Analysis of Knocking Characteristic in Dual Fuel Engine - the Effects on Diethyl Ether

B. KIRUBADURAI*[,1,a], K. KANAGARAJA[2], G. JEGADEESWARI[3,b]

*Corresponding author
[1]Department of Aeronautical Engineering,
Vel Tech Dr. Rangarajan Dr. Sagunthala R&D Institute of Science & Technology,
Chennai, India,
bkirubadurai@gmail.com
[2]Department of Mechanical Engineering, Rajalakshmi Institute of Technology,
Chennai, India,
kanagaraja.k@ritchennai.edu.in
[3]Department of Electrical and Electronics Engineering,
AMET Deemed to be University, Chennai, India,
jegadeeswari.dharan@gmail.com

DOI: 10.13111/2066-8201.2021.13.2.9

Received: 14 July 2020/ Accepted: 15 April 2021/ Published: June 2021

Abstract: *In Diesel engines, where fuel is pumped into highly compressed air towards the end of the compression cycle, knocking is more or less unavoidable. By this time there is already a quantity of fuel in the combustion chamber which will first burn in areas of higher oxygen density before the full charge is combusted. The sudden rise in pressure and temperature produces the distinctive 'knock' or 'clatter' diesel, some of which must be allowed in engine design. The aim of knock control strategies is to try to maximize the trade-off between protecting the engine from damaging knock incidents, and optimizing the output torque of the engine. Knock events are a random process and independent. Knock controllers can't be programmed in a deterministic model. Due to the random nature of arriving knock events, a single time history simulation or experiment of knock control methods cannot provide a repeatable measurement of the controller efficiency. The desired trade-off must therefore be achieved in a stochastic context that could provide an appropriate environment for designing and evaluating the output of various knock control strategies with rigorous statistical properties. Clutching characteristics of a dual fuel diesel engine with direct injection of diesel and a liquid petroleum product in dual fuel mode. The engine is tested for knock reduction by adding Diethyl ether in to the diesel along with Liquid petroleum product. Variation of knocking was plotted with respect to different parameters and the result booted as knocking is minimized by the addition of diethyl ether.*

Key Words: *knocking, dual fuel engine, Liquid petroleum product, Diesel, Diethyl ether*

I. INTRODUCTION

For the purposes of use, research is being carried out all over the world. Research is underway worldwide as the use of gaseous fuels in internal combustion (IC) engines have been

[a] Assistant Professor
[b] Assistant Professor

intensified due to environmental concern and/or exhaustion of conventional fossil fuels. The renewable energy sources, natural gas, bio-derived gases and liquids appear to be greener alternative sources for internal combustion (IC) engines. The fuel system of a gaseous fuel engine is somewhat differing from that of the liquid fuel engine. Means for utilization of gaseous fuel in spark ignition (SI) engines are well established and documented whilst development efforts are still going on towards its use in compression ignition (CI) engines due to higher ignition delay, self-ignition temperature and slow burning rate. In the gas-fumigated dual-fuel engine, the primary fuel is mixed with the air outside the cylinder before being introduced into the cylinder. A mixture of gas and air is compressed during the compression stroke and before the end of the stroke, a pilot quantity of diesel fuel (depending on the operating conditions) is injected to initiate combustion. The combustion processes of dual-fuel engines lie between that of the CI and SI engines. The longer burning rate of the gas allows more time for heat transfer to the end gas resulting in a tendency to knock. In CI engines, knocking is due to combustion of premixed fuel and the degree of knock depends on the period of the ignition delay [4].

The approach to dual fueling of internal combustion engines was carried out by Karim [5]. In some references namely [2, 6, 8] it may be found the opinion that combustion in dual fuel (gas fueled) engine is longer than in conventional diesel engine. Longer ignition delay may be the result of more difficult diffusion transport of the air to diesel fuel droplets due to the presence of gaseous fuel. After the start of ignition gaseous fuel-air homogeneous mixture should burn very quickly. The present study was designed to investigate the knock characteristics of dual-fuel engines using Liquid petroleum product as primary fuel.

