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The Experimental Reduction of Combustion Noise at Idle Speed in a 4 Cylinder CRDI Diesel Engine by Optimizing the Fuel Injection Pressure

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Abstract: The design and development of modern internal combustion engines are marked by a reduction in exhaust gas emissions and increase in specific power and torque. This paper aims at the study of noise reduction in4-stroke common rail direct injection engine at idle speed. Idle speed is basically a speed of the engine when the vehicle is not running i.e not in motion. Nowadays, this situation often comes at red lights, in traffic and in waiting while parked outside a business or residence etc. This paper presents a study about the effects of Fuel Injection Pressure on the combustion process. The end conclusion of the whole experiment is that reduction of noise takes place by optimizing the fuel pressure. In this experiment, idle speed is 850 rpm. Then we set the fuel pressure at 200 bars at this pressure the noise is minimum which is 56 dB. Further, increase the fuel pressure the noise of the 4 cylinder CRDI diesel engine increases gradually at different stages like at 300 bar fuel pressure the noise of CRDI diesel engine is 60db.

***Keywords**: CRDI, Idle Speed, Fuel Injection Pressure, ECU.*

I.INTRODUCTION

This paper aims at the study involved trying various injection pressures with the help of an Open ECU from Laptop in a four cylinder CRDi Diesel Engine. A general layout of the test bed installation, the instrumentation used and the data acquisition system. A brief description of the individual components is provided in the following subsections. The engine used for this experiment is a turbocharged four cylinder water cooled four stroke diesel engine. Diesel fuel is injected directly into the combustion chamber with common-rail fuel injection equipment [5]. The pressure in the rail can be changed online with the help of an Open ECU. The customer's subjective impression of the entire vehicle, regarding items such as diesel knock sensitivity, provides evidence to support its value [7]. Countries around the world continue to legislate against the release of specific levels of exhaust gas emissions, such as Nitrogen oxide, hydrocarbon, and carbon monoxide and smoke [1]. India typically introduces new emission legislation approximately every four years. Since last few years, new vehicles in India have been required to meet the BS4 exhaust emission levels [4]. Additionally, customer requirements for combustion noise need to be met, which can be accomplished through optimization of the combustion system. For a long time now, the reduction of noise and vibration is one of the major concerns of carmakers for their Diesel engines. Cold and idle conditions are considered to be the most critical conditions for both combustion noise and pollutant emissions [3]. These goals can be met through the development of advanced combustion systems and the increased flexibility of fuel injection systems and ECUs. This report presents the results of a study about the effects of Fuel Injection Pressure on the combustion process and on the combustion noise at the idle condition in a 4 Cylinder CRDi Engine.

II OBJECTIVES OF THE STUDY

For a long time now, the reduction of noise and vibration is one of the major concerns of carmakers for their Diesel engines. Idle conditions are considered to be the most critical from combustion noise point of view. It is also the case for the control of pollutant emission. Cold and idle conditions are considered to be the worst conditions in term of pollutant emission control. It is the case for the noise emission too. In such conditions, the piston and the chamber walls are cold, or at most not as hot as it could be in other conditions. The injection and the ignition occur in a cold environment which doesn't contribute positively to the combustion progress. The wall and chamber temperatures are well known to be key parameters for the pollutant emissions. It has also been required recently that diesel engines for passenger cars meet various requirements, such as low noise, low fuel consumption, low emissions and high power. The key to improving the noise is to reduce a combustion noise known as "Diesel knock noise". Conventional approaches to reducing the diesel knock are decreasing combustion excitation force due to pilot/pre-fuel injection, adding ribs to engine blocks or improving noise transfer characteristics by using insulation covers. However, these approaches have negative effects, such as deterioration in fuel economy and increase in cost/weight. We will try to lower the diesel combustion noise reduction by using this new technology. The aim of the present work is to evaluate the effects of injection parameters on the combustion process in regard to the combustion noise emission.

III. REVIEW OF LITERATURE

Jung, I., et al. [5] The source of the combustion noise of diesel engines was investigated in their study. In the development of exhaust emission and combustion noise, we must optimize the injection parameters at the cell where engine noise cannot be measured. To solve this problem, it is necessary to identify a method for developing combustion noise through in-cylinder pressure measurements. It is known that the combustion noise of a diesel engine is generated mainly in the phase of premixed combustion and depends on the rate at which the pressure increases. The combustion noise was analyzed by measuring the in-cylinder pressure and engine noise. Their results showed that the combustion noise has a low correlation with the maximum rate of pressure increase. For this reason, a new index called the combustion noise index was developed based on the cylinder pressure level. Their study described an advanced method for developing combustion noise and illustrates some examples of the results obtained.

