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To cite this article: Y Hemanth *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **263** 062064

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# Development of on-board fuel metering and sensing system

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**Abstract:** Usage of biodiesel fuels and their blends with diesel fuel has a potential to reduce the tailpipe emissions and reduce the dependence on crude oil imports. Further, biodiesel fuels exhibit favourable greenhouse gas emission and energy balance characteristics. While fossil fuel technology is well established, the technological implications of biofuels particularly biodiesel is not clearly laid out. Hence, the objective is to provide an on-board metering control in selecting the different proportions of diesel and bio-diesel blends. An on-board fuel metering system is being developed using PID controller, stepper motors and a capacitance sensor. The accuracy was tested with the blends of propanol-1, diesel and are found to be within 1.3% error. The developed unit was tested in a twin cylinder diesel engine with biodiesel blended diesel fuel. There was a marginal increase (5%) in nitric oxide and 14% increase in smoke emission with 10% biodiesel blended diesel at part load conditions.

## 1. Introduction

Increase in population and vehicle growth has led to several issues, like global warming. Renewable energy resources are better considered the optimal solution to deal with such problem. With increasing diesel fuel price and stricter emission norms, India's search for a sustainable, cost efficient and environmentally clean alternate fuel is inevitable. Due to the availability of large arid land and plenty of non-edible sources (karanja, jatropha, neem,..) the potential of cultivating biodiesel in India is enormous. Over 70% reduction in smoke emission has been observed for B40 (40% biodiesel blended with diesel fuel) in comparison with neat diesel operation. Few literature studies reveal the importance of sensing and metering the biofuels on-board. Milpied et al. [1] investigated a tuning fork flexural resonator, which can simultaneously measure dynamic viscosity, density and dielectric constant of a fluid. The physical property measurements are accomplished by high performance algorithms that provide direct feedback to Engine Control Module (ECM), Urea SCR and other fluid management systems. Several key application were presented in this paper, like assessment of fluid quality to make a proper use of engine oil, fuel quality monitoring and finally monitoring of urea solutions quality. Anandaraj et al. [2] studied about the accuracy of the fuel level sensor and suggested a sensor with better reliability, accuracy and adaptability. Capacitance based sensor is identified as one of the better solutions to meet the above demand requirements. The response to fuel level change and output resolution accuracy is some of the vital factors which determine the sensor suitability to the vehicle. Jadhav et al. [3] has provided an insight on developing a closed loop circuit using a PID logic controller for generating various fuel blends. In the control loop, the fluid flow is controlled by a rotameter. The measured pressure difference is converted into an electrical signal by a differential pressure transmitter. The output of the transmitter is given through a square root extractor to the PID controller. The controller compares the input with the desired flow and generates an output signal. In the electrical loop, the output of the controller is given to the auto manual station that generates 230V

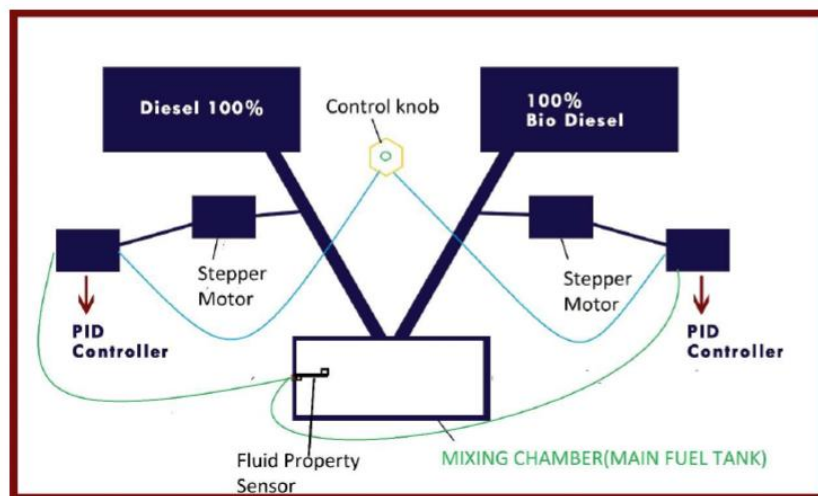


pulses to operate the electrical control valve, which control the flow. Further, Changhwan et al. [4] reported lower NO<sub>x</sub> and smoke emissions, with coconut blended diesel (B10) at a constant speed of 2000 rpm. This emission reduction is attributed to the presence of fuel-bound oxygen and lesser carbon content with biodiesel fuels. However, with increase in the biodiesel blend, the break power decreases due to its lower calorific value [5, 6].

From the literature survey, it was understood that the properties of biodiesel and their blends like viscosity and densities changes significantly. Hence, viscosity and density are the properties that we can rely on to identify the differences in the proportion of the biodiesel fuels. Further, the closed loop position controller is preferred over an open loop position controller.