The use of gaseous fuel in CI engines involves an evolution of two stages of ignition and combustion processes resulting in three types of knock: diesel knock, spark knock and erratic knock due to spontaneous ignition of the primary fuel. The dual fuel engine knock was seen to depend on engine load and speed, combustion temperature, pilot fuel/ gas ratio and turbulence in the cylinder [1].

It is the high pressure rise rates associated with the auto-ignition of fuel during the premixed combustion stage that produces the characteristic "knocking" noise widely associated with diesel engines.

This noise is often referred to as diesel knock or combustion roughness [3, 6, 7]. Spark-ignition knock is caused by the spontaneous ignition of gas ahead of the propagating flame front (the end gas) within the combustion chamber. This spontaneous ignition results in a rapid release of chemical energy and an accompanying rapid rise in cylinder pressure. Unlike spark-ignition knock, diesel knock occurs when injected fuel auto-ignites and combusted in the premixed stage of combustion.

Diesel knock has not been a fundamentally limiting factor in the same manner as spark-ignition knock in terms of engine design [5]. However, diesel knock is recognized as a considerable problem associated with the use of alternative fuels in dual-fuel type diesel engines. The increasing use of bio-fuels and the performance limitations associated with excessive diesel knock in dual-fuel engines combine to make diesel knock an important parameter to monitor from both, engine performance, and health viewpoints. In dual fuel diesel engine knock is visible in the cylinder pressure diagram as ripple, also accompanied by noise.

Knocking can be detected through a number of methods, normally accelerometers or cylinder pressure sensors are used. But in the case of the accelerometer (vibration measurement), the engine noise affects the quality of knock detection. On the other hand, the cylinder pressure data provide a direct and reliable way to analyze knocking. As a result, it's commonly used in studies.

II. ENGINE TEST RIG DESCRIPTION

The test bench consists of naturally aspirated, single-cylinder four-stroke water-cooled diesel engine of Kirloskar brand. The engine is having a rated power of 5.2 kW. The specifications of the engine are listed in table 1.

Table1. Engine specification

Engine	:	Kirloskar 218 A, single cylinder 4 stroke water cooled diesel engine
Rated power	:	5.2 kW
Speed	:	1500 rpm
Bore	:	87.5 mm
Stroke	:	110 mm
Compression ratio	:	17.5
Dynamometer type	:	Rope drum with set of weights

In the present work, the C. I engine is converted to run on dual fuel by using diesel as a pilot fuel, which is used as combustion initiator and Liquid petroleum product as the main fuel with air naturally aspirated to the engine.

The Liquid petroleum product gas is inducted into the inlet manifold of the engine at a pressure slightly higher than atmospheric pressure using a bypass valve. While supplying the gaseous fuel, the Liquid petroleum product cylinder is connected to the engine through a pressure regulator and a flame trap.

The purpose of the flame trap is to extinguish the flame in case of any back fire. The engine is capable to run on 100% diesel fuel or dual fuel in the intake manifold by a relevant bypass valve. Throughout the test the engine is running at 1500 rpm. The schematic diagram of the experimental setup is shown in Fig. 1.