I. Jung, et al. [6] has studied the development of exhaust emission and combustion noise, we must optimize the injection parameters at the cell where engine noise cannot be measured. To solve this problem, it is necessary to identify a method for developing combustion noise through in-cylinder pressure measurements. It is known that the combustion noise of a diesel engine is generated mainly in the phase of premixed combustion and depends on the rate at which the pressure increases. The combustion noise was analyzed by measuring the in-cylinder pressure and engine noise. Our results show that the combustion noise has a low correlation with the maximum rate of pressure increase. For this reason, a new index called the combustion noise index was developed based on the cylinder pressure level. This paper describes an advanced method for developing combustion noise illustrates some examples of the results obtained.

W. C. Starahle, et al.[7]Experiments have been performed on a single-cylinder air-cooled direct injection four stroke Dieselengine to determine the connection between combustion randomness and radiated noise. The tests reported have carried the engine to its maximum fuel flow condition and investigated the effects of Cetane rating. The tests have conclusively demonstrated that a substantial amount of the radiated noise is causally related to the randomness (turbulence) of the combustion process and not the mean pressure-time history. However, the higher the load, the less the effect of the randomness on total noise output.

JianguangHe , et al. [8]To investigate the characteristic of combustion noise in a non-road diesel engine, tests with different bio-diesel ratio fuel were conducted. According to the cylinder pressures of 100 consecutive combustion cycles, combustion noise was analyzed. The results show that, with the increase of blended bio-diesel ratio, both the maximum cylinder pressure and the maximum rate of pressure rise all have increasing trends. The cylinder pressure level at the frequency of 1000Hz increases with blended bio-diesel ratio. In the test with B50 fuel, the biggest value of combustion noise appears and its value is about 0.5 dB(A) bigger than that of diesel at full load. The blending of bio-diesel has a dual effect on combustion noise which contributes to the increase of combustion noise and the reduction of it. At the same time, advance angle of fuel supply has great influence on combustion noise of diesel engine fueled with bio-diesel and fuel supply delay can properly reduce combustion noise of diesel engine effectively.

A E Catania, et al.[9] In the present work, the model has been assessed in detail byanalyzing a wide set of experimental engine data that were acquired during the engine calibration phase. The experimental data set has been defined according to the DoE (Design of Experiment) methodology currently used for engine calibration purposes, and applied to six 'key points' that are representative of engine working operations during an NEDC (New

European Driving Cycle) for a D-class passenger car. Different injection strategies (pilot-main, double pilot-main; pilot-main-after; double pilot-main-after) have been considered for each key point, and all the main engine operating parameters (rail pressure, injected quantities, boost level, intake temperature, EGR rate, …) have been included in the DoE variation list. Therefore, about 1000 steady-state engine operating conditions have been investigated. In addition, several NEDC driving cycles have been realized with the engine installed on a dynamic test rig, and the combustion parameters and emission levels have continuously been measured during the transient operations. The model has been applied to all the investigated conditions. It has shown excellent accuracy in estimating the values of the main combustion parameters, and a good matching between the calculated and predicted NOx concentrations was found, for both steady-state and transient operations.

Kennie H. Jones, et al. [10] Emergent behavior, a subject of much research in biology, sociology, and economics, is a foundational element of Complex Systems Science and is apropos in the design of sensor network systems. To demonstrate engineering for emergent behavior, a novel approach to the design of a sensor/actuator network is presented maintaining optimal noise attenuation as an adaptation to changing acoustic conditions. Rather than use the conventional approach where sensors are managed by a central controller, this new paradigm uses a biomimetic model where sensor/actuators cooperate as a community of autonomous organisms, sharing with neighbors to control impedance based on local information. From the combination of all individual actions, an optimal attenuation emerges for the global system.

GequnShu, et al. [11] This paper studies combustion noise mechanism during transient operation of naturally aspirated-DI-Diesel engines by developing testing techniques and methods. By testing and analysing four load conditions, the mechanism that governs the differences between transient and steady-state combustion noise is studied. The analysis demonstrates that during transients, the combustion chamber wall temperature, fuel injection pressure, maximum needle lift and unseal standing time of needle lift are higher than those under steady-state conditions for the same speed and load; a fact causing differences in ignition delay, start point of combustion and fuel injection quantity during transient conditions with a low acceleration rate. It is shown that the differences between the combustion chamber wall temperature, fuel injection pressure, and ignition delay, as well as high-frequency oscillation of combustion pressure, develop during transients in a different pattern compared to the respective steady-state conditions, thus resulting in different combustion noise emissions.

Q. Leclere , et al.[12] We are interested in the low-frequency amplitude modulation of the noise generated by an engine operating at idle. This phenomenon, perceived inside the car, is particularly annoying. Modulated vibrations are transmitted to the frame mainly by one of the three engine mounts. The combustion is the first potential source to be inspected, but pragmatic observations on consecutive measurements show that it is not the cause of the amplitude modulation. Spectral analysis tools are applied to multi-channel measurements to identify the source of the phenomenon. A sensor is placed on each potential noise and vibration source. A virtual source analysis shows that several uncorrelated sources are contributing to the operating response, particularly on frequencies for which a high amplitude modulation is observed. The computation of residual spectra obtained by means of conditioned spectral analysis proves that the diesel pump is involved in the amplitude modulation. Experiments are carried out to validate this diagnosis. Added masses appropriately placed on the injection circuit strongly attenuate the phenomenon.