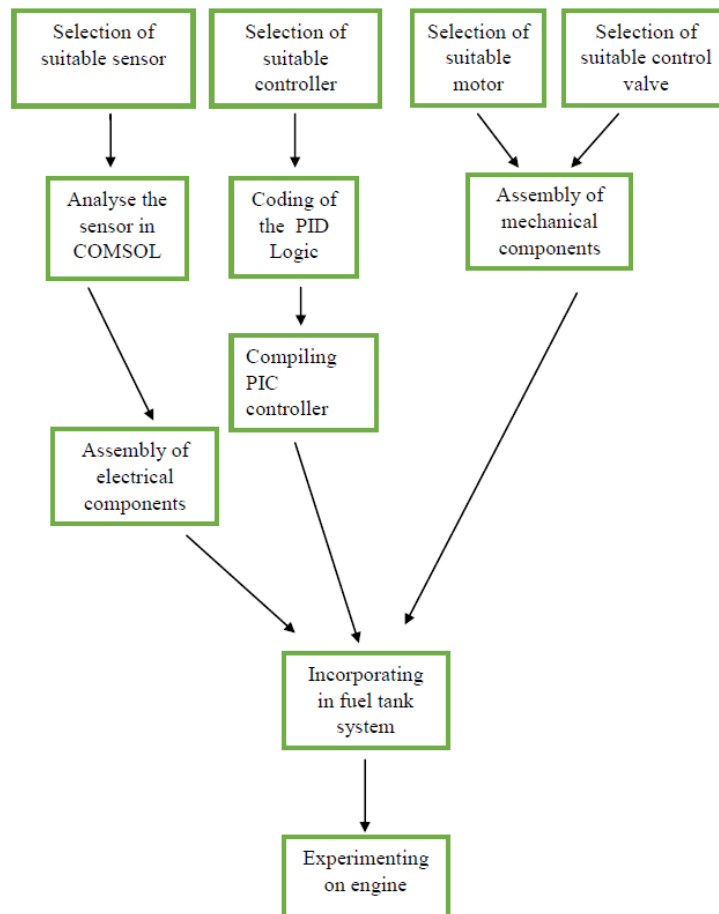
## 2. Methodology

The objective of this study is twofold, to design a fuel supply system which meters the proportionate amount of fuel based on the desired set point as shown in Figure 1. Second is to integrate the stepper motor with the control valve and to check the setup feasibility in an engine as shown in Figure 2. As shown in Figure 1, two main tanks of two liter capacity are selected. One will be used for neat (100%) diesel and another for neat (100%) biodiesel. Each tank is attached with a 4mm pneumatic pipe. These pneumatic pipes are then connected to the inlet of their respective control valves. Two sets of gears are used on either side for the transmission of motion from the stepper motor. The stepper motors are aligned according to the control valve and then are mounted to the stand as shown in Figure 4.



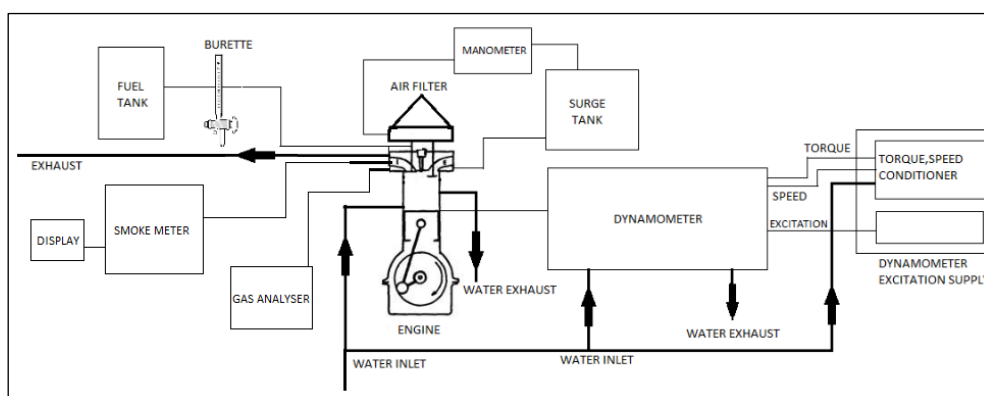
**Figure 1.** Schematic of the proposed setup

A Matlab code is developed for driving the stepper motors at different conditions and for blending the following proportions of biodiesel namely B0, B10, B20, B30, B40, and B50. A three way straight flare pipe split is used, where the two ends are connected to the outlet of control valves and the other end is placed in a mixing chamber. The bottom of the mixing chamber is connected with a pneumatic pipe which allows the fuel to flow into the engine's fuel tank. A frequency generator is implemented in the fuel tank, to obtain the viscosity of the fuel in the mixing tank based on the output voltage. Peripheral interface controller (PIC) is employed for controlling the stepper motors, which in turn operates the valve. The power supply after the step-down transformer is sent via rectifier where alternating current is converted to direct current.



