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CFD Based Optimization of Intake Effect to Reduce NOx in Twin Cylinder Diesel Engine

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A B S T R A C T

This study presents a Computational Fluid Dynamics (CFD) based optimization approach to reduce NOx emissions in a twin-cylinder diesel engine by optimizing the intake system. The methodology involves creating a detailed 3D CAD model of the engine intake system, generating a high-quality computational mesh, and defining appropriate boundary conditions. Transient CFD simulations are conducted to analyze various intake geometries, valve timings, and operating conditions. Post-processing and analysis of simulation results enable the identification of regions with high NOx formation and areas for improvement. Optimization algorithms are employed to search for intake configurations that minimize NOx emissions while meeting performance criteria. Validation against experimental data ensures the reliability of the optimized intake design. This iterative process aims to refine the intake system for enhanced NOx reduction while balancing other engine performance metrics.

Keywords: CFD, optimization, intake, NOx reduction, twin-cylinder diesel engine, simulation

1. INTRODUCTION

The introduction sets the stage by providing context, significance, and a brief overview of the study. Here's an example:
In the pursuit of sustainable transportation, reducing emissions from internal combustion engines is paramount. Nitrogen oxides (NOx), a group of highly reactive gases, are among the most significant contributors to air pollution and adverse health effects. Diesel engines, while efficient, are notorious for their NOx emissions. Computational Fluid Dynamics (CFD) has emerged as a valuable tool for optimizing engine designs to mitigate emissions. This study focuses on utilizing CFD-based optimization techniques to enhance the intake system of a twin-cylinder diesel engine, specifically targeting NOx reduction. The intake system plays a critical role in regulating air-fuel mixture formation and combustion processes, thereby influencing emission levels. By systematically investigating different intake geometries, valve timings, and operating conditions through transient CFD simulations, this research aims to identify configurations that minimize NOx emissions without compromising engine performance. Such optimizations hold promise not only for meeting stringent emission regulations but also for improving air quality and public health. Through this introduction, the study underscores the importance of addressing NOx emissions in diesel engines and outlines the methodology and objectives of the research.

2. OBJECTIVES

- Utilize Computational Fluid Dynamics (CFD) for optimizing the intake system of a twin-cylinder diesel engine.
- Investigate various intake geometries to understand their impact on air-fuel mixture formation and combustion processes.
- Analyze the influence of valve timings and operating conditions on NOx emissions.
- Identify intake configurations that minimize NOx emissions while maintaining or improving engine performance.
- Employ transient CFD simulations to capture the dynamic behavior of intake airflow and combustion processes.
- Validate the optimized intake design through comparison with experimental data or published literature.quations and formulae should be typed in Mathtype, and numbered consecutively with Arabic numerals in parentheses on the right hand side of the page (if referred to explicitly in the text). They should also be separated from the surrounding text by one space.

3. METHODOLOGY

- Develop a detailed 3D CAD model of the engine intake system.
- Generate a high-quality computational mesh for the intake geometry.
- Define boundary conditions including inlet air properties, engine speed, and fuel injection timing.
- Select appropriate turbulence and combustion models for CFD simulations.
- Conduct transient CFD simulations to analyze intake geometries, valve timings, and operating conditions.
- Post-process simulation results to identify regions of high NOx formation and areas for improvement.
- Utilize optimization algorithms to search for intake configurations that minimize NOx emissions while meeting performance criteria.
- Validate the optimized intake design through comparison with experimental data or published literature.

4. PROPLEM DEFINATION

Large diesel engines are widely used for stationary power generation and ship propulsion. But it is important to reduce their emissions to a reasonable level because diesel engines are one of the major sources for air pollution. Recently, the maximum quantities of oxides of nitrogen (NO_x) are limited for marine applications by the IMO regulation. In case of land installations for generating electricity, there are many different regulations specific to the various countries and regions. It has become clear that the development of diesel engines must concentrate on reducing exhaust gas emissions. Many methods for reduction of the emissions, especially for NO_x, however have a contradictory effect on fuel oil consumption of an engine. It is desirable to reduce both fuel oil consumption and NO_x emission at the same time for a competitive engine.

The experimental data in table 1 shows the various emissions of the twin cylinder engine under various load conditions have been tabulated below.

Load/Parameters	0 kw	1.5 kw	3 kw	4.5 kw	6 kw
λ	5.442	5.521	5.579	5.612	5.620
CO(% by vol)	0.08	0.08	0.08	0.09	009
CO_2(% by vol)	2.7	2.6	2.5	2.5	2.5
O_2(% by vol)	17.4	17.3	17.3	17.4	17.4
HC(ppm)	65	75	78	81	78
NO_x(ppm)	93	80	66	61	56

Table1 Emission levels under loading

It is the evident from the table values that the NO_x emissions find the major portion of the emission levels and it is also observed that at higher loads level NO_x reduces.

5. EXPERIMENTAL PROCEDURE

Twin cylinder of electrically loaded, direct injection, four stroke Kirlosker heavy-duty diesel engine is simulated in this work. Table 5.1 provides important specifications of the engine model

Engine Parameters	Value
Bore (mm)	85.0
Stroke (mm)	155.0
Displacement (cc)	1759
Number of cylinder	2
Connecting rod length (mm)	118.1
Engine speed (rpm)	1500
Fuel nozzle diameter (mm)	0.25
Fuel nozzle hole number (pc)	3
Power	13.8kw (18.7Hp)
Fuel type	Diesel

5.1 EMISSIN TEST ANALYZER

The emissions from the twin cylinder DI diesel engine has to be measured experimentally by using AVL DI gas analyzer. The results of the emission have to be considered as a problem definition and the emission results are shown in the table 5.1.

The specific application of the AVL analyzer is as follows:

i. Periodic measurement of the opacity of exhaust gases from diesel engines of passenger cars, trucks, buses, agricultural and construction plant etc. in accordance with the legal requirements.

ii. For checking exhaust gas opacity in diesel vehicles and for approval by the authorities.

iii. Measurement of peak opacity during free acceleration

Measurement principle - CO, HC, CO_2 - Infrared measurement

Fig 1: AVL DI Gas Analyzer

Measurement parameters	**Measurement parameters**	**Resolution**
Engine speed	250….800 rpm	10rpm
Oil temperature	0….120°C	1°C
CO	0….10% by vol.	0.01% by vol
CO_2	0….20% by vol.	0.01% by vol
HC	0….20000 ppm vol.	1 ppm vol.
O_2	0….4% by vol. 4….22% by vol.	0.001% by vol. 0.1% by vol.
NO	0….4000 ppm vol.	1 ppm vol.

Table 2: Specifications of AVL DI GAS ANALYZER

5.2 PERFORMANCE TEST

Performance test has been carried out on twin cylinder DI diesel engine under varying electrical load conditions and the fuel consumption level is calculated.

$$\text{Fuel consumption } (F_c) = \frac{\text{specific gravity} * \text{volume of fuel consumption (20 cc)}}{t_{avg} * 1000}$$

The above mentioned formula is used for finding the fuel consumption. The parameters required for finding the fuel consumption are specific gravity, volume of fuel consumption and time average.

Serial No	Applied load		Time for 20cc of fuel consumption			Fuel consumption
	A(amps)	V(volt)	T_1	T_2	Tavg	F_c (kg/s)
1	0	250	26	25	25.5	$6.51*10^{-4}$
2	15	250	18	18	18	$9.22*10^{-4}$
3	3	250	16	16	16	$1.04*10^{-3}$
4	4.5	250	14	14	14	$1.19*10^{-3}$
5	6	250	13	13	13	$1.28*10^{-3}$

Table 3: Experimental Parameters

The table showed above mentions various fuel consumption values for different input parameters of applied load and time for 20cc of fuel consumption. The fuel consumption values thus obtained are taken as input values for CFD analysis.

