associated with each factor and the interaction effects.
5. Design of an appropriate Orthogonal Array (OA).
6. Preparation of the experiment.

7. Running of the experiment with appropriate data collection

8. Statistical analysis and interpretation of experimental results

4.2 Analysis of Various Response for Injection Pressure Variation

In the experiment, Three parameters is considered which are Injection pressure (160,180,200), Diffuser (No, Diffuser A, Diffuser B), Load (1, 7, 13). From this parameter to Discuss mechanical efficiency, Brake thermal efficiency, specific fuel consumption. This results obtained from the Minitab software.

4.2.1 Taguchi Analysis for Mechanical Efficiency

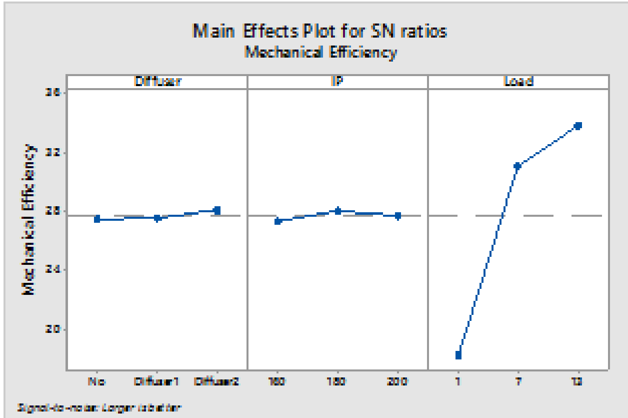

Fig9 : Main Effects Plot for S/N ratios of Mechanical Efficiency

Table 6: Response Table for S/N Ratios of Mechanical Efficiency

Level	Diffuser	IP	Load
1	27.58	27.40	18.23
2	27.58	28.09	31.12
3	28.12	27.78	33.93
Delta	0.54	0.69	15.70
Rank	3	2	1

Response curve analysis is aimed at determining influential parameter and their optimum set of control parameters. Fig 9 shows response at each factor level. The S/N Ratio for different performance response were calculated at each factor level and the average effect were determined by taking the total of each factor level and divided by the number of data points in the total. The greater difference between S/N ratio values in the levels, the parametric influence will be much. The parameter level having the highest S/N ratio corresponds to the sets of parameters indicates highest performance. The term optimum setting is reflects only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the highest S/N ratio. Referring fig.9 the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (13 kg), Diffuser B and Injection pressure (180), which are optimum parameter setting for highest mechanical efficiency. From delta values as mention table 9, maximum (15.70) for engine load and minimum (0.54) for diffuser. Parameter engine load is most significant parameter and fuel is least significant for mechanical efficiency. Optimum parameter set as shown in table 6.

Table 7: Optimize Set of Parameter for Mechanical Efficiency

Diffuser	I	Load	Mech. Eff. (%)	SN Ratio
Diffuser B	18	1	51.8133	34.6170

Experiment has been carried out using optimum set of parameter. Experimental Mechanical efficiency for optimum set of parameter is 50.80 %. This experimental value is nearer to predicted value 51.8133 % as shown in table 8.

Table 8: Validation Results for Mechanical Efficiency

Predicted Value	Experimental Value	% Variation
51.8133%	50	1

4.2.2 Taguchi Analysis for Brake Thermal Efficiency

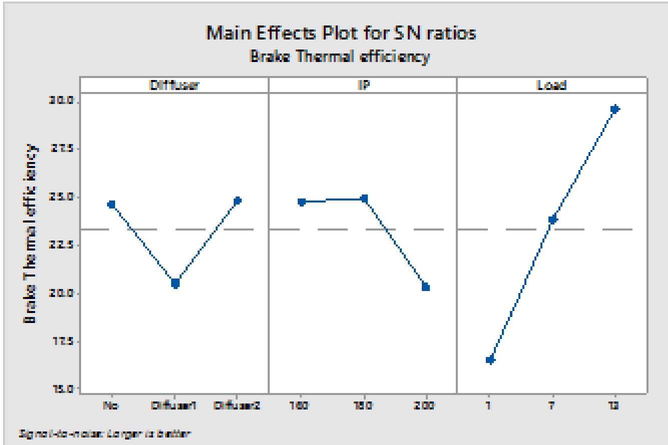

Fig10 : Main Effects Plot for S/N ratios of Brake Thermal Efficiency

Table 9: Response Table for S/N Ratios of Brake Thermal Efficiency

Level	**Diffuser**	**IP**	**Load**
1	24.70	24.78	16.53
2	20.51	24.99	23.89
3	24.89	20.31	29.66
Delta	4.38	4.68	13.13
Rank	3	2	1

The term optimum setting is reflects only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the highest S/N ratio. Referring fig.10 the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (13 kg), Diffuser B and Injection pressure (180 bar), which are optimum parameter setting for highest Brake thermal efficiency. From delta values as mention table 9, maximum (13.13) for engine load and minimum (4.38) for diffuser. Parameter engine load is most significant parameter and diffuser is least significant for Brake Thermal efficiency. Optimum parameter set as shown in table 10.