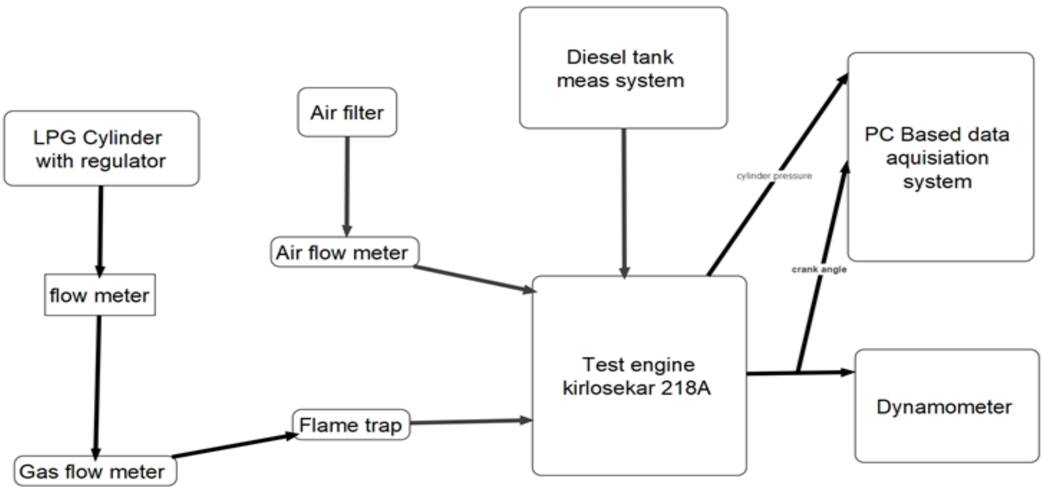

Fig. 1 The schematic diagram of the experimental setup

This work consists of testing the engine in pure diesel mode and dual-fuel mode. In dual-fuel mode, the diesel is supplied as usual as in pure diesel mode; along with that, the Liquid petroleum product is supplied at three different flow rates 0.118, 0.221 and 0.375 kg/hr. In dual-fuel mode engine, the engine is also tested by adding Diethyl ether into diesel (15% by volume). The engine is loaded from no load to maximum load for different fuel proportions i.e. pure diesel, diesel + Liquid petroleum product, diesel + Liquid petroleum product + diethyl ether. The fuel flow rates are estimated on mass basis. At each test conditions the pressure and crank angle at each and every stage of the operating cycle is obtained by using the PC based data acquisition system.

The data acquisition system consists of:

- Piezo sensor, Range 5000PSI with low noise cable and water cooled adaptor,
- Crank angle sensor, Resolution 1 Deg, speed 5000 rpm with Top death center marker pulse,
- Engine indicator for data scanning and interfacing with speed sensor.

Table 2. Fuel consumption details in Diesel mode

Engine load (%)	**Liquid petroleum product flow rate (kg/h)**	**Diesel flow rate (kg/h)**	**x (%)**
0	0.118	0.5464	17.76
25		0.6510	15.34
50		0.8720	11.91
75		0.9273	11.28
100		1.0551	10.05
0	0.221	0.5464	17.76
25		0.6510	15.34
50		0.8720	11.91
75		0.9273	11.28
100		1.0551	10.05
0	0.375	0.4434	45.82
25		0.5464	40.69
50		0.6375	37.03
75		0.7116	34.51
100		0.8270	31.19

The fuel consumption details were obtained during the test conditions i.e, in normal diesel mode, Diesel + Liquid petroleum product. The diesel fuel supplementary ratio x, which represents the quotient of the mass flow rate of natural gas divided by the total fuel (diesel and Liquid petroleum product) mass flow rates, is given by the formula:

$$x = \frac{m_{LPG}}{m_{Diesel} + m_{LPG}} \times 100\%$$

Table 3. Fuel consumption details in Dual fuel mode

Engine load (%)	**Liquid petroleum product flow rate (kg/h)**	**Diesel + diethyl ether flow rate (kg/h)**	**x (%)**
0	0.375	0.8317	45.08
25		0.9417	39.82
50		1.055	35.54
75		1.14	32.89
100		1.3022	28.79

The term m_{Diesel} represents the diesel fuel consumption measured by a flow meter appropriate for the liquid fuel, while m_{LPG} is the gaseous fuel consumption measured by a rotary displacement gaseous fuel flow meter.

The maximum value of LPG mass ratio is obtained at no load, 45%. With increase in load o, the engine consumes more diesel which results in a reduced LPG mass ratio.

Table 4. Fuel consumption details in Dual fuel mode with Diethyl ether additive

Engine load (%)	Diesel consumption (kg/h)
0	0.5884
25	0.7116
50	0.9
75	1.092
100	1.275

III. RESULTS AND DISCUSIONS

Cylinder pressure-Crank angle curves for different loads and fuel proportions

The cylinder pressure crank angle curves obtained while running the engine with different fuel proportions are plotted in figures 2, 3, 4, 5 and 6.