6. RESULT AND DISCUSSION

Air Velocity (m/s)	**Temperature (k)**	**NO_x (ppm)**
0.5	2404.257	212.8326
1	2373.014	119.3681

1.5	2305.704	75.12712
2	2163.651	36.14581
2.5	2148.03	29.7076
3	2163.789	24.87245
3.5	2163.298	20.32022
4	2157.443	15.64244
4.5	2147.129	11.74867
5	2152.927	10.12925
5.5	2184.438	10.45406
6	2252.403	12.17822
6.5	2291.823	13.91881
7	2311.645	14.00733
7.5	2309.506	14.72999
8	2329.121	15.67008
8.5	2329.686	17.44686
9	2330.156	20.42359
9.5	2329.927	27.05153
10	2341.899	33.47605
10.5	2322.488	38.93446
11	2342.461	42.64009
11.5	2332.645	44.96497
12	2288.759	49.15229
12.5	2243.94	47.70113
13	2242.508	46.37826
13.5	2244.176	44.16431
14	2241.664	42.94903
15	2238.32	37.92718

Table 4: Results for Mass Flow Rate of 6.51*10^{-4} kg/s

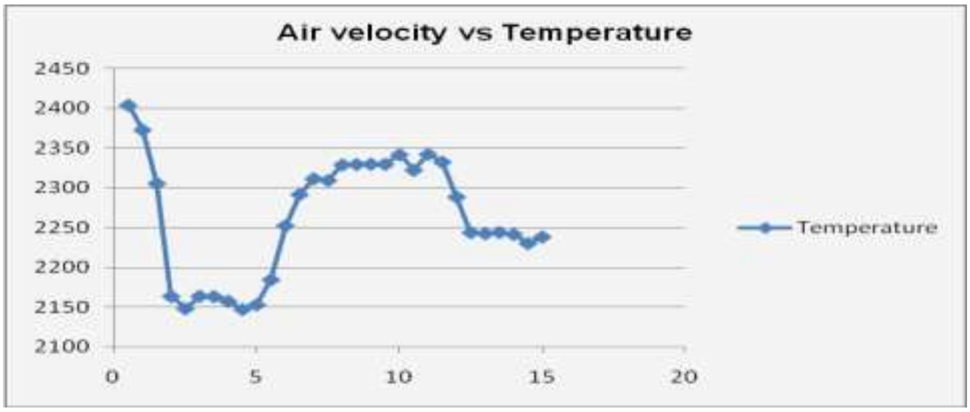

Fig 2: Air velocity vs Temperature for fuel mass flow rate of 6.51*10^{-4} kg/s

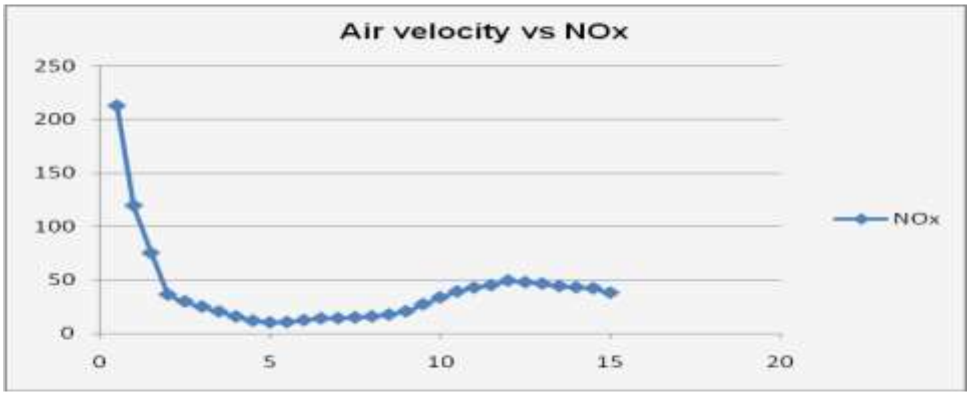

Fig 3: Air velocity vs NO$_x$ for fuel mass flow rate of 6.51*10^{-4} kg/s

From the above graph it is evitable that NO_X emission at a mass flow rate of 6.51*10^{-4} kg/s is minimum of air velocity of 5 m/s.

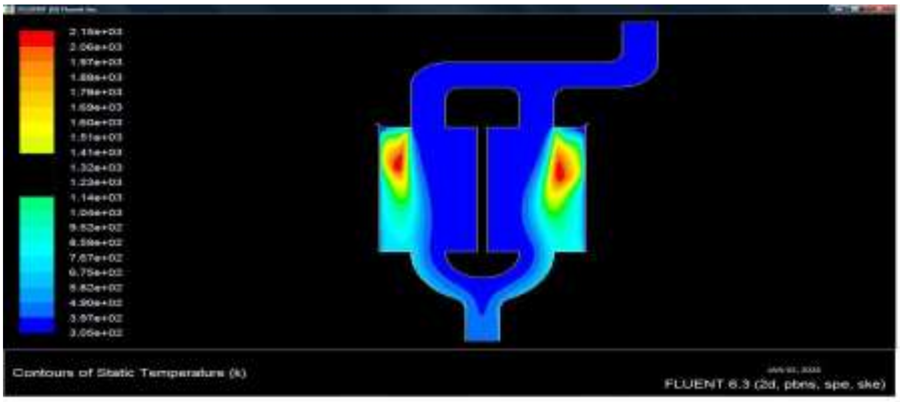

Fig 4 Contours of static temperature of fuel mass flow rate of 6.51*10^{-4} kg/s at air velocity of 5m/s

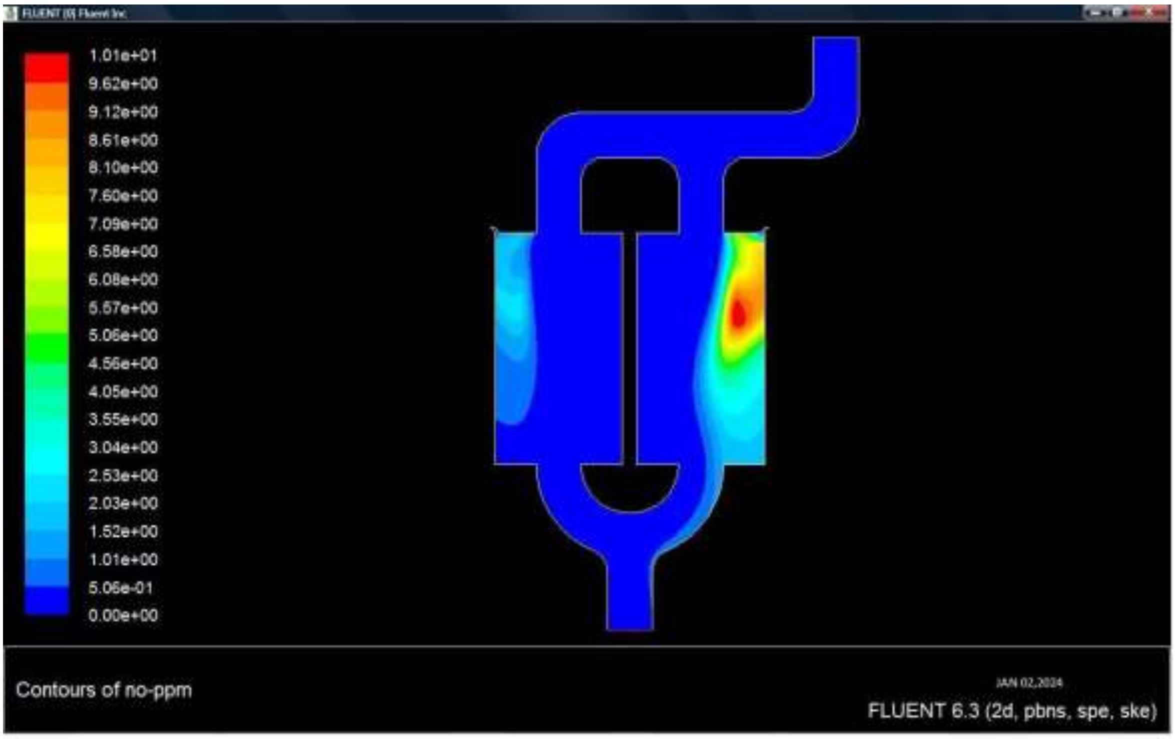

Fig 5 Contours of NO-PPM of fuel mass flow rate of 6.51*10^{-4} kg/s at air velocity of 5m/s