Table 10: Optimize Set of Parameter for Brake Thermal Efficiency

Diffuser	**IP**	**Load**	**BTHE (%)**	**SN Ratio**
Diffuser B	180	13	34.5978	32.8175

Experiment has been carried out using optimum set of parameter. Experimental brake thermal efficiency for optimum set of parameter is 32.20 %. This experimental value is nearer to predicted value 34.5978 % as shown in table 11.

Table: 11: Validation Results for Brake Thermal Efficiency

Predicted Value	**Experimental Value**	**% Variation**
	32.20	6.

4.2.3 Taguchi Analysis for Specific Fuel Consumption

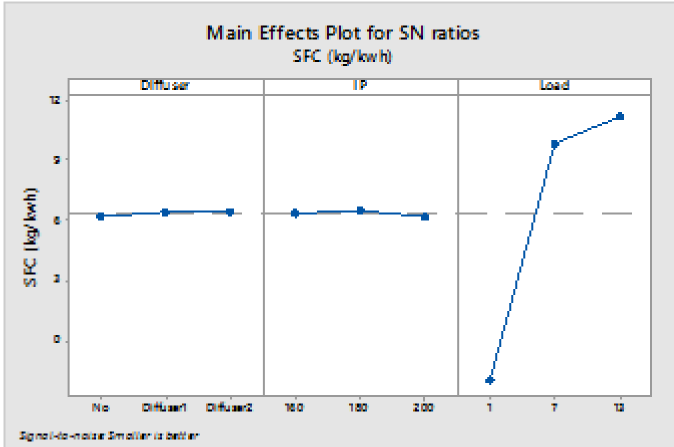

Fig11 : Main Effects Plot for S/N ratios of Specific Fuel Consumption

Table 12: Response Table for S/N Ratios of Specific Fuel Consumption

Level	Diffuser	IP	Load
1	6.180	6.352	-1.961
2	6.429	6.477	9.824
3	6.431	6.212	11.177
Delta	0.251	0.265	13.138
Rank	3	2	1

The term optimum setting is reflects only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the largest S/N ratio. Referring fig 11 the response curve for S/N ratio, the largest S/N ratio was observed at Engine Load (13 kg), Diffuser B and Injection pressure (180 bar), which are optimum parameter setting for Smaller Specific fuel Consumption. From delta values as mention table 12, maximum (13.138) for engine load and minimum (0.251) for diffuser. Parameter engine load is most significant parameter and diffuser is least significant for Specific fuel Consumption. Optimum parameter set as shown in table 13.

Table 13: Optimize Set of Parameter for Specific fuel Consumption

Diffuser	IP	Load	SFC	SN Ratio
Diffuser B	180	13	0.2588	11.3893

Experiment has been carried out using optimum set of parameter. Experimental Specific fuel consumption for optimum set of parameter is 0.235 kg/kWh. This experimental value is nearer to predicted value 0.2588 kg/kWh as shown in table 14.

Table 14: Validation Results for Specific fuel Consumption

Predicted Value	Experimental Value	% Variation
0.2588 kg/kWh	0.235 kg/kWh	9.19

4.2.4 Taguchi Analysis for HC

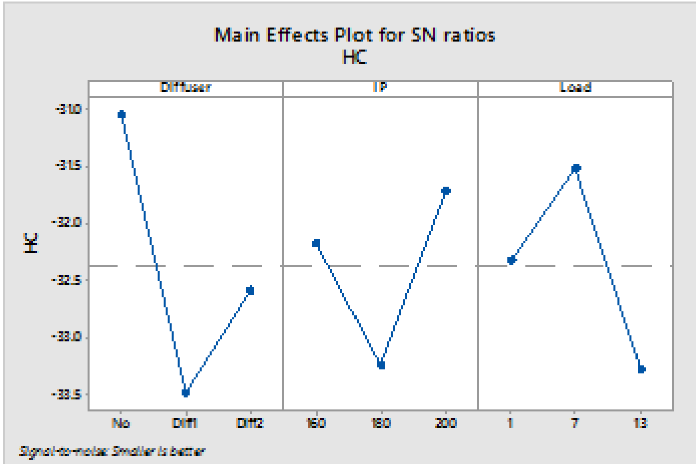

Fig12 : Main Effects Plot for S/N ratios of HC with Injection Pressure

Table 15: Response Table for S/N Ratios of HC with Injection Pressure

Level	Diffuser	IP	Load
1	-31.04	-32.16	-32.32
2	-33.48	-33.23	-31.51
3	-32.58	-31.71	-33.28
Delta	2.45	1.53	1.77
Rank	1	3	2

