Preliminary Optimization of Duel Fuel Engine using Dimethyl Ether Premixed Combustion

Mr. Yogesh Ambekar[1], Dr. J. A. Hole[2]

[1]PG Student, Dept. of Mechanical Engineering, JSPM'S Rajarshi Shahu College of Engineering, Pune-33, Maharashtra, India.
[2]Professor, Dept. of Mechanical Engineering, JSPM'S Rajarshi Shahu College of Engineering, Pune-33, Maharashtra, India.

Abstract - *The environmental concerns become a serious issue in the present. The higher amount of vehicle has grown considerably within last few decades. Compression ignition engine that is known as diesel engine is being interested recently in order to exhibit more beneficial in term of viable technology in the future. Several successful technologies for clean diesel engine could be divided into four strategies: alternate fuel technology, in-cylinder technology, low friction lubrication oil, development of efficient turbocharging machines, and after treatment emission control device. But considering the cost and time of development, there is a need of introducing alternative solution to minimizing in cylinder emission. It is very challenging to achieve these stringent emission norms, without modifying the fuel, without modifying the engine hardware. Here in this research paper, it has been shown that oxygenated fuel called Dimethyl Ether has huge potential in reducing particulate emissions from diesel engines. This paper examines dimethyl ether (DME), as a potential ultra clean fuel, cost effective replacement for diesel fuel. The area of research work focuses on optimization of performance and raw emission of single cylinder 4 stroke diesel engine.*

Key Words: Port Injection, PCCI, Dimethyl Ether, Duel Fuel, Raw Emission.

1. INTRODUCTION

Several oxygenates have been proposed and tested for use with diesel fuel as a means of reducing exhaust emissions. This paper examines dimethyl ether (DME), which is a potential ultra clean fuel, in blends with diesel fuel. This is an important step in not only showing that the fuel does perform well in an engine with minor modifications to the fuel system, but also in showing that DME can give consistent, significant results in lowering emissions. The Dimethyl ether and diesel fuel can be blended to achieve a net addition of 5 and 10 wt. % oxygen in the blended fuel. The data confirms that the addition of DME can reduce the particulate emissions from a compression ignition engine. However, the NOx emissions were not favourable for all conditions [1]. It is believed that through further modification of injection timing, NOx emissions can be effectively reduced. Additionally, pressure trace analyses showed that the fuel affects the ignition delay of the combustion process, and that optimization of the engine controls would be needed to further improve performance and reduce exhaust emissions. There are various alternative fuels available but production process, storage systems limitations, application feasibility and fuel handling hazards for human being have limited their scope for automotive application [2]. The main reason due to which DME is most popular is minimal changers are required in existing diesel engine, the only additional change which needs to be introduce is dedicated port fuel injection system for Dimethyl Ether. In this research work, diesel fuel is used as a main fuel & DME is used a pilot fuel for premixing the charge in intake manifold before it is made available for combustion.

1.1 Why Dimethyl Ether

DME, Dimethyl Ether, is the simplest non-toxic colourless gaseous ether. It is also known as wood ether, methyl ether and dimethyl oxide. DME has the Formula CH_3OCH_3 which is that makes it more profitable among other organic compounds one of which is that It can be derived from many sources some of which are considered as renewable. Biomass (waste and agricultural products), natural gas and cool are the most known renewable sources used for the DME production [8]. It is accounted as a clean source of energy since it does not generate Sulphur oxides or smut during combustion. In addition, it is liquefied easily when lightly pressurized which makes it more profitableDME is that fuel which is very volatile in nature and gaseous at normal ambient temperature. DME can be introduced in the engine manifold and not in the engine cylinder. Manifold fuel injection requires only modest injection pressures and designing durable fuel injection equipment is then easier. DME has been chosen for investigation since it can be produced sustainably and with the lowest CO_2 emissions amongst the alternative fuels. Duel fuel i.e. Diesel + DME combustion has been chosen since it produces the lowest levels of harmful emissions [3]. In the diesel engines was optimized to run on gaseous DME with the port injection (sequential) or trans-intake valve-injection system, a high-speed gas jet was pulsed from the intake port through the open intake valve into the combustion chamber, where it caused effects of turbulence and charge stratification particularly at engine parts load operations. The system is able to diminish the cyclic variations and to expand the limit of lean operation of the engine. The flexibility of gas pulse timing offers the potential advantage of lower emissions and fuel consumption. There are several advantages of port injection. The better possibility DME + Diesel duel fuel PCCI engine is to equalize the air-fuel ratio of the cylinders, optimization of the gas injection timing and of the gas pressure for different operating conditions. DME permits the use of very high exhaust gas recirculation (EGR) rates to lower oxides of nitrogen (NOx) emissions without having to use after-treatment devices such as particulate traps and SCR catalysts that require the injection of urea to lower NOx in the exhaust stream [5,6].