Air Velocity (m/s)	Temperature (k)	NO_x (ppm)
0.5	2434.969	261.622
1	2451.69	161.0053
1.5	2450.758	123.5608
2	2424.001	99.72151
2.5	2377.183	75.07653
3	2291.388	49.46581
3.5	2217.579	32.99378
4	2222.621	28.35014
4.5	2230.046	24.22012
5	2230.643	20.0224
5.5	2222.103	16.5068
6	2210.493	13.49605
6.5	2207.5	11.46855
7	2217.686	10.60098
7.5	2242.363	10.41714
8	2290.259	11.24126

8.5	2334.299	12.18747
9	2352.231	13.0054
9.5	2363.511	13.01384
10	2347.116	13.09187
10.5	2362.041	13.62889
11	2371.12	13.75172
11.5	2377.397	15.54419
12	2376.875	16.73866
12.5	2367.145	21.96215
13	2367.932	28.82411
13.5	2385.076	33.64527
14	2380.479	38.72235
14.5	2362.617	44.14764
15	2377.099	48.17042

Table 5: Results for Mass Flow Rate of $9.22*10^{-4}$ kg/s

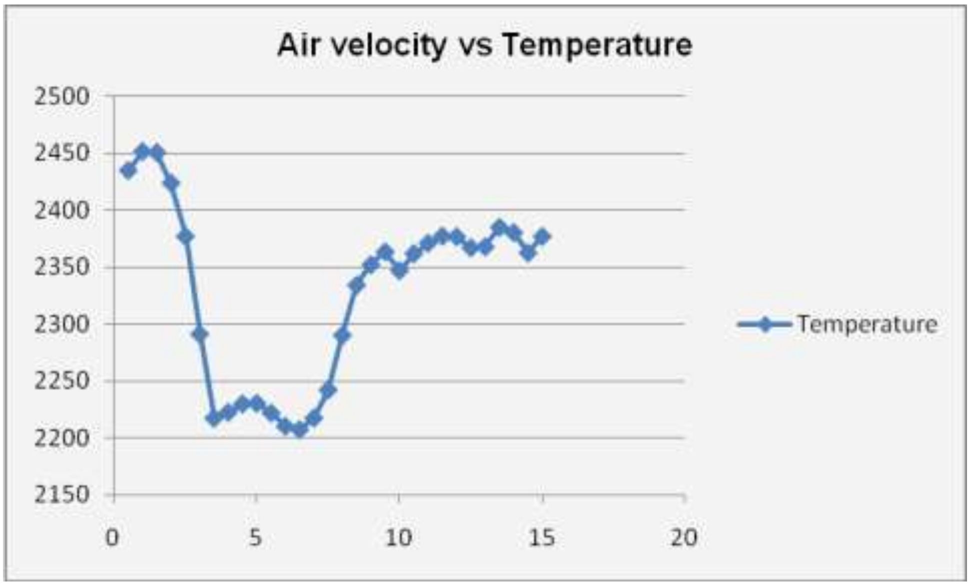

Fig 6: Air velocity vs temperature for fuel mass flow rate of $9.22*10^{-4}$ kg/s

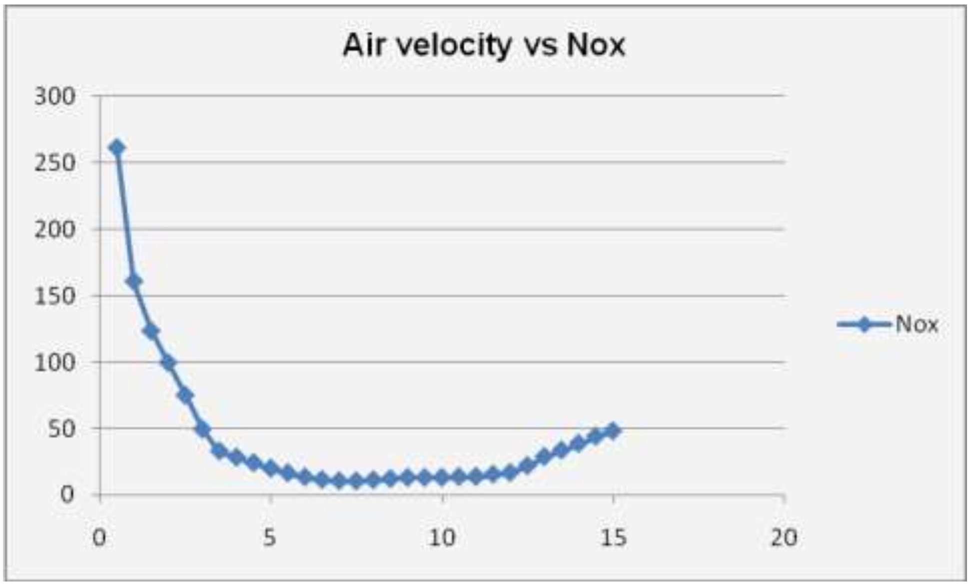

Fig 7:Air velocity vs NO_x for fuel mass flow rate of $9.22*10^{-4}$ kg/s

From the above graph it is evitable tat NO_X emission at a mass flow rate of $9.22*10^{-4}$ kg/s is minimum for air velocity of 7.5 m/s.

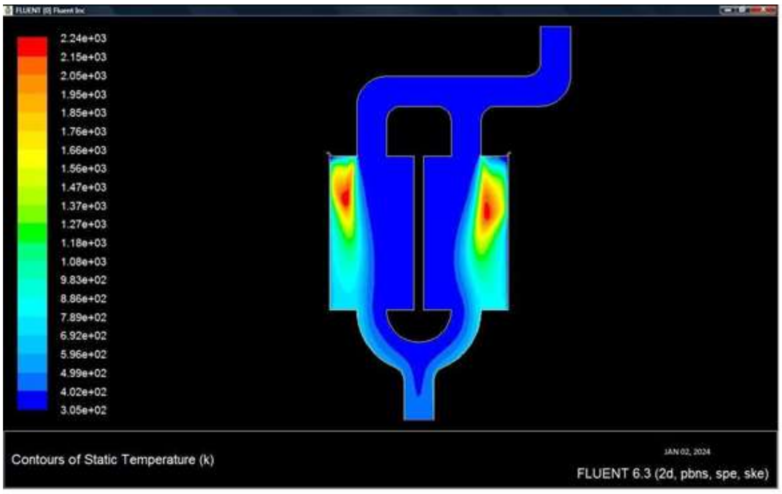

Fig 8: Contours of static temperature of fuel mass flow rate of $9.22*10^{-4}$ kg/s at air velocity of 7.5m/s