The considerable pressure rise in the cylinder is obtained in the crank angles 355 to 385 degrees. (Flow rates of 0.118, 0.221, 0.375 kg/h), 85% Diesel + 15% Diethyl ether + 0.375 kg/h of Liquid petroleum product is shown in tables 2, 3 and 4.

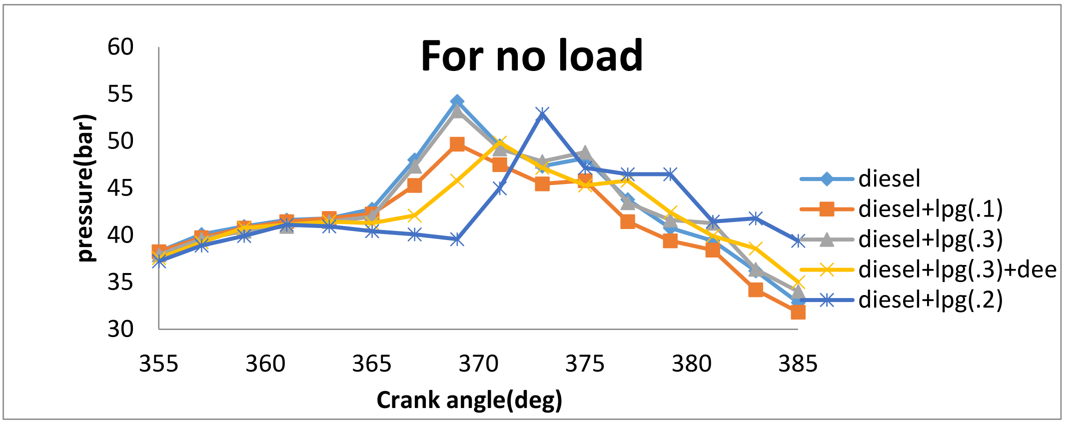

Fig. 2 Pressure-crank angle curves for no load for Diesel, Diesel + different Liquid petroleum product flow rates (0.118, 0.225 and 0.375 kg/h), 85% Diesel + 15% Diethyl ether + 0.375 kg/h of Liquid petroleum product

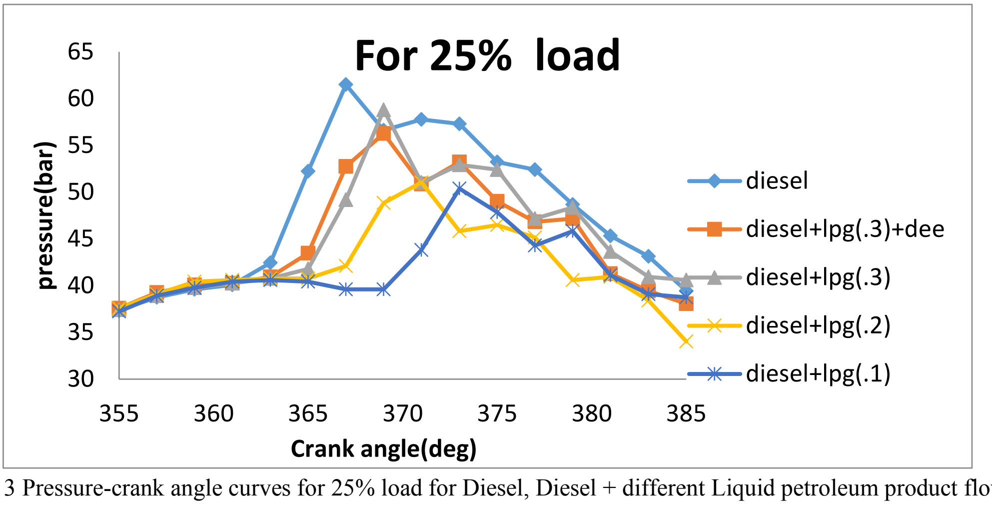

Fig. 3 Pressure-crank angle curves for 25% load for Diesel, Diesel + different Liquid petroleum product flow rates (0.118, 0.225 and 0.375 kg/h), 85% Diesel + 15% Diethyl ether + 0.375 kg/h of Liquid petroleum product