Table -1: Properties of Dimethyl Ether

Properties	Diesel	DME
Chemical Formula	$C_{10}H_{20}$ to $C_{15}H_{28}$	CH_3-O-CH_3
Liquid Density (kg/m^3)	813	667
Molecular weight/g	168	46.07
Boiling point / °C	360	-24.9
Reid vapour pressure /Mpa at 20 °C	<<.0.01	0.51
Liquid viscosity / cP	37.8	0.25
Low heat value / MJ/kg	42.5	28.5
Explosion limit in air / vol.%	0.6	3.4
Auto Ignition temperature/ °C	210	235
Cetane number	40-50	>55
Stoichiometric air/fuel ratio	14.6	9.0
Latent heat evaporation / kJ/kg	250	466.9
%wt of carbon	86.0	52.2
%wt of hydrogen	14.0	13.0
% wt of oxygen	0	34.8
Kinetic Viscosity at 40°C	2.58	<0.1

1.2 Premix Charge Compression Ignition

In this paper, premix charge compression i.e. PCCI is realized by the port injection of high volatility fuel i.e. Dimethyl Ether. Dual-fuel combustion is more favorable to implement 'PCCI' combustion, because there is much more freedom of controlling premixed condition from low reactivity/high volatility fuel [1]. A lot more time is available for mixture formation of air and fuel outside the combustion chamber unlike direct injection diesel engine. Theoretically, PCCI is the hybrid of HCCI and diesel combustion, which has more control on combustion/ignition and heat release rate with lower level of NOx and soot emission because premixed charge can be controlled with different fuel blending in different compositions to get optimum results/better control over ignition. The PCCI mode of combustion is obtained by the injection of part of the fuel early in the cycle so as to allow the formation of a premixed charge prior to the main fuel injection and diffusion-controlled combustion. Here advanced combustion strategies have attempted to find an in-cylinder approach to meet emission standards fully and thus avoiding the need to use after treatment devices. The term Low Temperature Combustion (LTC) is the most suitable to premix charge combustion concepts because the overall goal is to lower combustion temperatures to advantageously alter the chemistry of NOx and or soot formation.

2. Experimental Setup

An experimental test setup consists of single cylinder engine, an eddy current dynamometer, fuel tank fitted with volumetric flow measurement system, air flow meter, water column manometer. In addition, exhaust system fitted with calorimeter. Set up is capable of logging various analogue, digital parameters like temperature, pressure, and engine speed, engine torque (load cell). It is having digital data acquisition system. The computer software, Engine Soft Version 4.0 is used for recording the test parameters. Engine performance parameter like power, torque, engine speed, and in cylinder pressure are measured with dynamometer data logger system. A preliminary test activity has been performed in order to identify the main engine control variables that can be managed in order to obtain a PCCI combustion strategy. In conventional diesel combustion, the mixture ignites in the region where the local equivalent ratio is between 2 and 4 [5], i.e. in fuel-rich conditions. The targets of PCCI combustion strategies are, first, to ignite the charge at much lower local equivalent ratios in order to reduce the formation of soot, and, secondly, to slowdown the combustion development to lower peak temperatures, and consequently decrease the formation of NOx [6]. The attainment of PCCI combustion conditions means increasing the ignition delay. During this time interval, the injected fuel atomizes, vaporizes and mixes with air in to the intake port before reaching auto-ignition conditions.