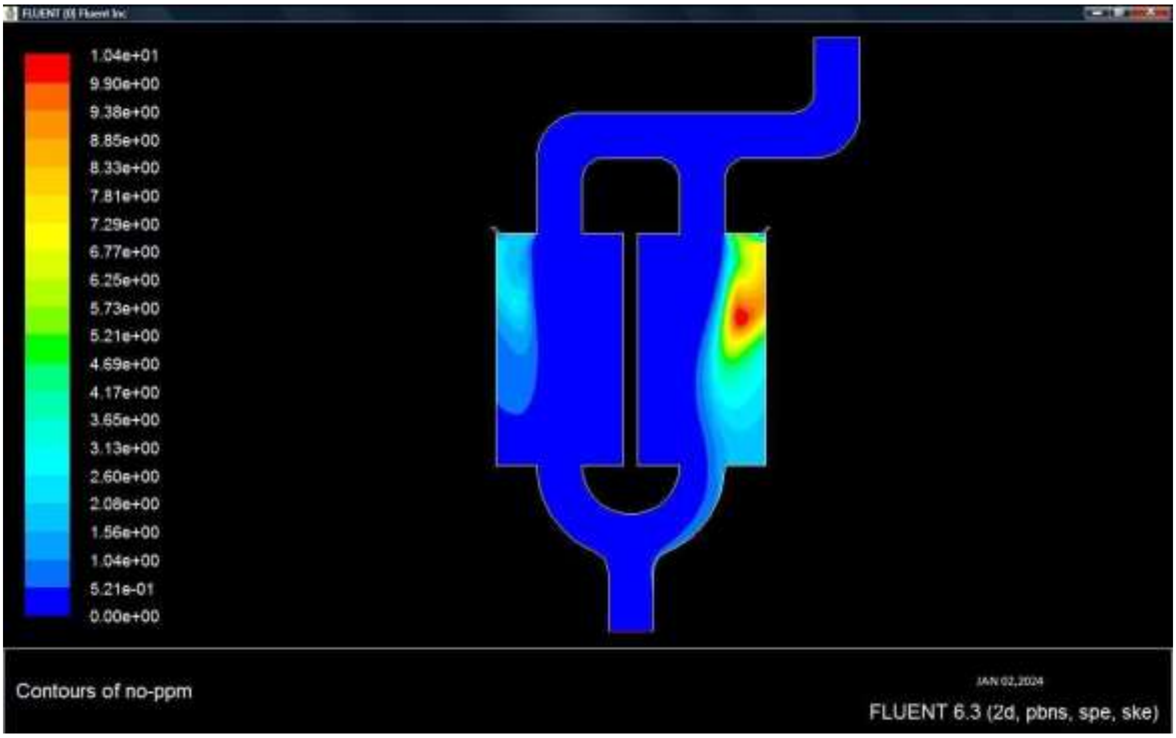

Fig 9: Contours of NO-PPM of fuel mass flow rate of 9.22*10^{-4} kg/s at air velocity of 7.5m/s

Air Velocity (m/s)	Temperature (k)	NO_x (ppm)
0.5	2435.076	280.062
1	2485.897	175.7717
1.5	2496.594	141.7921
2	2464.299	113.7109
2.5	2446.168	95.70564
3	2376.723	65.36366
3.5	2256.82	36.96636
4	2236.188	32.20177
4.5	2247.282	28.75506
5	2252.63	24.46999
5.5	2250.407	20.69504
6	2244.004	17.45219
6.5	2233.966	14.4478
7	2225.999	12.1263
7.5	2233.779	11.10209
8	2242.179	10.31696

8.5	2268.081	10.41769
9	2311.594	11.18483
9.5	2352.529	11.88339
10	2368.868	12.54418
10.5	2385.001	12.50008
11	2372.077	12.5265
11.5	2370.175	12.58298
12	2384.733	13.34304
12.5	2390.005	14.42386
13	2382.943	15.13381
13.5	2393.257	16.04062
14	2377.918	21.45944
14.5	2382.682	29.09981
15	2395.902	34.90672

Table 6: Results for Mass Flow Rate of 1.04*10^{-3} kg/s

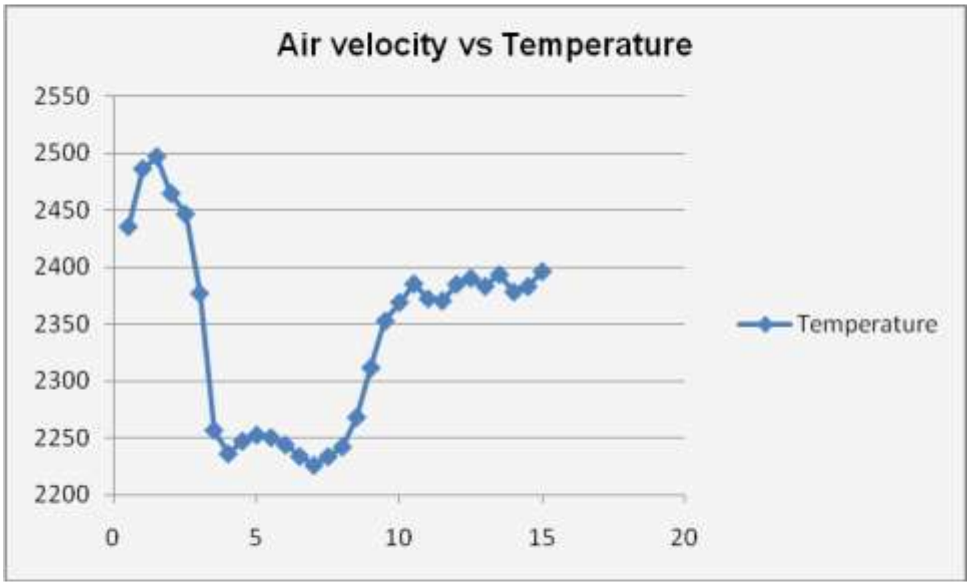

Fig 10 Air velocity vs temperature for fuel mass flow rate of 1.04*10^{-3} kg/s

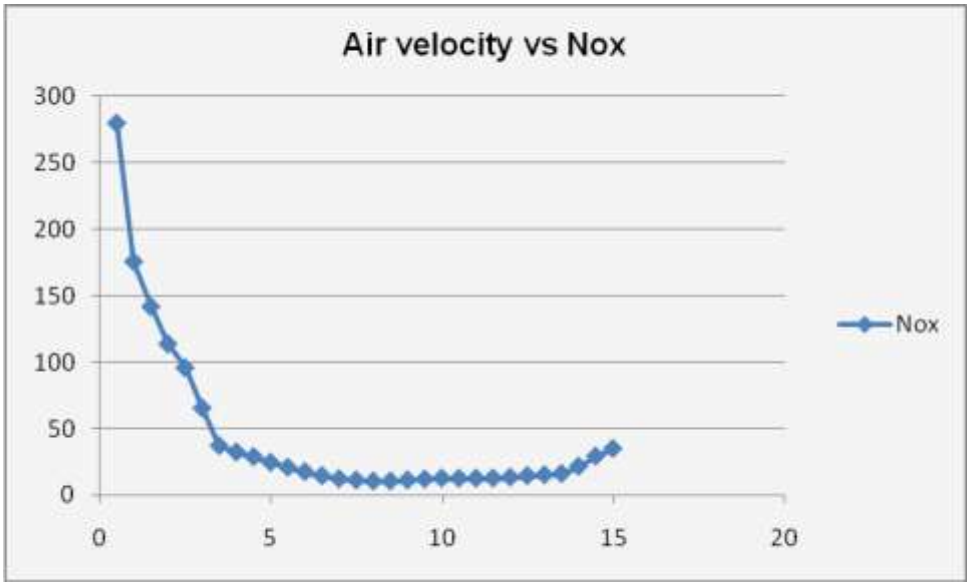

Fig 11: Air velocity vs NO_x for fuel mass flow rate of $1.04*10^{-3}$ kg/s

From the above graph it is evitable tat NO_X emission at a mass flow rate of $1.04*10^{-3}$ kg/s is minimum for air velocity of 8 m/s.

