A Review of Combustion-Based Noise in Engines

Dr. **Vipul GUPTA[1],** Dr. **S. NARAYAN[2*]**

[1] Indus University, India

[2] Qassim University, Saudi Arabia

* Corresponding author's e-mail address: rarekv@gmail.com

Abstract: *This portion of noise is attributed due to combustion process taking place inside cylinders. Previous works have shown that engine block vibrations are also sensitive towards various changes in fuel injection parameters. Accelerometer signals have been able to locate various important features of combustion process in diesel engines. Use of in cylinder pressure and block vibration transducers form an important methodology for analysis of combustion process taking place in diesel engines. Data from microphones located at a suitable distance from engine also provides an important information about performance of engines, however there is a major risk of contamination of these signals.*

Keywords: *Noise, vibrations, acoustic*

1. Introduction

Combustion noise generated mainly depends upon the rate of in cylinder pressure developed during ignition delay period. Overall design of combustion chamber as well as variations in various fuel injection parameters e.g., injection pressure, amount of fuel injected and its timings also play a crucial role in contributions of combustion noise emissions from engines [1]. Depending upon the type of engine as well as various operational parameters, overall noise emissions from a typical diesel engine may be in range 80-110dBA [2, 3]. Split injection using electronic control unit (E.C.U.) may help to shortens the period of premixed phase of combustion and hence help to reduce the overall noise emissions by about 5-8dBA [4]. Head and Wakes have shown that during transient operational conditions, overall noise levels are about 4-7dBA higher as compared to steady state operations [5]. Cold starting conditions may lead to higher ignition delay period, which in turn causes increase in the premixed period of combustion [6]. Quality of fuel injected inside combustion chamber also affects the magnitude of combustion noise. It has been observed that a reduction of Cetane number of fuel from 50 to 40 causes a rise of up to 3 dBA in combustion based noise emissions [7]. For a naturally aspirated engine, the combustion-based noise depends upon the quantity of fuel that mixes with air charge during the course of delay period and hence the compression ratio of engines also plays a vital role [7]. In case of gasoline engines, the delay period is longer due to lower compression ratio, which may lead to lower temperature of charge and hence more noise emissions [7].

2. Background of combustion process in diesel engines

Due to high efficiency, diesel engines have been a favorite choice in case of heavy-duty automobiles including trucks [8]. However, they suffer from major drawbacks of high noise, weight and vibrations. These engines may be further classified into following two major types:
1. Direct injection (D.I.) engines
2. Indirect injection (I.D.I.) engines
In case of D.I. engines, the fuel is injected directly inside the combustion chamber and as a consequence of it, lesser time is available for formation of fuel and air mixture. Hence, a heterogeneous mixture consisting of both rich as well as lean parts is formed inside the chamber.

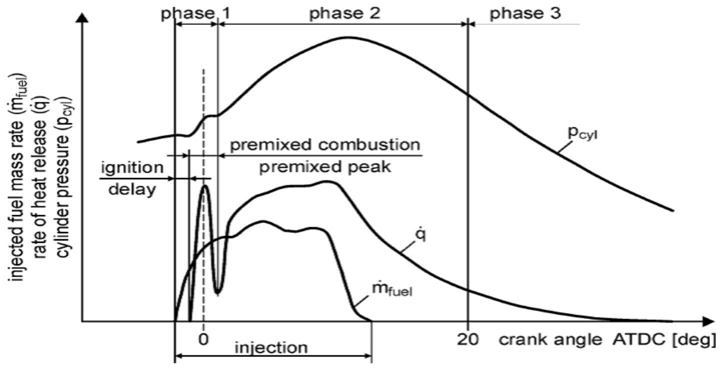

Fig. 1. Various phases of Diesel engine combustion [8]

Figure no 1 shows various phases of combustion as observed during course of operation of a typical diesel engine. The delay phase starts with onset of injection process and ends with beginning of premixed phase of combustion. The injection of fuel inside combustion chamber begins a few degrees before TDC position depending on the various injection conditions of engine. As soon as the cold jet of fuel penetrates the chamber, it mixes up with hot compressed air already present inside. The droplets thus formed vaporize, forming layers of fuel-air mixture around the periphery of jet. As the temperature rises to about 750K, the first break down of Cetane fuel takes place. Further propagation of various chemical reactions produces C_2H_2, C_3H_3, C_2H_4, CO_2 as well as water vapors [9].