The duration of the ignition delay depends on the charge density, fuel and oxygen concentrations and in-cylinder temperature [8]. A prototype port fuel injection system is developed and optimized on a wide range of engine operating conditions on a single cylinder diesel, naturally aspirated, direct injection. Low Pressure DME fuelling system successfully helped in injecting the higher flow rates for DME (since DME being highly volatile). The dedicated tank with low-pressure (5bar) inline fuel pump used for pressurizing the fuel. A specific benefit of duel fuel operation in connection with DME is that fuel is introduced in the engine manifold and not in the engine cylinder. Manifold fuel injection requires only modest injection pressures and designing durable fuel injection equipment is then easier. The injector pulse width was controlled using PWM modulator. The pictorial view of port fuel supply system of DME is shown in figure 2.

Fig.1 : Intake Port Fuel Injection

The injector can be placed in close proximity to the cylinder's intake port. It also enables fuel to be delivered precisely as required and enables more sophisticated technologies such as Pre injection- Pilot Injection. This enables even more efficient use of the fuel at low loads, further lowering fuel consumption and unburned hydrocarbon. Selection of proper DME injector with nozzle holes geometries is important. As compression-ignition combustion process is unsteady, heterogeneous, turbulent and three dimensional, very complex and the nozzle fuel injector hole needs to be enough large to provide required amount of DME in shorter duration of time period.

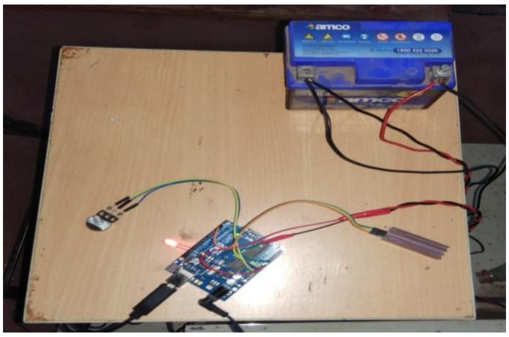

Fig.2 : DME Port Injection Control Unit.

When, the injector driver and controller commands injection, the solenoid is energized, this starts the injection stage. Actually speaking, the operation of fuel injector is divided into three different stages namely filling the injector, start of injection (SOI), holding of solenoid on as per duty cycle defined, and end of injection (EOI). The poppet valve is lifted, and pressurized fuel enters the intake port area. Which increases the oxygen concentration and is responsible for creating turbulence within the cylinder is important for mixing of the fuel, which in turn reduces emissions. The fuel nozzle injector multi holes geometries development is to produce optimum fuel air mixing and increasing the volumetric efficiency of the engine that will promote a comparable engine performance. Gaseous fuel injection implications and its behavior on combustion chamber design have received considerable attention in recent years. The optimal configuration may be different from what is required for gaseous fuels. Various experiments examined the relative effects of combustion on liquid and gaseous fuel direct injection jets. Initially, the liquid jet was more effective at entraining air and hence was better at producing flammable mixture regions within the combustion chamber. In the end, however, the liquid spray did not burn as completely as the gas jet. Beyond the initial stage, the gas direct injection jet exhibited a higher combustion rate than that of the liquid fuel. DME port fuel spray results from vaporization of the remainder of the liquid fuel in the mixture. This causes an increase in the richness of mixture readily available for combustion. In duel fuel mode, there is a flexibility of adjusting the mass flow rate of two different fuels as per load demand. This is quite challenging task also to smoothen the engine operation. The engine initially became unstable, with lot of and noise and vibration. Following table shows detailed setup.