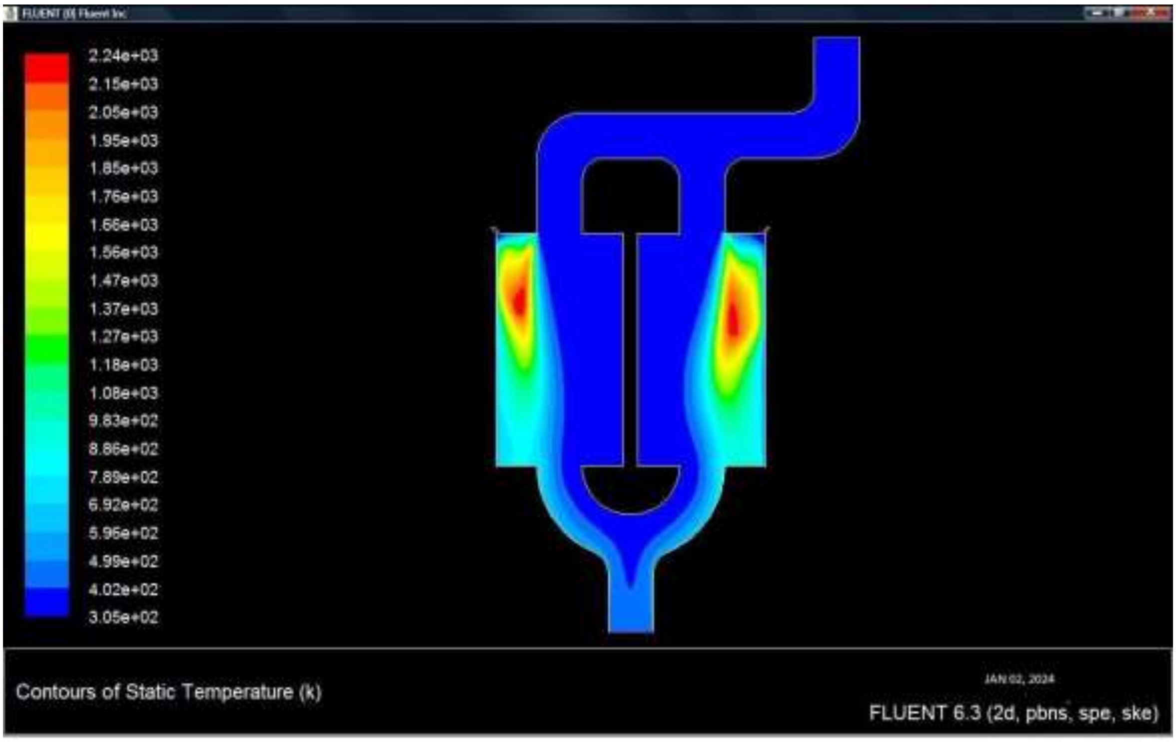

Fig 12: Contours of static temperature of fuel mass flow rate of $1.04*10^{-3}$ kg/s at air velocity of 8m/s

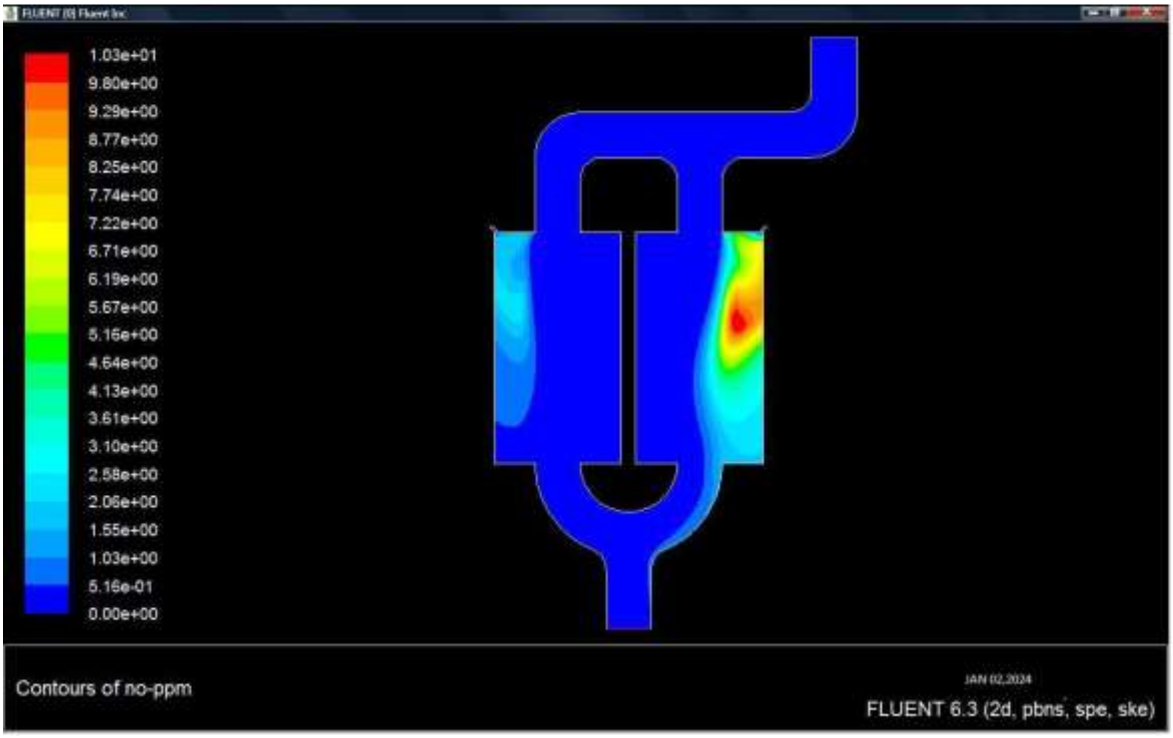

Fig 13: Contours of NO-PPM of fuel mass flow rate of $1.04*10^{-3}$ kg/s at air velocity of 8m/s

Air Velocity (m/s)	Temperature (k)	NO_x (ppm)
0.5	2441.33	287.239
1	2521.761	192.3633
1.5	2517.314	153.2814
2	2500.202	124.8697
2.5	2489.479	108.3826
3	2461.606	86.78397
3.5	2409.553	65.9378
4	2322.006	44.02804
4.5	2261.914	33.08311
5	2271.448	29.00015
5.5	2275.289	25.43256
6	2274.379	22.01423
6.5	2269.776	18.95749
7	2263.57	16.02742
7.5	2254.128	13.7543
8	2249.052	11.86557

8.5	2252.94	10.60364
9	2262.883	10.18349
9.5	2282.749	10.10894
10	2315.732	10.51964
10.5	2351.073	11.19078
11	2387.295	11.94823
11.5	2387.325	12.16307
12	2399.058	11.94081
12.5	2387.327	11.94412
13	2376.265	12.35086
13.5	2397.611	12.53136
14	2399.873	13.62389
14.5	2407.753	13.55532
15	2401.83	15.00543