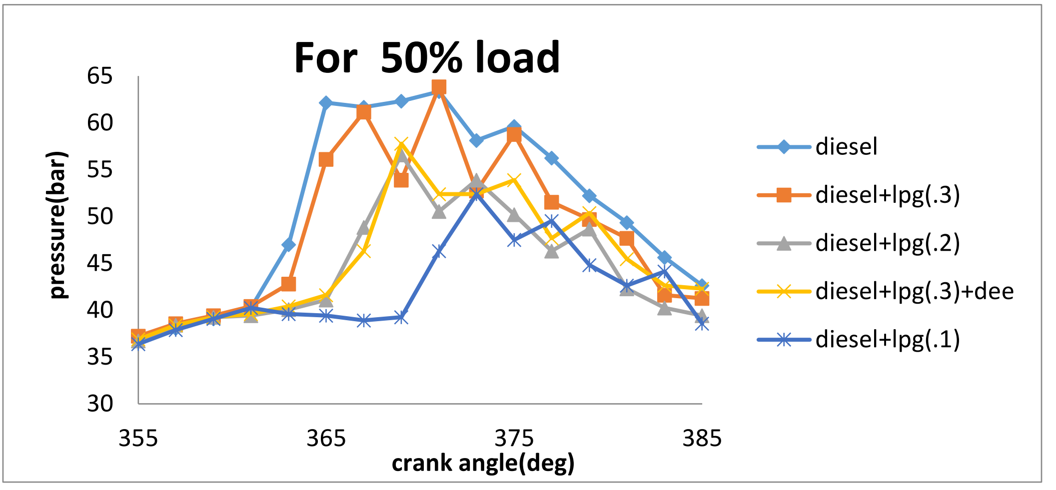

Fig. 4 Pressure-crank angle curves for 25% load for Diesel, Diesel + different Liquid petroleum product flow rates (0.118, 0.225 and 0.375 kg/h), 85% Diesel + 15% Diethyl ether + 0.375 kg/h of Liquid petroleum product

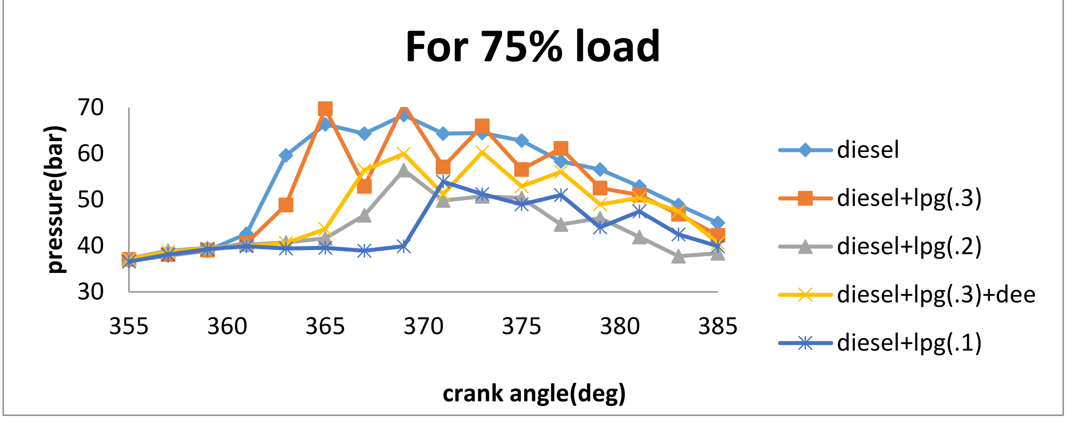

Fig. 5 Pressure-crank angle curves for 75% load for Diesel, Diesel + different Liquid petroleum product flow rates (0.118, 0.225 and 0.375 kg/h), 85% Diesel + 15% Diethyl ether + 0.375 kg/h of Liquid petroleum product