Evangelos G. Giakoumis , et al .[13] Diesel engine noise radiation has drawn increased attention in recent years since it is associated with the passengers' and pedestrians' discomfort, a fact that has been acknowledged by the manufacturers and the legislation in many countries. In the current study, experimental tests were conducted on a truck, turbocharged diesel engine in order to investigate the mechanism of combustion noise emission under various transient schedules experienced during daily driving conditions, namely acceleration and load increase. To this aim, a fully instrumented test bed was set up in order to capture the development of key engine and turbocharger variables during the transient events. Analytical diagrams are provided to explain the behavior of combustion noise radiation in conjunction with cylinder pressure (spectrum), turbocharger and governor/fuel pump response. Turbocharger lag was found to be the main cause for the noise spikes during all test cases examined, with the engine injection timing calibration and the slow adjustment of cylinder wall temperature to the new fueling conditions playing a vital role. The analysis was extended with a quasi-steady approximation of transient combustion noise using steady-state maps, in order to better highlight the effect of dynamic engine operation on combustion noise emissions.

T.M Nguyen,et al .[14] This study investigates the characteristics of combustion noise from a diesel engine with hydrogen added to intake air. The engine noise with hydrogen addition of 10 vol% to the intake air was lower than that with diesel fuel alone at late diesel-fuel injection timings. A transient combustion-noise-generation model was introduced to discuss noise characteristics based on energy conversion from combustion impact to noise via structure vibration. The results show that the maximum combustion impact energy had a predominant effect on the maximum engine noise power for each cycle. Therefore, the combustion noise largely contributed to the total engine noise in an early stage of the expansion stroke. The dependences of engine noise on the diesel-fuel injection timing for different hydrogen fractions are discussed considering the characteristics of maximum combustion impact energy for each frequency.

L. Pruvost, et al .[15] The present paper is dedicated to diesel engine combustion and mechanical noise separation. It is shown that this separation can be performed by a spectro filter if and only if the spectro filter is computed using only the random part of the engine signals. This source separation is a difficult task, since the sources are correlated and overlapped both in time and frequency domains. Considering only the random part of the signals virtually uncorrelated the noise sources, making them easier to separate. This approach is validated by the results of a simulation. An experiment based on real engine signals shows that the spectrometer is more causal and more robust if computed using only the signals random part. This experiment also shows that speed rotation and load condition affect the engine transfer functions.

John C. Mossing, et al.[16] The problem of detecting and classifying outside sound sources (i.e., diesel engines, rotors, etc.) by their acoustic emissions is applicable to a number of industries. The key to successful detection and classification is selecting harmonically related narrowband peaks in the frequency domain. These harmonically related narrowband features are directly attributed to physical phenomena (i.e., engine firing rates and rotor RF'M). The spectral signatures of these sources are non-stationary and require the use of time-frequency analysis techniques to achieve high-resolution spectral estimates.

Evangelos G Giakoumis , et al ,[17] In the current study, experimental tests were conducted on a turbocharged truck diesel engine in order to investigate the mechanism of combustion noise radiation during various accelerations and for various fuel blends. With this aim, a fully instrumented testbed was set up in order to capture the development of key engine and turbocharger parameters. Apart from the baseline diesel fuel, the engine was operated with a blend of diesel with either 30 vol % biodiesel or 25 vol % n-butanol. Analytical diagrams are provided to explain the behaviour of combustion noise radiation in conjunction with the cylinder pressure, the pressure rise rates, the frequency spectrum and the turbocharger and governor–fuel pump responses. The blend of diesel fuel with n-butanol exhibited the highest noise emissions throughout each of the transient tests examined, with differences up to 4 dBA from those with neat diesel operation. On the other hand, the biodiesel blend was found to behave marginally noisier than neat diesel oil but without a clear trend established throughout the transient events.

Ming Shen , et al. [18]A measurement method for characterizing the substrate noise over the ultra-wideband (UWB) frequency band in UWB systems implemented using lightly doped CMOS processes is presented. The measurement structure in this method is based on modified ground-signal-ground (GSG) pads. In addition, the effects of the distance-based substrate resistance and the capacitive coupling between the substrate and the ground of the measurement setup are evaluated by on-wafer measurement of a test chip fabricated in a 0.18μm lightly doped CMOS process. An equivalent circuit model of the presented measurement structure is given and shows accurate fit. From the measurement results, the presented method is shown to provide a measurement band from 3 GHz to 10 GHz. To further validate the usability of the method a practical class-E PA is used.to the increase of combustion noise and the reduction of it.