Table 7Results for Mass Flow Rate of 1.19*10^{-3} kg/s

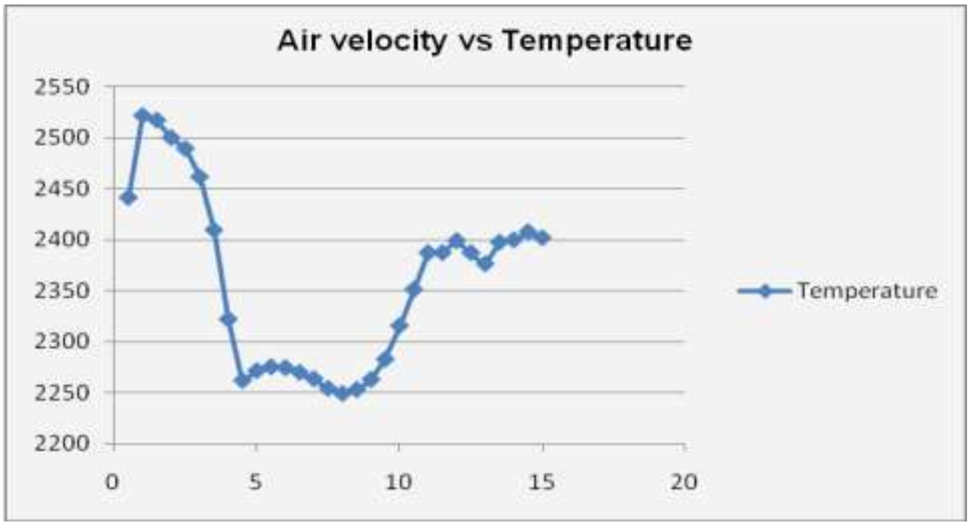

Fig 14 Air velocity vs temperature for fuel mass flow rate of 1.19*10^{-3} kg/s

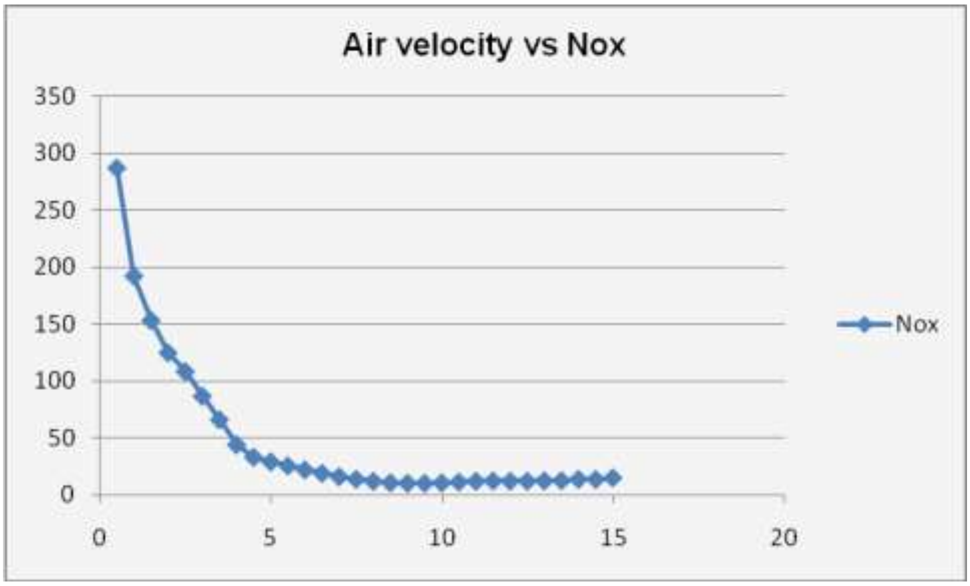

Fig 15: Air velocity vs NO_x for fuel mass flow rate of $1.19*10^{-3}$ kg/s

From the above graph it is evitable tat NO_X emission at a mass flow rate of $1.19*10^{-3}$ kg/s is minimum for air velocity of 9.5 m/s.

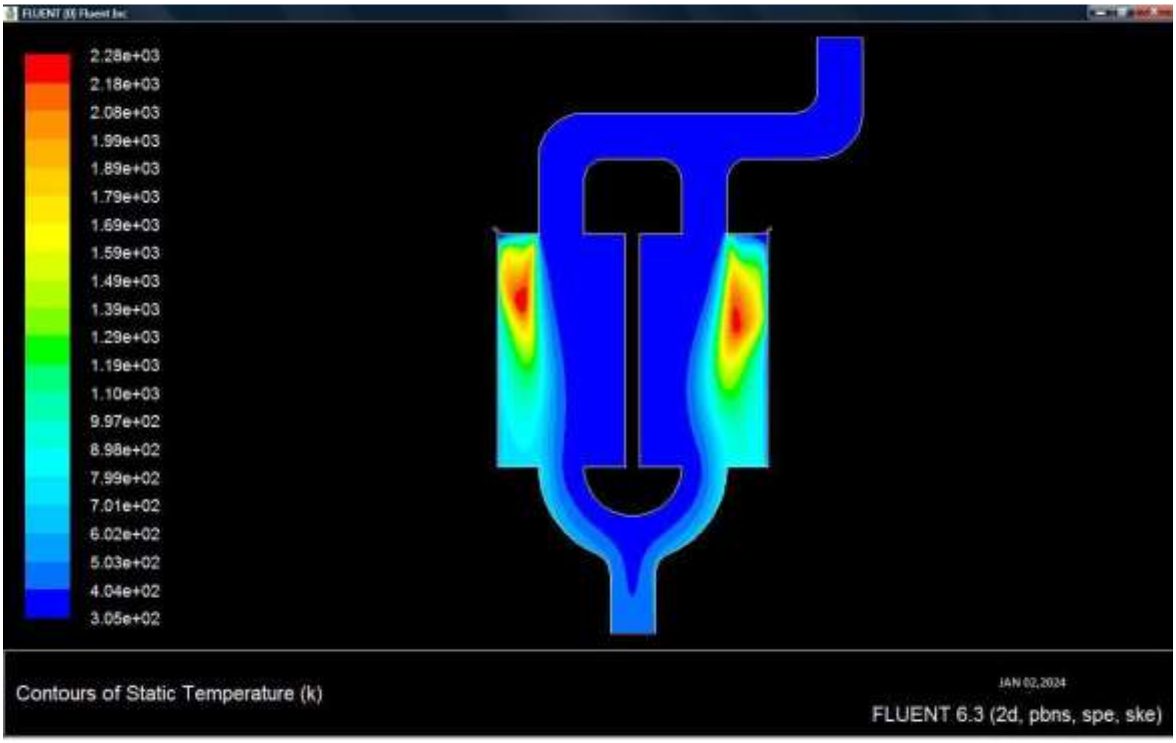

Fig 16: Contours of static temperature of fuel mass flow rate of $1.19*10^{-3}$ kg/s at air velocity of 9.5m/s

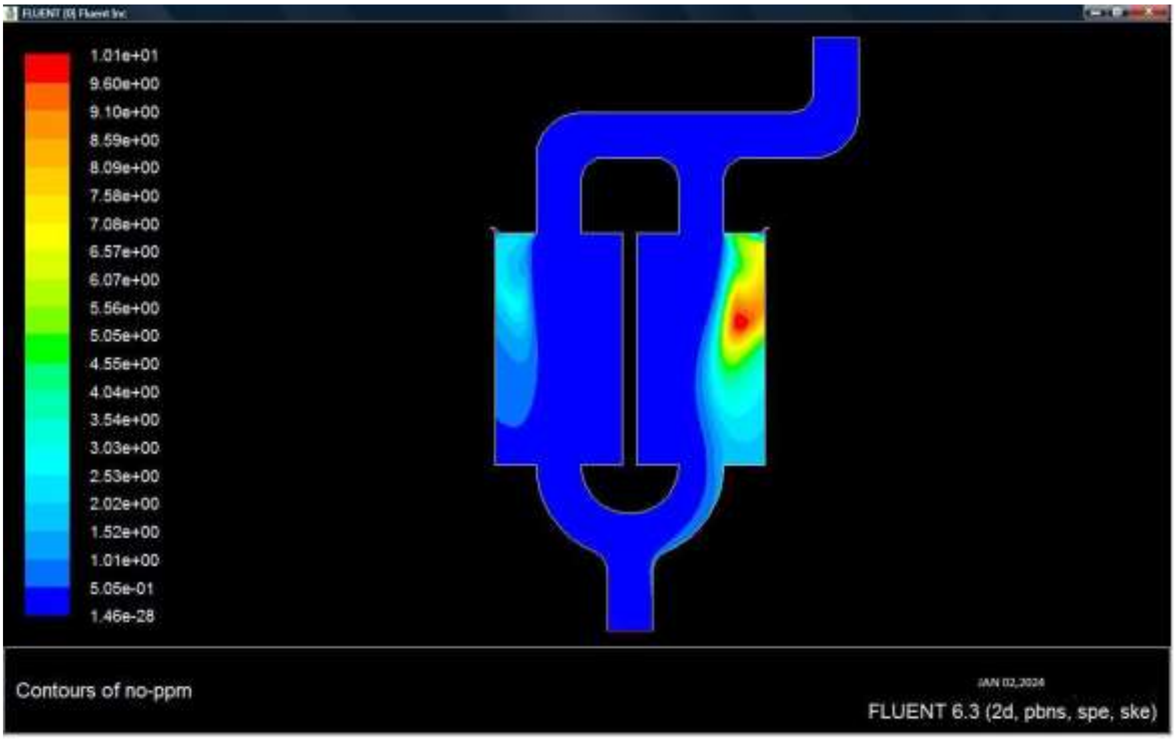

Fig 17: Contours of NO-PPM of fuel mass flow rate of $1.19*10^{-3}$ kg/s at air velocity of 9.5m/s