Resulting rise in temperatures causes a complete combustion of fuel-air mixture formed. This sudden period of combustion further leads to rise in the heat release rate as well as high pressure gradient($\frac{dP}{d\theta}$). This further enhances temperatures in the pre-mixed zone leading to conditions favourable for production of NO_x. Once the premixed phase consumes all mixture formed,oxygen available for combustion is consumed around the inner regions wherein the temperatures in ranges of 1600-1700K are reached [8]. Now various partially burnt particles diffuse towards outer layers and begin to burn withina thin region of reaction formed around the periphery of spray leading to formation of a diffusion flame.

This phase of combustion is known as diffusion controlled combustion and is depicted by region 2 and 3 in figure no 1. Higher temperatures along with lack of oxygen provides an ideal condition for the formation of soot.

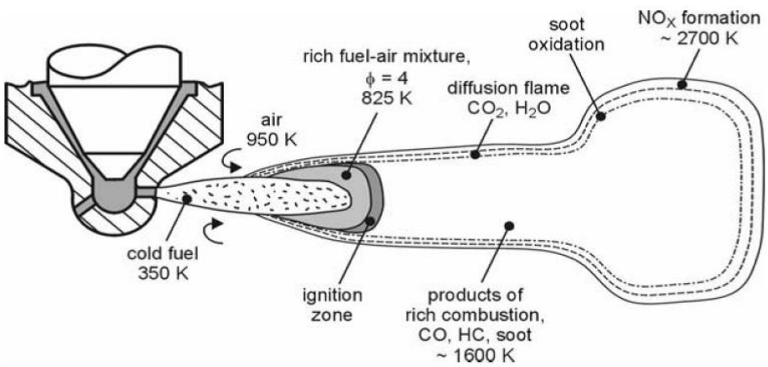

Fig. 2. Conventional diesel engine spray formation [8]

The diffusion flame thus formed then uses rest of oxygen available from surrounding environment resulting in high temperatures of order 2700K, which consumes all the soot formed. At outer zone of flame, there is enough oxygen content for formation of NO_x. Figure no 3 shows the rate of soot formation as a function of crank angle. Most of soot that is formed during earlier stages is later consumed and hence final exhaust emissions may have only a fraction of initial soot emissions. As seen from figure no 1, the diffusion-controlled combustion can be divided into further three phases. During the second phase, the burning rate is dependent on rate of mixing of fuel fragments formed and air and hence rate of reaction is faster. During the third phase, oxidation of remaining unburnt particles and soot takes place, however due to decreased temperature of end gas formed during the expansion stroke as well as lesser oxygen content available, slower reaction rates are observed.

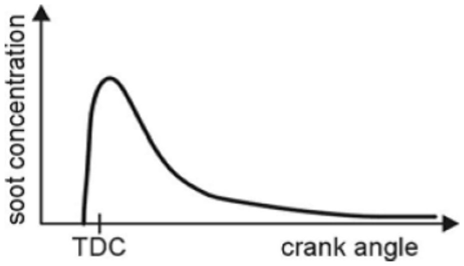

Fig. 3. Rate of soot formation [8]

Process of NO_X and soot formation in combustion engines has shown an opposite trend as shown in figure no 4. In order to reduce the NO_x formation rate it is necessary that local temperatures must not rise beyond 2000K [8]. A possible way to do so is to inject fuel late inside combustion chamber, which further shifts the combustion phase towards expansion phase resulting in significant reduction of chamber temperatures. However, rate of consumption of fuel and soot formation increases due to late combustion.