IV EXPERIMENTAL ANALYSIS

This paper aims at the study involved trying various injection pressures with the help of an Open ECU from Laptop in a four cylinder CRDi Diesel Engine. A general layout of the test bed installation, the instrumentation used and the data acquisition system is illustrated below. A brief description of the individual gogo components is provided in the following subsections. The engine used for this experiment is a turbocharged four cylinder water cooled four stroke diesel engine. Diesel fuel is injected directly into the combustion chamber with common-rail fuel injection equipment. The pressure in the rail can be changed online with the help of an Open ECU.

No. of Cylinders	4
Application	Automotive (Multispeed)
Volume	1994cc
Bore x Stroke (mm)	84.45 x 88.95
Compression Ratio	17.5:1
No. of Valves/Cyl	2
No. of Strokes	4
Ignition	CI
Camshaft	SOHC
Cooling System	Water Cooled
Max. Torque	260 Nm@1750-2500 rpm
Max. Power	100 bhp@4000 rpm

Fig. 1 Engine Details to be used for the study.

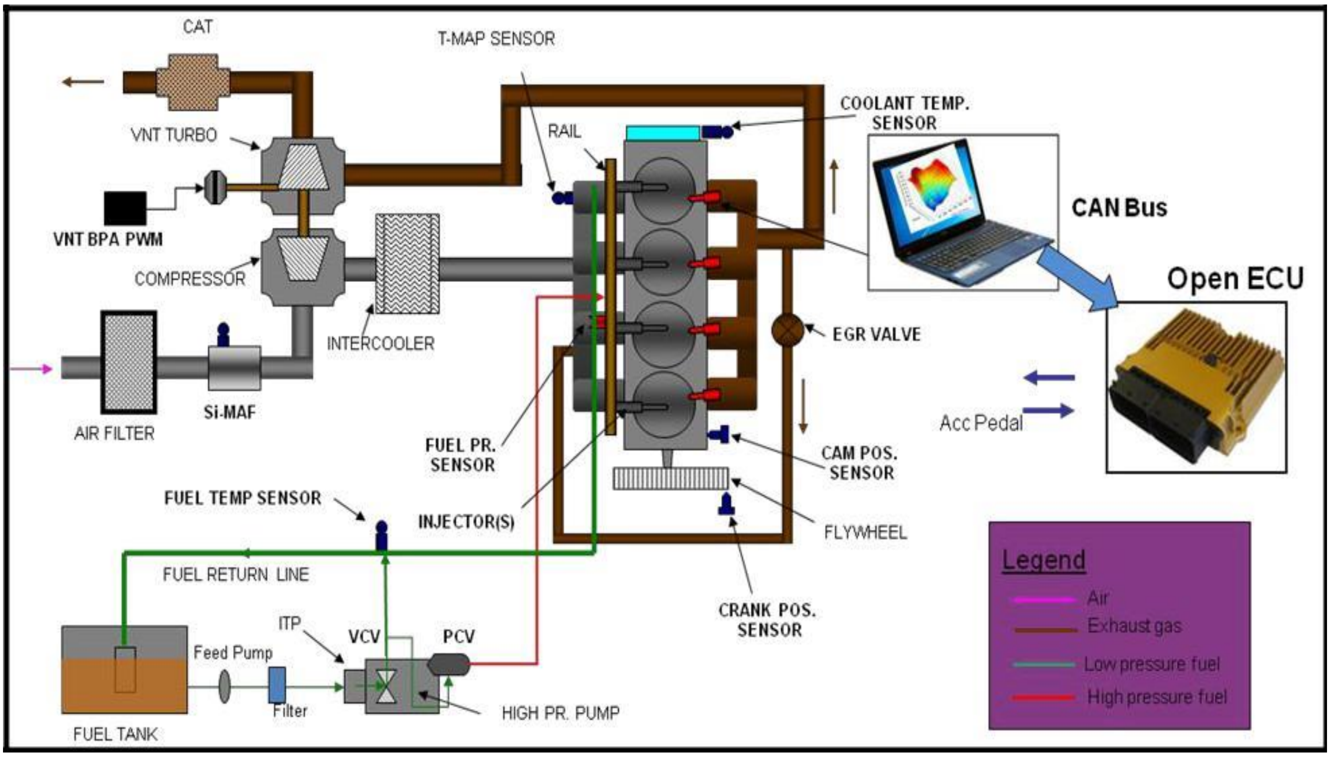

Fig.2 General Layout of Bed Installation.

RESULTS

TABLE: 4.1. Effect of change in pressure on Engine Temperature.

SNO.	ENGINE SPEED	FUEL PRESSURE	ENGINE TEMPERATURE
1	850	200	38.9
2	850	300	39.7
3	850	400	40
4	850	500	40.4
5	850	600	40.7
6	850	700	41
7	850	800	41.1
8	850	900	41.4
9	850	1000	41.4
10	850	1100	41.1
11	850	1200	40.7
12	850	1300	40.7
13	850	1400	41.1
14	850	1500	41.1
15	850	1600	41.5
16	850	1700	41.7

The table shows the effect of a change in pressure on engine temperature. As the fuel pressure increases, the engine temperature also increases. Results showed that when the fuel pressure is minimum, the engine temperature is also minimum.