Air Velocity (m/s)	**Temperature (k)**	**NO_x (ppm)**
0.5	2438.466	285.3179
1	2517.945	198.9883
1.5	2535.238	161.5938
2	2542.586	139.6385
2.5	2504.967	111.4205
3	2490.747	94.0551
3.5	2438.882	71.94554
4	2387.736	55.59253
4.5	2294.836	36.19157
5	2278.775	31.86563
5.5	2284.825	28.10843
6	2286.243	24.63565
6.5	2284.722	21.46
7	2280.784	18.44975
7.5	2274.972	15.9635
8	2265.828	13.78637

8.5	2260.805	11.81871
9	2263.295	10.6539
9.5	2272.16	10.20567
10	2288.521	9.952856
10.5	2312.238	10.10512
11	2349.317	10.62988
11.5	2386.953	11.26705
12	2399.639	11.84441
12.5	2405.682	12.04235
13	2404.151	11.68078
13.5	2387.94	11.6525
14	2388.464	12.16364
14.5	2402.103	12.40872
15	2407.093	13.22922

Table 8: Results for Mass Flow Rate of $1.28*10^{-3}$ kg/s

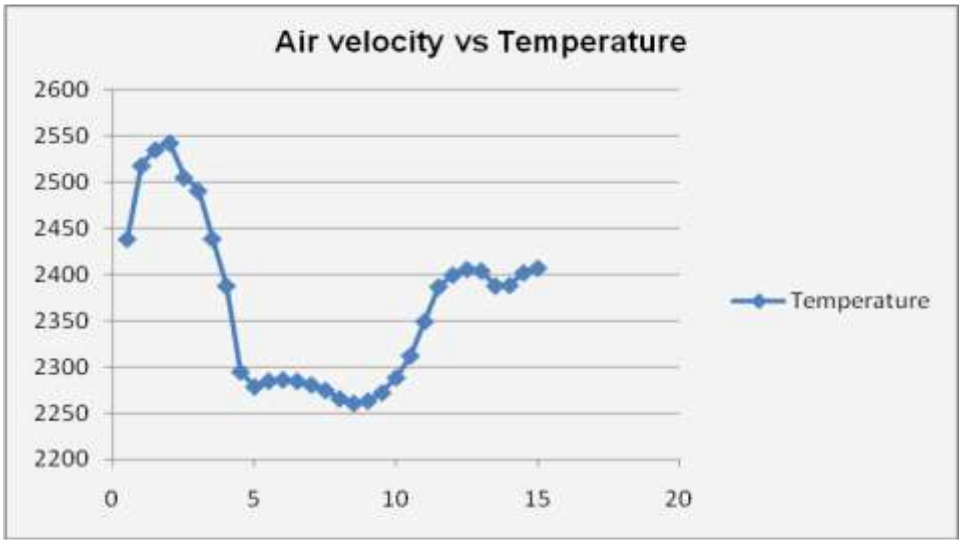

Fig 18: Air velocity vs Temperature for fuel mass flow rate of $1.28*10^{-3}$ kg/s

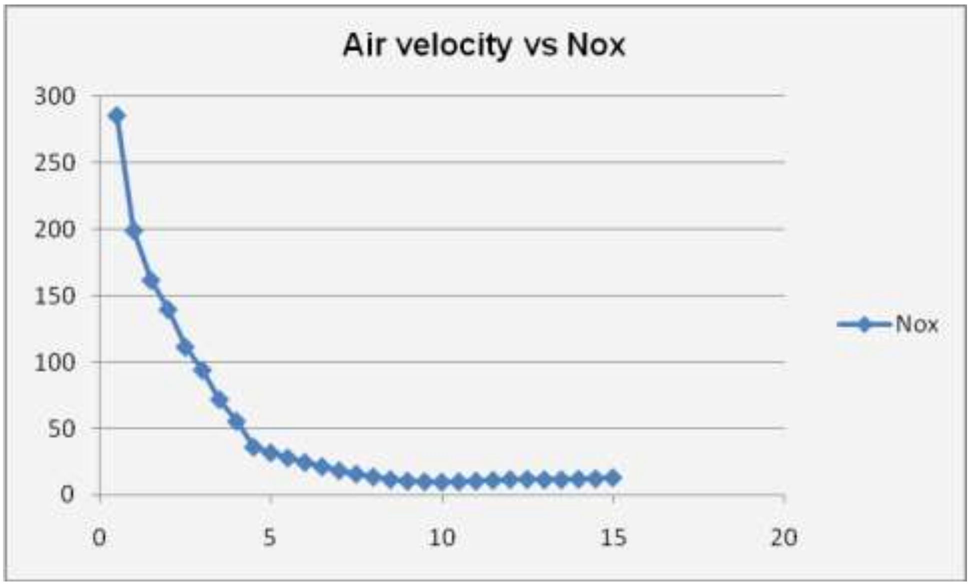

Fig 19 Air velocity vs NO_x for fuel mass flow rate of $1.28*10^{-3}$ kg/s

From the above graph it is evitable tat NO_X emission at a mass flow rate of $1.28*10^{-3}$ kg/s is minimum for air velocity of 10 m/s.