Table -2: Experimental Set up

Engine	Type - single cylinder, four stroke Diesel, water cooled, rated power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18
Dynamometer	Type eddy current, water cooled, with loading unit
Piezo sensor	Range 5000 psi, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse
Data acquisition device	NI USB-6210, 16-bit, 250kS/s.
Piezo powering unit	Make-Cuadra, Model AX-409.
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Type two wire, Input RTD PT100, Range 0–100 Deg C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 Deg C, Output 4–20 Ma
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Software	Engine soft LV Engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Exhaust gas	Make – Indus Scientific, Five gas

analyzer	analyzer
Smoke meter	Make – Indus Scientific, Range – 0 to 100% HSU

3. RESULTS AND DISCUSSION

In this chapter, the results based on the observations from the tests conducted on duel fuel DME+ diesel engine is given in graphical form. Part load and full load performance testing at various loads was conducted to evaluate the performance combustion and emission parameters of a diesel engine. Performance characteristics include brake specific fuel consumption and brake thermal efficiency. Emission characteristics include HC, CO and NOx. Performance and emission parameters are drawn against load for various compression ratios.

3.1 Engine Brake Power

Variation of brake power with % of load is shown in chart1. It is observed that the dual fuel mode develops a brake power more than diesel only mode. At lower loads, the power developed in different modes of operation is nearly the same. At higher loads, it is seen that the dual fuel mode develops somewhat higher power than that of diesel.

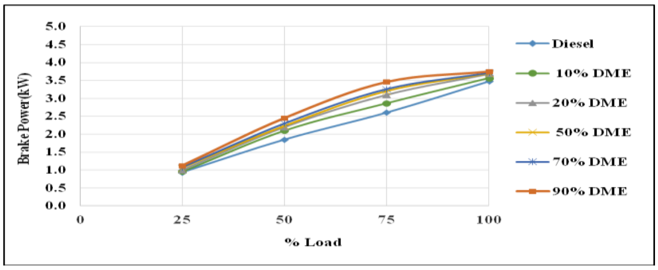

Chart -1: Load vs. Engine Brake Power

3.2 Brake Thermal Efficiency

The variation of brake thermal efficiency of the engine with % of load is show in chart 2. The brake thermal efficiency of the engine was found to have gradual increase with increase in dimethyl fuel flow rate. When engine is fuelled with 90% weight of DME to diesel, we observed, same engine produced large amount of mechanical work and smaller amount of wasted internal heat in exhaust gas. The maximum brake thermal efficiency was found at 75% load in dual fuel mode.

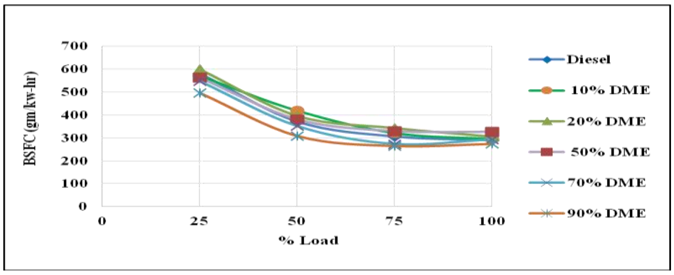

Chart -2: Load vs. Brake Thermal Efficiency

3.3 Brake Specific fuel consumption

It was observed that, brake specific fuel consumption was decreased with increase in flow rate of dimethyl ether. The conventional diesel engine has characteristic of governing the fuel flow rate according to the load increase. As we introduce the dimethyl ether fuel in intake port, the extra amount of power was provided by DME; hence, diesel governor adjusted the diesel supply to just meet the power requirement. Hence, combined effect of duel fuel has resulted in decrease in overall brake specific fuel consumption. It is observed that, overall B.S.F.C. is decreases with 90% DME flow rate. Following graph shows load vs. brake specific fuel consumption trend for different flow rates. Combined brake specific fuel consumption is calculated by using following formula:

e-B.S.F.C. = $\{\dot{m}_{Diesel} + \dot{m}_{DME^*} (LCV_{Diesel} / LCV_{DME})\}$/B.P