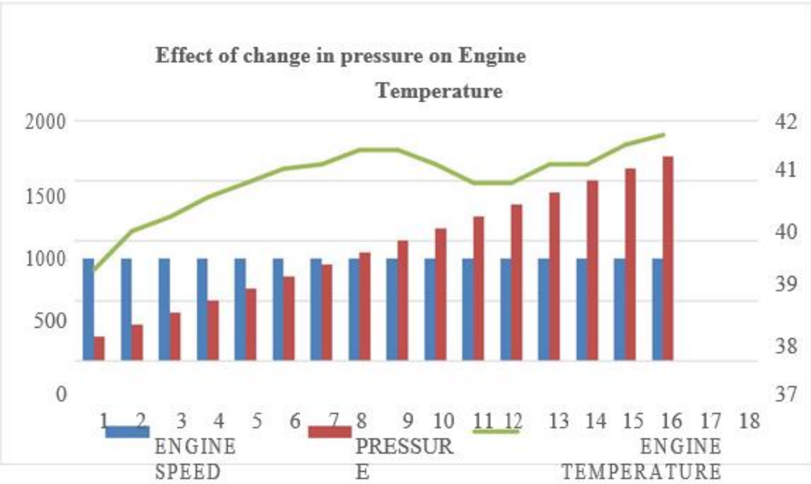

Fig: 4.1.Effect of change in pressure on Engine Temperature.

The figure shows the variation of engine temperature with respect to engine pressure. As the engine pressure decreases, the engine temperature also decreases correspondingly.

We can see that the ideal speed is same in all the cases and when we increase fuel pressure the noise level increases gradually. The noise at 1400 bar is maximum which 67 db is. Noise is very low at 200 bar and is 56 db.In this experiment, the combustion pressure also increases after increasing fuel pressure. Thus reduction of noise is seen the experiment**.**

Table: 4.2. Effect of change in pressure on Fuel Temperature

SNO.	ENGINE SPEED	FUEL PRESSURE	FUEL TEMPERATURE
1	850	200	39.6
2	850	300	40.9
3	850	400	42.6
4	850	500	44.7
5	850	600	47.4
6	850	700	49.4
7	850	800	51.3
8	850	900	53.8
9	850	1000	55.4
10	850	1100	56.7
11	850	1200	57.9
12	850	1300	58.8
13	850	1400	59.6
14	850	1500	60
15	850	1600	60.3
16	850	1700	60.6

The table shows the effect of a change in pressure on fuel temperature. It is shown in the table that as the fuel temperature decreases, the pressure of fuel is also increased correspondingly.

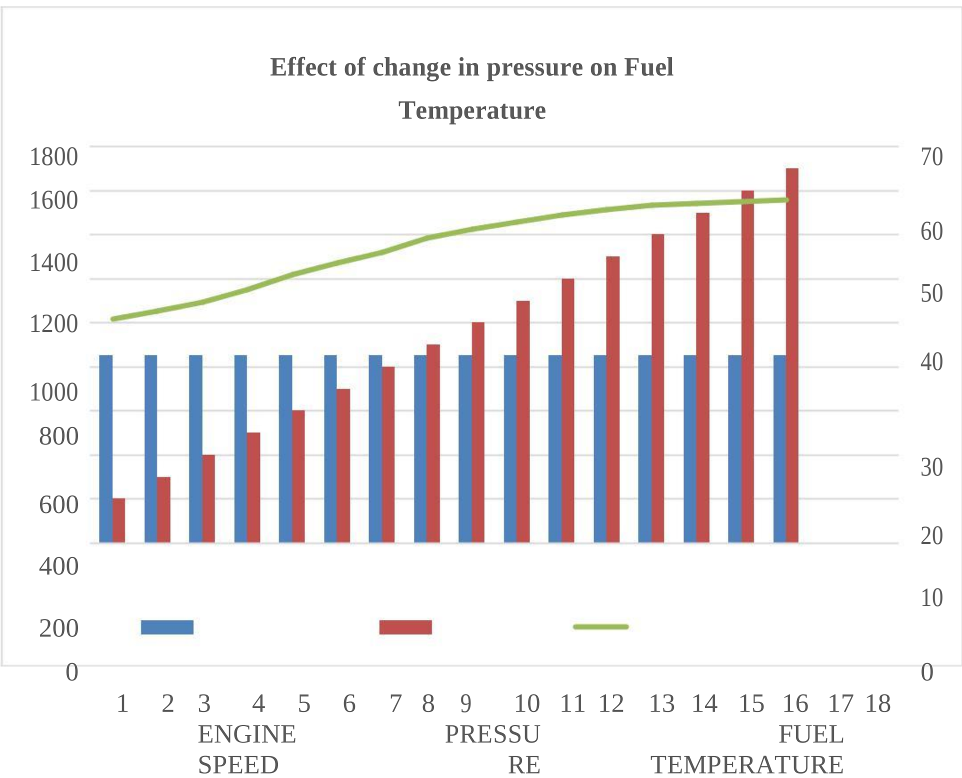

Fig: 4.2.Effect of change in pressure on Fuel Temperature

The figure shows the variation of fuel temperature with respect to fuel pressure. As the fuel pressure increases, the fuel temperature also increases.