The term optimum setting is reflects only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the largest S/N ratio. Referring fig.12 the response curve for S/N ratio, the largest S/N ratio was observed at Engine Load (7 kg), No Diffuser and Injection pressure (200 bar), which are optimum parameter setting for Smaller HC. From delta values as mention table 15, maximum (2.45) for diffuser and minimum (1.53) for IP. Parameter diffuser is most significant parameter and IP is least significant for HC. Optimum parameter set as shown in table 16.

Table 16: Optimize Set of Parameter for HC with Injection Pressure

Diffuser	IP	Load	HC (ppm)	SN Ratio
No	200	7	27.778	-29.5167

Experiment has been carried out using optimum set of parameter. Experimental HC for optimum set of parameter is 29.51 ppm. This experimental value is nearer to predicted value 27.778 ppm as shown in table 17.

Table 17: Validation Results for HC with Injection Pressure

Predicted Value	Experimental Value	% Variation
27.778 ppm	29.51 ppm	6.23

4.2.5 Taguchi Analysis for CO_2

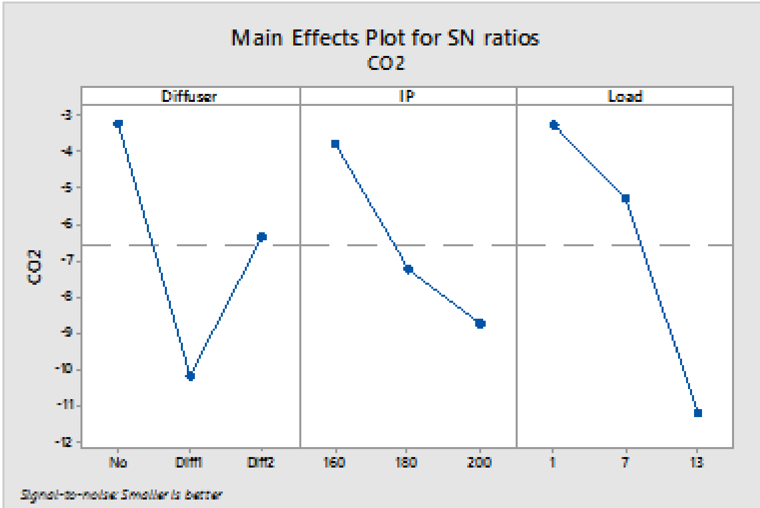

Fig13 : Main Effects Plot for S/N ratios of CO_2

Table 18: Response Table for S/N Ratios of CO_2

Level	Diffuser	IP	Load
1	-3.204	-3.771	-3.255
2	-10.168	-7.218	-5.281
3	-6.349	-8.733	-11.186
Delta	6.964	4.961	7.931
Rank	2	3	1

The term optimum setting is reflects only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the largest S/N ratio. Referring fig 13. the response curve for S/N ratio, the largest S/N ratio was observed at Engine Load (1 kg), No Diffuser and Injection pressure (160 bar), which are optimum parameter setting for Smaller CO_2. From delta values as mention table 18, maximum (7.931) for load and minimum (4.961) for IP. Parameter load is most significant parameter and IP is least significant for CO_2. Optimum parameter set as shown in table 19.

Table 19: Optimize Set of Parameter for CO_2

Diffuser	IP	Load	CO_2	SN Ratio
No	160	1	0.40866	2.9173

Experiment has been carried out using optimum set of parameter. Experimental CO_2 for optimum set of parameter is 0.49 This experimental value is nearer to predicted value 0.4086 as shown in table 20.