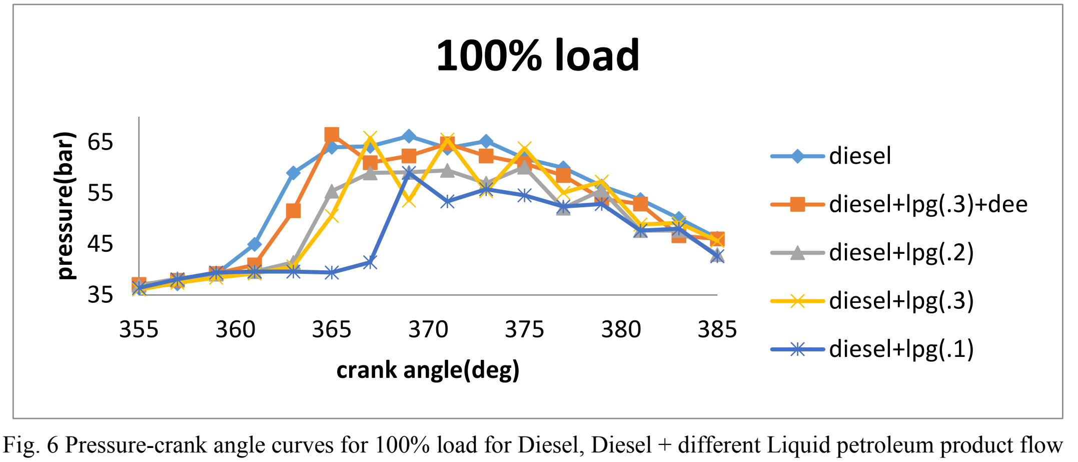

Fig. 6 Pressure-crank angle curves for 100% load for Diesel, Diesel + different Liquid petroleum product flow rates (0.118, 0.225 and 0.375 kg/h), 85% Diesel + 15% Diethyl ether + 0.375 kg/h of Liquid petroleum product

While operating the engine especially at 75% and 100% loads with Liquid petroleum product mass flow rate of 0.375 kg/h and diesel as fuel, the engine knocks severely and produces audible knocking and it is visible as ripples in the cylinder pressure – crank angle curves also the peak pressures are lower than that of curves for diesel fuel. While operating the engine with the same mass flow rate of Liquid petroleum product, 85% diesel and 15% Diethyl ether knocking gets reduced due to the reduction in ignition delay related to the addition of diethyl ether.

At higher loads with increased amount of gaseous fuel supply, high temperatures due to high compression ratio seem to have caused the propane to have less ignition delay and auto-ignites early in compression stroke and increase the pressure rise rate and noise [9, 10, 11]. At the low loads, the mass of gaseous fuel admitted was low, while this mass is increased at higher outputs. The increase in gaseous fuel mass seems to increase the charge temperature and pressure (especially at higher compression ratios) and cause earlier self-ignition to the fuel air mixture (less ignition delay) [12, 13, 14]. Combustion in dual-fuel engine is retarded at the beginning of the process, afterwards become faster and is finished earlier than combustion of pure diesel fuel. Due to rapid rise in cylinder pressure, the noise emitted by the Liquid petroleum product dual-fuel engine is higher than in the case of the conventional diesel engine.

IV. CONCLUSIONS

In the present work, Liquid petroleum product is during the suction stroke and some quantity of pilot diesel fuel is injected for the purpose of initiating combustion. In the dual-fuel engine, the combustion processes are seen to lie between those of CI and SI engines. The ignition delay of the dual-fuel engine increases with decrease in engine speed, in contrast to pure diesel fuel operation. Maximum peak cylinder pressure is reduced and the initial rate of pressure rise is low compared to diesel fuel operation. The power output of the dual-fuel operation is less compared to diesel fuel test results. In dual-fuel cycle, the diesel knock arises due to combustion of premixed pilot fuel, the spark knock due to auto-ignition of end gas and the erratic knock due to secondary ignition of the alternative fuel. The main factors that influence the occurrence of these knocks are the pilot quantity, load, speed, gas flow rate and time interval for secondary ignition. Increasing the pilot fuel and reducing primary fuel reduces the knocking phenomena in dual-fuel engines.