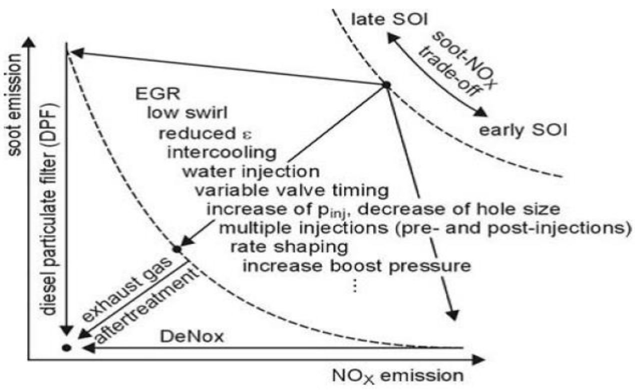

Fig. 4. Soot & NOx trade off [8]

Hence, modern systems utilize multiple injection techniques in order to control both NO_x as well as soot formation rate [8, 9, 10, 11].

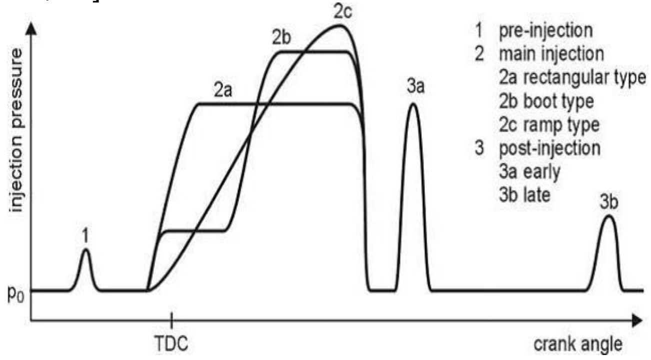

Fig. 5. Multiple injection methods adopted for modern diesel engines [8]

3. Conclusions

There are generally three phases of injection process used, namely pre-injection period, main-injection period & post injection period. There is a delay period between instant at which fuel is injected inside the combustion chamber and actual start of ignition process. Greater this delay period, more is the temperature achieved during course of combustion and hence better conditions exist for NOx formation. In order to shorten this delay period, a small amount of fuel is pre-injected before main injection occurs during the phase of pre-mixed combustion. Torque and power produced in engine mainly depends on the duration of main injection period. It is advantageous to vary the injected fuel mass with time in order to reduce the specific consumption of fuel. This is achieved by rate shaping as seen in figure no 5. Rate shaping curve may be rectangular, step or boot type in shape. Post-injection of fuel is done in order to reduce the soot emissions and in some cases may be useful for exhaust gas recirculation treatment [12]. It has been reported that post injection may reduce the rate of soot formation by about 70% without increasing the fuel consumption [13-20].