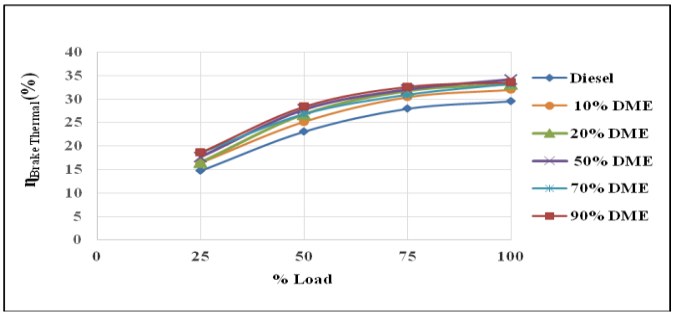

Chart -3: Load vs. Brake Specific Fuel Consumption

3.4 Carbon Monoxide Emission Characteristics

There are two major causes of formation of CO emissions. The first one is the incomplete combustion due to insufficient supply of oxygen to combustion chamber and second one is the poor mixture formation. It is observed that, CO emission decreases with increase in flow rate of dimethyl ether. Following graph shows load vs. CO emission trend for different fuel flow rates.

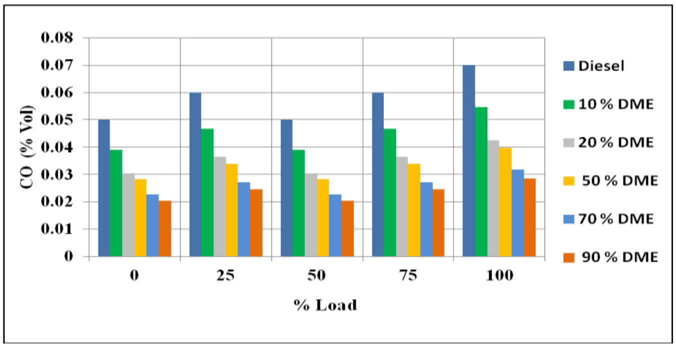

Chart -4: Load vs. CO Emission traces

3.5 Hydrocarbon Emission Characteristics

It is observed that, HC emission decreases with increase in flow rate of dimethyl ether. This is purely because of absence of lower C: H ratio of DME fuel and extra oxygen which is available for complete combustion of diesel fuel. Following graph shows load vs. HC emission trend for different fuel flow rates.

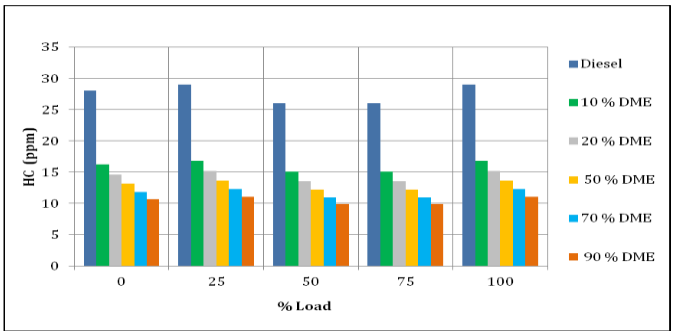

Chart -4: Load vs. HC Emission traces

3.6 NO_x Emission Characteristics

Chart 5 shows there is increase in NOx emission as the load increases. This is due to higher oxygen content in exhaust gas which further increases the NO emissions. This can be reduced by using Exhaust Gas Recirculation system. DME allows higher rates of EGR mixing rates due to its higher cetane number. This topic being extensively studied by many researchers, this is not discussed here in this paper.