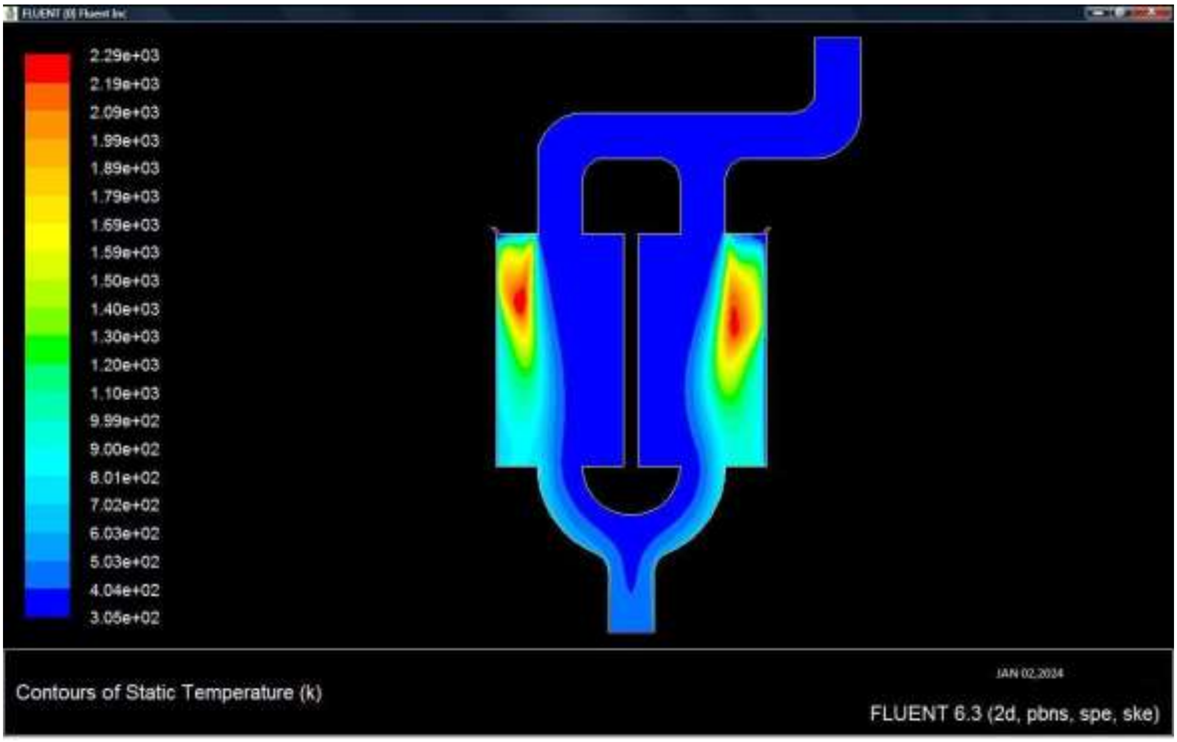

Fig 20: Contours of static temperature of fuel mass flow rate of $1.28*10^{-3}$ kg/s at air velocity of 10m/s

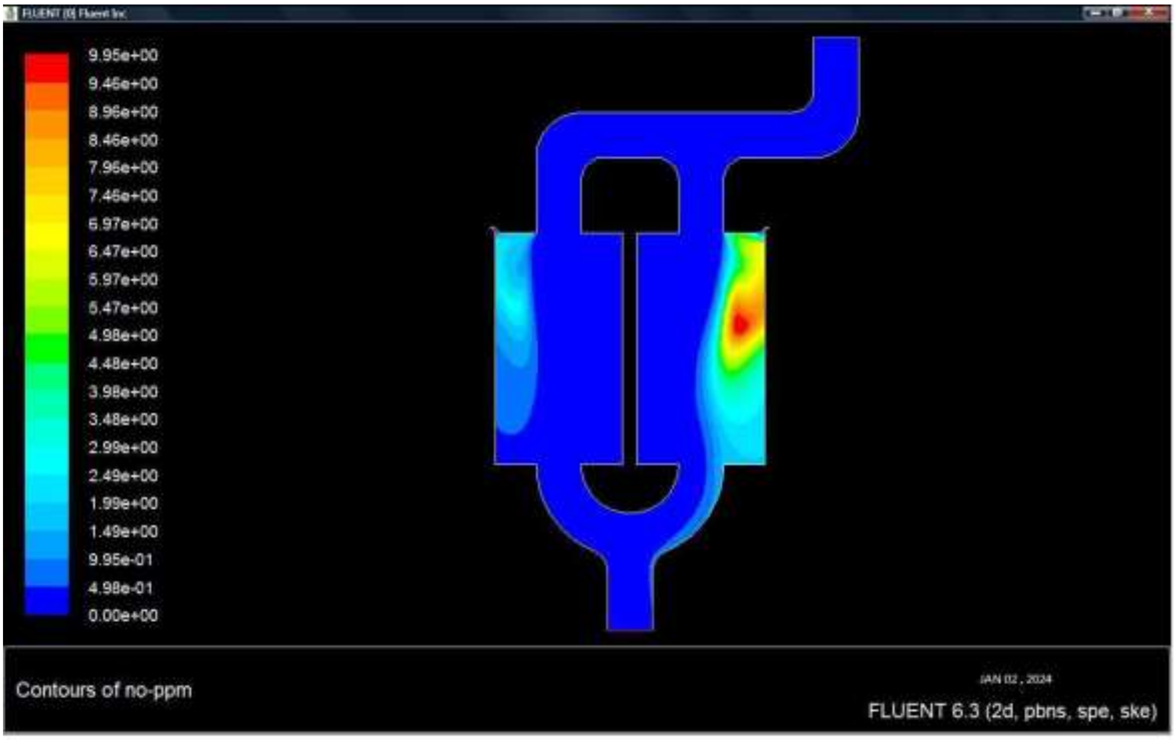

Fig 21: Contours of NO-PPM of fuel mass flow rate of $1.28*10^{-3}$ kg/s at air velocity of10m/s

7 CONCLUSION

The engine needs variable flow rate to enhance the combustion in the cylinder according to its operating condition. Optimum flow rate is necessary according to the engine operating condition for optimum combustion and emission reduction. So an experimental set up is been chosen and corresponding fuel consumption for various electrical loading conditions are found. These values are taken as input for CFD analysis. For each fuel consumption value corresponding air flow rate values are tabulated and from that air flow rate which produces minimum NO_x is found. These values are tabulated below.

Electrical loading(kw)	Fuel consumption (kg/s)	Air velocity(m/s)	Temperature(k)	NO_x(ppm)
0	$6.51*10^{-4}$	5	2152.927	10.12925
1.5	$9.22*10^{-4}$	7.5	2242.363	10.41714
3	$1.04*10^{-3}$	8	2242.179	10.31696
4.5	$1.19*10^{-3}$	9.5	2282.749	10.10894
6	$1.28*10^{-3}$	10	2288.521	9.952856

Table 9 Optimized Results

The CFD results provided clearly shows that the nitrous oxide is reduced drastically by apply varying air flow rate according to its condition. Thus the minimum NO_x emission values are found for variable fuel consumption and air flow rate

REFERENCES

1) Abdel Rahman, A. A, 1998, " On the Emissions from Internal-Combustion Engines: *A Review*", *International journal of energy research Int. J. Energy Res., 22, 483-513.*

2) Bassem Ramadan, "A study of swirl generation in DI engines using KIVA-3A, *Kettering University.*

3) Benajes. J, Molina. S, Garcı´a, J M and Riesco. J M, 2004," The Effect of Swirl on Combustion and Exhaust Emissions in Heavy-Duty Diesel Engines" *Proc. Instn Mech. Engrs Vol. 218.*

4) Chatterjee. D, Datta. A, Ghosh. A K & Som S K, 2004, “Effects of Inlet Air Swirl and Spray Cone Angle on Combustion and Emission Performance of a Liquid Fuel Spray in a Gas Turbine Combustor”, *IE (I) Journal.AS, Vol 85, November.*

5) David Rathnaraj. J, and T. Michael. N. Kumar, 2007, “Studies on Variable Swirl Intake System for DI Diesel Engine Using CFD”, *International Journal of Applied Engineering Research ISSN 0973-4562 Volume 2.*

6) Frassoldati. A., Frigerio. S., Colombo E., Inzoli. F., and Faravelli.T., 2004,

“Determination of No_x Emission From Strong Swirling Confined Flames with an Integrated CFD-Based Procedure” , *Chemical Engineering Science 60 (2005) 2851 – 2869.*

7) Fuchs .T. R. and Rutland .C. J., “Intake Flow Effects on Combustion and Emissions in a Diesel Engine”, *University of Wisconsin-Madison.*

8) Junichi Kawashima, 1998, “Research on a Variable Swirl Intake Port for High-Speed 4 Valve DI Diesel Engine”, *SAE Technical series 980508, Yokosuka 237-8523.*

9) Kern Y. Kang and Rolf D. Reitz, 2000, “Intake Flow Structure and Swirl Generation in a Four-Valve Heavy-Duty Diesel Engine”, *ASME, Vol. 122, October.*

10) Ki-Doo Kim and Dong-Hun Kim, “Improving the NOx-BSFC Trade Off of a Turbocharged Large Diesel Engine Using Performance Simulation*”, Hyundai Heavy Industries Co., Ltd.*

11) Lewellen. D. C, Lewellen. W.S and Xia. J, 1999 “The Influence of a Local Swirl Ratio on Tornado Intensification near the Surface” *American Meteorological Society, 15 February, Volume57.*