References

[1] Narayan, S., Ivan Grujic, Nadica Stojanovic, Aleksandar Davinić, Jovan Dorić, and Jasna Glisovic. "Engine load impact on maximum value of normal force in piston mechanism." *Tractors and power machines* 23, no.1-2 (2018): 10-16.
[2] Narayan, S., Ivan Grujic, Nadica Stojanovic, Kaisan Muhammad Usman, Shitu Abubakar, and Faisal O. Mahroogi. "Design and analysis of an automotive single plate clutch." *Mobility & Vehicle Mechanics* 44, no. 1 (2018): 13-26.
[3] Narayan, S., Ivan Grujic, Nadica Stojanovic, Kaisan Muhammad Usman, Shitu Abubakar, and Faisal O. Mahroogi. "Application of various signal processing methods in combustion engines." *Mobility & Vehicle Mechanics* 44, no.1 (2018): 1-12.
[4] Stojanovic, Nadica, Jasna Glisovic, Ivan Grujic, Aleksandar Davinić, S. Narayan, Muhammad Usman Kaisan, and Shitu Abubakar. "3D Modelling and Aerodynamic simulation of a passenger car." *Machine Design* 10, no. 4 (2018): 153-156.
[5] Stojanovic, Nadica, Jasna Glisovic, Ivan Grujic, Sunny Narayan, Sasa Vasiljevic, and Bojana Boskovic. "Experimental and numerical modal analysis of brake squeal noise." *Mobility & Vehicle Mechanics* 44, no.4 (2018): 73-85.
[6] Mahroogi, Faisal O., and S. Narayan. "A recent review of hybrid automotive systems in GCC region." *Proceedings of institute of mechanical engineers Part D: Journal of Automotive engineering* 234, no.7 (2019): 1393-1402.
[7] Kaisan, M.U., S. Abubakar, B. Ashok, Dhinesh Balasubramanian, S. Narayan, Ivan Grujic, and Nadica Stojanovic. "Comparative analyses of biodiesel produced from Jatropha and neem seed oil using a gas chromatography mass spectroscopy technique." *Biofuels* (December 2018): DOI: 10.1080/17597269.2018.1537206.
[8] Narayan, Sunny, and Vipul Gupta. "Numerical Analysis of Secondary Motion of Piston Skirt in Engines." *International Journal of acoustics and vibrations (IJAV)* 23, no. 4 (2018): 557-565.
[9] Narayan, Sunny. "A review of diesel engine acoustics." *FME Transactions* 42, no.2, (2014): 150-154, DOI:10.5937/fmet1402150N.
[10] Narayan, S., Sasa Milojevic, and Vipul Gupta. "Combustion monitoring in engines using accelerometer signals." *Journal of Vibro-engineering* 21, no. 6 (2019): 1552-1563.
[11] Mahroogi, Faisal O., S. Narayan, and Vipul Gupta. "Acoustic transfer function in gasoline engines." *International Journal of Vehicle Noise and Vibration (IJVNV)* 13, no. 3 (2018): 270-280.
[12] Narayan, S. "Wavelet analysis of diesel engine noise." *Journal of Engineering and Applied Sciences* 8, no. 8 (2013): 255-259.
[13] Narayan, S. "Analysis of Piston Slap Motion." *International Journal of Applied Mechanics and Engineering IJAME* 20, no. 2 (2015): 445-450.
[14] Narayan, Sunny. "Piston Slap Noise in engines." *International Journal of Applied Engineering Research* 8, no. 14 (2013): 1695-1700.
[15] Narayan, Sunny. "Effect of dwell time on noise radiated from Diesel engine." *International Journal of Applied Engineering Research* 8, no. 11 (2013): 1339-1347.
[16] Kaisan, Muhammad Usman, Shitu Abubakar, Muhammed Mustapha M, and S. Narayan. "Determination of Wear Metals Debris Concentration in Aircraft Engines." *International Journal of Recent Technology and Engineering (IJRTE)* 8, no. 2 (July 2019): 1289-1292.

[17] Narayan, S., Ali Sulaiman Alsagri, and Vipul Gupta. "Design and analysis of hybrid automotive suspension system." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8, no. 2 (2018): 637-642.
[18] Mahroogi, Faisal O., and S. Narayan. "Design and analysis of Double Wishbone suspension systems for automotive applications." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8, no. 11 (2018): 1433-1442.
[19] Stojanovic, Nadica, Nouby M. Ghazaly, Ivan Grujic, Jasna Glisovic, and S. Narayan. "Influence of size of ventilated brake disc's ribs on air flow velocity." *International Journal of Advanced Science and Technology IJAST* 29, no. 1 (2020): 637-647.
[20] Mahroogi, Faisal O., and S. Narayan. "Effects of dampers on piston secondary motion." *International Journal of Vehicle Noise and Vibration (IJVNV)* 16, no. 1-2 (2018): 46–57.