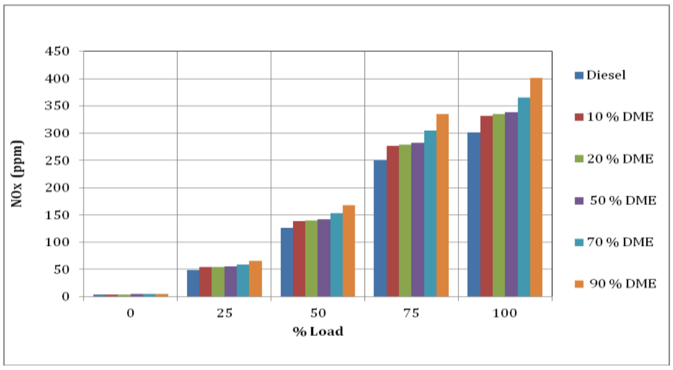

Chart -5: Load vs. NOx Emission traces

4. CONCLUSIONS

With above experimentation, it is concluded that, DME as a secondary fuel port injection, brake thermal efficiency increases by 5 to 7%. Premixed oxygenated fuel with diesel has lowered the exhaust gas temperature by 50°C compared to only diesel fuel. Dimethyl Ether has substantially reduced Hydrocarbon Emissions and smoke. But increase in NO_x emissions observed at higher engine loads but which can be reduced by using higher EGR flow rates. Use of Dimethyl Ether in conventional CI engines can eliminate the costlier after treatment devices like DPF, Heavy Loaded Catalytic Converters and NO_x reduction devices. Compression Ratio of Diesel Engine can be lowered up to 10, as Cetane value of DME is higher than Diesel.

REFERENCES

[1] Elana M. Chapman, et al, Annual Progress Report for Project "Impact of DME-Diesel Fuel Blend Properties on Diesel Fuel Injection Systems" DOE Award Number: DE-FC26-01NT41115, June 2003.

[2] Babak Torab, "The Adaptation of Solenoid Actuated Injectors Use with Dimethyl Ether Fuel in Diesel Engines" Department of Mechanical Engineering, Degree of Master of Applied Science, Concordia University, Montreal, Quebec, Canada.

[3] J. Patten, P. Eng. Et al, Dimethyl ether fuel literature review, Publication of National Research Council Canada, 18 June 2015.

[4] Qiao Xinqi, "Investigation of combustion characteristics of a diesel engine fuelled with DME-biodiesel blends", Shanghai Jiao Tong University, China, 7th Asian DME Conference.

[5] Parks JE II, et al, Emissions from premixed charge compression ignition (PCCI) combustion and effect on emission control devices. Catalysis Today 2010, Volume 151, p. 278-284.

[6] Stefano d'Ambrosioa, Daniele Iemmoloa, Alessandro Mancarellaa, Roberto Vitoloa, "Preliminary optimization of the PCCI combustion mode in a diesel engine through a design of experiments," 71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy.

[7] Ryan TW, Callahan TJ. Homogeneous Charge Compression Ignition of Diesel Fuel. SAE Technical Paper 1996, n. 961160

[8] Somkid Khunaphan1 et al, "Characterization and Potential of Dimethyl Ether (DME) as Dual Fuel Combustion in a Compression Ignition Engine" IJESIT, ISSN: 2319-5967 Volume 2, Issue 3, May 2013.

[9] Kyunghyun Ryu , "Effects of pilot injection timing on the combustion and emissions characteristics in a diesel engine using biodiesel–CNG dual fuel." applied energy 111(2013)721-730

[10] Shuichi Kajitani and Zhili Chen, Fundamental Research on Next Generation Fuel (Dimethyl Ether) Engines, Journal of Scientific and Industrial Research, Vol. No. 62, January- February 2003, pp 133-144.

BIOGRAPHIES

Mr. Yogesh B Ambekar.
Masters in Heat & Power Engineering,
Area of Interest: Thermal Engineering, Internal Combustion Engines, Vehicle Engineering.

Dr. J. A. Hole.
PhD in Mechanical Engineering.
Area of Interest: Thermal and Energy