We can see that the ideal speed is same in all the cases and when we increase fuel pressure the noise level increases gradually. The noise at 1400 bar is maximum which 67 db is. Noise is very low at 200 bar and is 56 db.In this experiment, the combustion pressure also increases after increasing fuel pressure. Thus reduction of noise is seen the experiment**.**

Table: 4.3.Effect of change in pressure on Noise

SNO.	ENGINE SPEED	FUEL PRESSURE	NOISE(db)
1	850	200	56
2	850	300	60
3	850	400	63
4	850	500	64
5	850	600	64
6	850	700	65
7	850	800	65
8	850	900	65
9	850	1000	66
10	850	1100	66
11	850	1200	66
12	850	1300	67
13	850	1400	67
14	850	1500	67
15	850	1600	68
16	850	1700	68

The table shows the effect of a change in pressure on noise. As the fuel pressure increases, the noise also increases. Results showed that when the fuel pressure is minimum, the noise is also minimum.

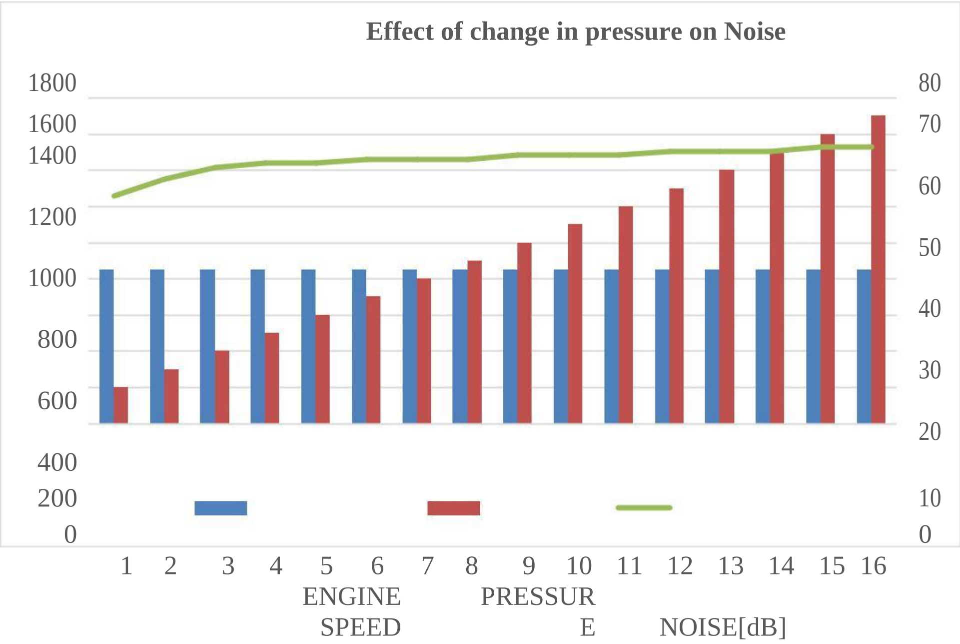

Fig: 4.3. Effect of change in pressure on Noise

As the engine pressure decreases, the noise also decreases correspondingly. We can see that the ideal speed is same in all the cases and when we increase fuel pressure the noise level increases gradually. The noise at 1400 bar is maximum which 67 db is. Noise is very low at 200 bar and is 56 db. In this experiment, the combustion pressure also increases after increasing fuel pressure. Thus reduction of noise is seen the experiment**.**

Table: 4.4.Effect of Pressure on FMSP

SNO.	ENGINE SPEED(RPM)	FUEL PRESSURE(Bar)	FMSP(mg/stroke)
1	850	200	8.5
2	850	300	8.5
3	850	400	8.5
4	850	500	8.5
5	850	600	9.2
6	850	700	9.7
7	850	800	9.7
8	850	900	9.7
9	850	1000	10
10	850	1100	11.5
11	850	1200	13
12	850	1300	13.5
13	850	1400	13.9
14	850	1500	13.9
15	850	1600	14.3
16	850	1700	14.7

Table shows the effect of change in pressure on FMSP. As the fuel pressure increases, the FMSP decreases. Results showed that when the fuel pressure is minimum, the FMSP is also minimum.