Table 20: Validation Results for CO_2

Predicted Value	Experimental Value	% Variation
0.40866	0.49	19.90

4.2.6 Taguchi Analysis for NO_X

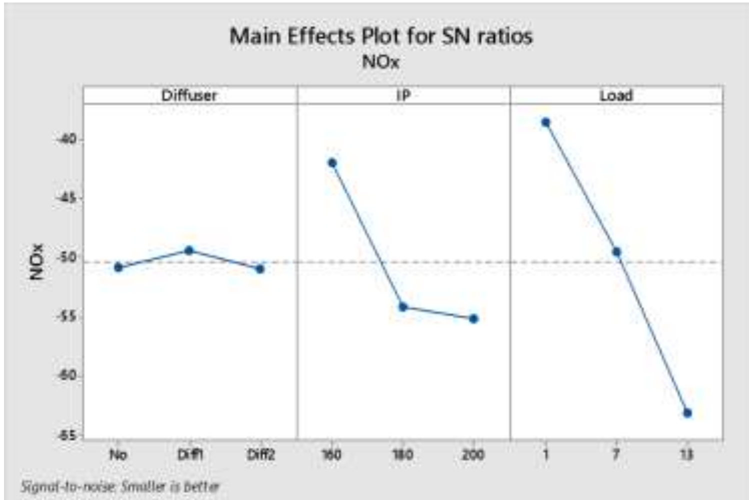

Fig14 : Main Effects Plot for S/N ratios of NO_X

Table 21: Response Table for S/N Ratios of NO_X

Level	**Diffuser**	**IP**	**Load**
1	-50.85	-41.92	-38.52
2	-49.42	-54.15	-49.53
3	-50.91	-55.12	-63.14
Delta	1.48	13.20	24.62
Rank	3	2	1

The term optimum setting is reflects only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the largest S/N ratio. Referring fig.14 the response curve for S/N ratio, the largest S/N ratio was observed at Engine Load (1 kg), Diffuser A and Injection pressure (160 bar), which are optimum parameter setting for Smaller NO_X. From delta values as mention table 21, maximum (24.62) for load and minimum (1.48) for Diffuser. Parameter load is most significant parameter and Diffuser is least significant for NO_X. Optimum parameter set as shown in table 22.

Table 22: Optimize Set of Parameter for NO_X

Diffuser	**IP**	**Load**	**NO_X**	**SN Ratio**
Diff1	160	1	220.222	-29.0630

Experiment has been carried out using optimum set of parameter. Experimental NO_X for optimum set of parameter is 237.445 This experimental value is nearer to predicted value 220.222 as shown in table 23.

Table 23: Validation Results for NO_X

Predicted Value	**Experimental Value**	**% Variation**
220.222	237.445	7.82

4.3 Optimum Set of Parameter

Table 24: Optimum Set of Parameter for various Injection Pressure

Variable	**Optimum Set Of Parameter**	**Response**	**Predicted value**	**Experiment Value**	**% Variation**
Diffuser	Diffuser B	Mechanical Efficiency	51.8133	50.80	1.9
IP(bar)	180				
Load(kg)	13				
Diffuser	Diffuser B	Brake Thermal Efficiency	34.5978	32.20	6.9
IP(bar)	180				
Load(kg)	13				
Diffuser	Diffuser B	Specific Fuel Consumption(kg/kwh)	0.2588	0.235	9.19
IP(bar)	180				
Load(kg)	13				
Diffuser	No	HC ppm	27.78	29.51	6.23
IP(bar)	200				
Load(kg)	7				
Diffuser	No	CO_2 (%)	0.4086	0.49	19.90
IP(bar)	160				
Load(kg)	1				
Diffuser	Diff1	NO_X (%)	220.222	237.445	7.82
IP(bar)	160				
Load(kg)	1				

5. CONCLUSIONS

The Taguchi's approach has been carried out for optimizing the performance of diesel engine. Four input parameters have been optimized using SNR. The higher-the-better quality characteristic has been used for maximizing the thermal efficiency and Mechanical efficiency of the engine. Also the Smaller-the-better Quality Characteristics has been used for minimizing the Specific fuel consumption and Emission of the engine. Experiments Results are given below**.**

1.For Mechanical efficiency, Diffuser B, Injection pressure (180) and Engine Load (13 kg), which are optimum parameter. This experimental value 50.80 % is nearer to predicted value 51.81 %.

2.For Brake Thermal efficiency, Diffuser B, and Injection pressure (180 bar) and Engine Load (13 kg), which are optimum parameter. This experimental value 32.80 % is nearer to predicted value 34.59 %.

3.For Specific fuel Consumption, Diffuser B, and Injection pressure (180 bar) and Engine Load (13 kg), which are optimum parameter. This experimental value 0.235 kg/kWh is nearer to predicted value 0.258 kg/kWh.
4.For HC emission, No Diffuser, Injection pressure (200 bar) and Engine Load (7 kg), which are optimum parameter. This experimental value 29.51 ppm is nearer to predicted value 27.78 ppm.
5.For CO_2 emission, No Diffuser, Injection pressure (160 bar) and Engine Load (1 kg), which are optimum parameter. This experimental value 0.49 % is nearer to predicted value 0.41 %.
6.For NO_X emission, Diffuser A, Injection pressure (160 bar) and Engine Load (1 kg), which are optimum parameter. This experimental value 237.45 ppm is nearer to predicted value 220.22 ppm.

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