Combustion in dual-fuel engine is retarded at the beginning of the process, afterwards become faster and is finished earlier than the combustion of the pure diesel fuel. Due to the rapid rise in the cylinder pressure, the noise emitted by the Liquid petroleum product dual-fuel engine is higher than for the conventional diesel engine. At higher loads and higher mass flow rates of Liquid petroleum product (0.375 kg/hr) the knocking is severe and it tends to damage the engine. By adding diethyl ether, the knocking can be controlled and the engine can be safely operated without any damages.

REFERENCES

[1] C. Allen, M. Joshi, D. Gosala, S. Shaver, L. Farrell, J. McCarthy, Experimental assessment of diesel engine cylinder deactivation performance during low-load transient operations, *Int J Engine Res.*, **22**(2): 606–615, 2021.

[2] T. Kumar, R. Mohsin, Z. A. Majid, M. F. Abdul Ghafir, A. Manickam Wash, Experimental study of the anti-knock efficiency of high-octane fuels in spark ignited aircraft engine using response surface methodology, *Appl Energy*, **259**: 114150, 2020.

[3] R. C. Li, G. G. Zhu, Y. Men, A two-zone reaction-based combustion model for a spark-ignition engine, *Int J Engine Res*, **22**(1): 109–124, 2021.

[4] T. Franken, C. Netzer, F. Mauss, et al., Multi-objective optimization of water injection in spark-ignition engines using the stochastic reactor model with tabulated chemistry, *Int J Engine Res*, **20**: 1089–1100, 2019.

[5] S. Aramkitphotha, H. Tanatavikorn, C. Yenyuakc, T. Vitidsant, Low sulfur fuel oil from blends of microalgae pyrolysis oil and used lubricating oil: properties and economic evaluation, *Sustain Energy Technol Assess*, **31**: 339–346, 2019.

[6] G. T. Kalghatgi, Knock onset, knock intensity, superknock and preignition in spark ignition engines, *Int J Engine Res*, **19**(1): 7–20, 2018.

[7] A. Kawaguchi, Y. Wakisaka, N. Nishikawa, et al., Thermo-swing insulation to reduce heat loss from the combustion chamber wall of a diesel engine, *Int J Engine Res*, **20**(7): 805–816, 2019.

[8] O. M. I. Nwafor, Knock characteristics of dual-fuel combustion in diesel engines using natural gas as primary fuel, *Sadhana*, vol. **27**, part 3, pp. 375–382, June 2002, DOI: 10.1007/BF02703658.

[9] G. Brecq, J. Bellettre, M. Tazerout, A new indicator for knock detection in gas SI Engines, *Int J Therm Sci* **2**:523–32, 2004.

[10] C. Rahmounia, G. Brecq, M. Tazerout, O. L. Corre, Knock rating of gaseous fuels in a single cylinder spark ignition engine, *Fuel*, **83**:327–36, 2004.

[11] A. R. Sivaram, R. RajaveL, K. Umanath, S. Ruban kumar & S. B. Narayana swamy, A technical review on emulsion fuel with nano additives, *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, vol. **8**, Special Issue 7, 1196-1200, Oct 2018.

[12] A. R. Sivaram, R. RajaveL, M. Vinothkumar, S. Ruban kumar & S. B. Narayana swamy, An Impact of Nano Additives on Emissions of Biodiesel Fuelled Diesel Engine, *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, vol. **8**, Special Issue 7, 1189-1195, Oct 2018.

[13] A. R. Sivaram, R. Rajavel, N. Jayakumar, M. Vinothkumar, Exhaust back pressure effect on the performance features of a diesel engine, *ARPN Journal of Engineering and Applied Sciences*, **12**(15):5353-5356, 2017.

[14] A. Krishnasamy, S. K. Gupta, R. D. Reitz, Prospective fuels for diesel low temperature combustion engine applications: a critical review, *Int J Engine Res*., Epub ahead of print 30 September 2020.