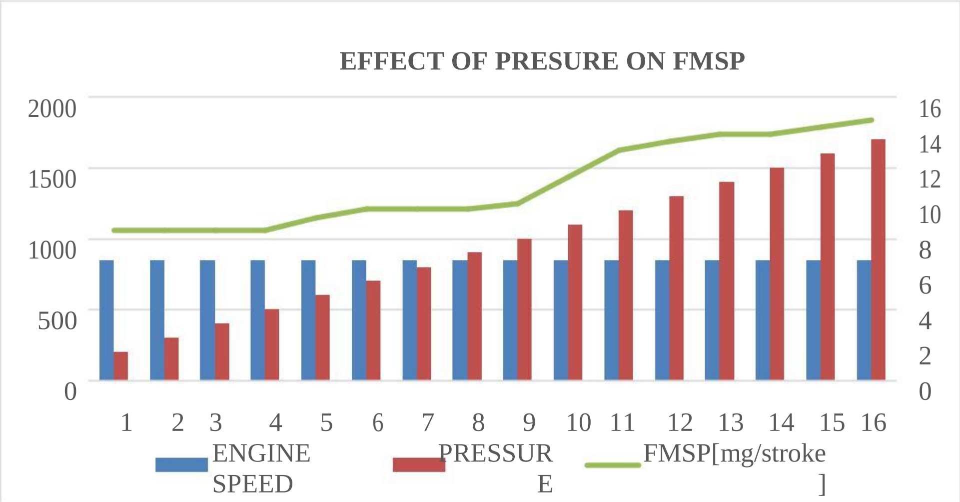

Fig: 4.4. Effect of Pressure on FMSP

The figure shows the variation of FMSP with respect to engine pressure. As the engine pressure decreases, the FMSP decreases correspondingly.

Table: 4.5. Effect of pressure on combustion pressure

SNO.	ENGINE SPEED	FUEL PRESSURE	COMBUSTION PRESSURE
1	850	200	50.4
2	850	300	51.4
3	850	400	52.7
4	850	500	51.9
5	850	600	53.6
6	850	700	51.1
7	850	800	52.7
8	850	900	52.1
9	850	1000	53.9
10	850	1100	56.1
11	850	1200	54.9
12	850	1300	53.3
13	850	1400	53.5
14	850	1500	53.8
15	850	1600	54.2
16	850	1700	54.9

The table shows the effect of a change in pressure on combustion pressure. As the fuel pressure increases, the combustion pressure decreases. Results showed that when the fuel pressure is minimum, the combustion pressure is also minimum.

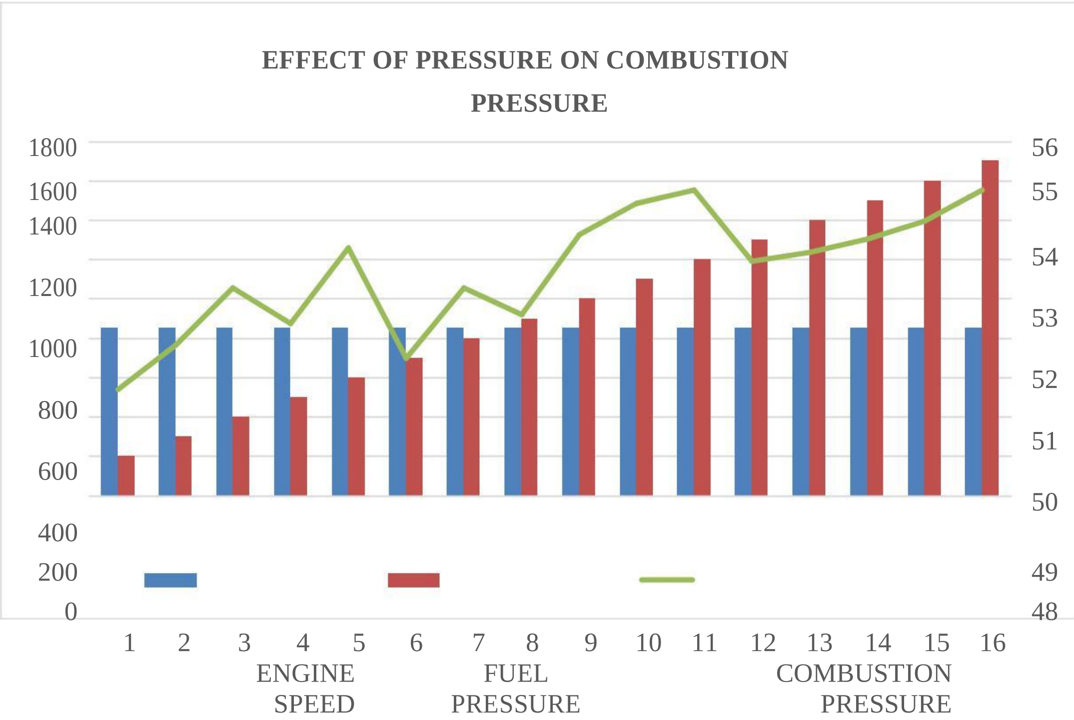

Fig: 4.5.Effect of pressure on combustion pressure

The figure shows the variation of combustion pressure with respect to engine pressure. As the engine pressure decreases, the combustion pressure decreases correspondingly.

CONCLUSIONS

1. The end conclusion of the whole experiment is that reduction of noise takes place by optimizing the fuel pressure.
2. In this experiment, idle speed is 850 rpm. Then we set the fuel pressure at 200 bar at this pressure the noise is minimum which is 56 db.
3. Further, increase the fuel pressure the noise of the 4 cylinder CRDI diesel engine increases gradually at different stages like at 300 bar fuel pressure the noise of CRDI diesel engine is 60db.
4. Increase in fuel pressure the noise increases the maximum noise is found at 1500 bar fuel pressure the noise at this point is 67db.This is the conclusion of the whole experiment.

REFERENCES

1. Kennie H. Jones, Douglas M. Nark, and Michael G. Jones [2009] “Cetane Rating and Load Effects on Combustion Noise in Diesel Engines” SAE Technical Paper, 745-749.
2. GequnShu and Haiqiao Wei Fijisova N, James L. Natalie and Woodard J.C [2003] “Study of combustion noise mechanism under accelerating operation of a naturally aspirated diesel engine.”,Int. J. Vehicle Design, Vol. 45, Nos. 1/2, 2007
3. Leclere Q, Pezerat C, Laulagnet B, Polac L. Multi-channel analysis of complex vibroacoustic sources. In: Proceedings of Inter-Noise 2004, Tcheck Republic: Prague; 2004.
4. Evangelos G. Giakoumis, Davies P, Bernhard RJ, Ufford DA. A technique to determine the number of incoherent sources contributing to the response of a system. J MechSyst Signal Proc1994;8(4):363–80.
5. T.M Nguyen, Ma del Rocıo Fernandez, R.Vijande Diaz, R. Tucho Navarro [2003] “Cetane Rating and Load Effects on Combustion Noise in Diesel Engines” SAE Technical Paper, 255,38-43.
6. L. Pruvost, Mondel D.P, H.K Khaira and A.K. Jha [1999] “Study of combustion noise mechanism under accelerating operation of a naturally aspirated diesel engine,SAE Technical Paper8, 711-715.
7. John C. Missing and Onodera M. Performance of a diesel engine fuelled by rapeseed oil blended with oxygenated organic compounds. SAE paper 2002-01-2854, 2002.
8. Evangelos G Giakoumis and Hosoz M. Performance and emission characteristics of a diesel engine using isobutanol–diesel fuel blends. Renewable Energy 2009; 34: 1554– 1559.
9. Ming Shen, Carlson RW, McConnell SS, et al. Drive cycle analysis of butanol/diesel blends in a light-duty vehicle. SAE paper 2008-01-2381, 2008.
10. M. Kondo, Kristof L, Bereczky A and Mbarawa M. Experimental investigation of fuel properties, engine performance, combustion and emissions of blends containing croton oil, butanol, and diesel on a CI engine. Fuel 2011; 90: 505–510.
11. M. Y.E. Selim, Filipi ZS and Assanis crimre DN. Transient diesel emissions: analysis of engine operation during a tip-in. SAE paper 2006-01-1151, 2006.
12. Boehman AL, Morris D and Szybist J. The impact of thebulk modulus of diesel fuels on fuel injection timing. Energy Fuels 2004; 18: 1877–1882.
13. Rakopoulos CD, Dimaratos AM, Giakoumis EG and Peckham MS. Experimental assessment of turbocharged diesel engine transient emissions during acceleration, load change and starting. SAE paper 2010-01-1287, 2010.
14. Tsolakis A, Megaritis A, Wyszynski ML and TheinnoiK. Engine performance and emissions of a diesel engine operating on diesel–RME (rapeseed methyl ester) blend with EGR (exhaust gas recirculation). Energy 2007; 32: 2072–2080.
15. Yao M, Wang H, Mater Chang Z and Yue Y. Experimental study of n-butanol additive and multi-injection on HD diesel engine performance and emissions. Fuel 2010; 89: 2191– 2201.
16. Hansen AC, Kyritsis DC and Lee CF. Characteristics of biofuels and renewable fuel standards. In: AA Verte` s, N Qureshi cheeku, HP Blaschek and H Yukawa (eds) Biomass to biofuels – strategies for global industries. Oxford: Blackwell Publishing, 2009
17. Dong Tang, Chaofeng Lai, Zhengquan Hu, ect. Combustion noise of biogas diesel dual-fuel engine [J]. Journal of Jiangsu University, 255,417–425.
18. Mohsmrd Y.E. Selim, M.S.Radwan, H.E.Saleh., et al. improving the performance of dual fuel engines running on natural gas/LPG by using pilot fuel derived from jojoba seeds [J]. Renewable Energy