**Figure 2.** Flowchart illustrating the proposed study

The stepper motor requires a variable voltage ranging between 5 to 12V because of the varying load, hence a voltage regulator drives the motor based on the input from PIC controller. A voltage regulator is designed to maintain a constant voltage supply. Further, a fuel sensor is mounted in the mixing chamber at a level of 3 liters capacity. This is used as a precautionary measure to prevent overflow condition in the mixing chamber. As shown in Figure 3, a twin cylinder diesel engine coupled with an eddy current dynamometer is employed for testing the developed system. The specification of the engine is provided in Table 1.



**Figure 3.** Schematic of the engine setup

Figure 3 represents the schematic of the experimental setup, where the performance and emission tests were conducted. There is a proper inlet and outlet of water supply for cooling the engine and the dynamometer.

**Table 1.** Test engine specifications

Make & Model	Kirloskar (DM20, Agricultural engine)
Engine Type	2 cylinder, in-line naturally aspirated, direct injection compression ignition 4 stroke and 2 valves per cylinder
Cubic Capacity (ltr)	1.896
Rated Speed (rpm)	1500
Rated power (kW)	14.1
Cooling system	Water cooled

A manometer and burette is employed for measuring the air and fuel consumptions. The intake air from atmosphere was filtered and dampened with a surge tank and the pressure difference was measured using a U-tube manometer. A probe is connected to the engine exhaust manifold for emission measurements. The equipment makes along with their specifications and measurement uncertainty are provided in Annexures 1 and 2 respectively. The setup is placed over the fuel tank so that the fuel flow takes place gravitationally as shown in Figure 4. Initially, both valves are in closed condition and one tank is filled with biodiesel and another with fossil diesel. Now the blend is set to B0 and started the engine operating at various load conditions.

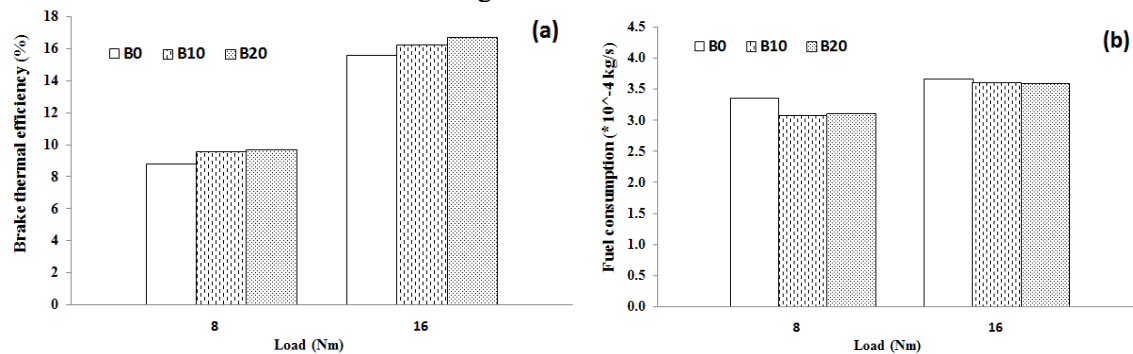


**Figure 4.** Mounted fuel tank systems and the stepper motor arrangement

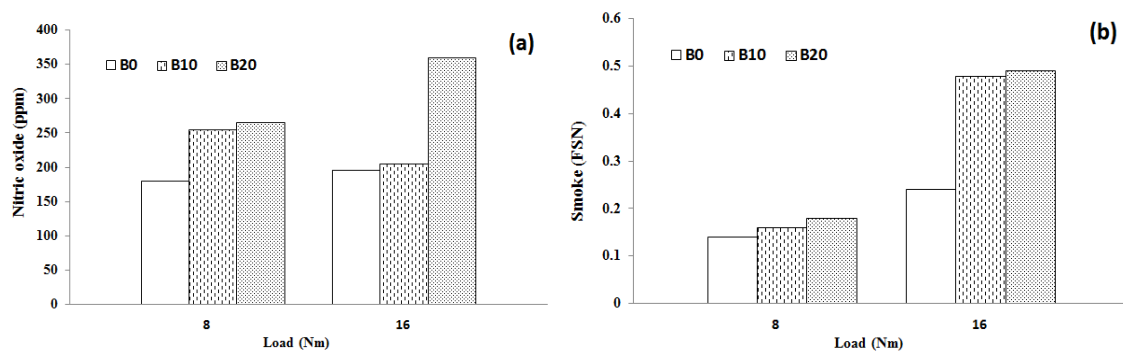
### 3. Results and Discussion

A preliminary experiment was conducted with diesel blended propanol for testing the blend accuracy. The density of propanol-1 and diesel blends was calculated initially. Then the experiment is conducted with the same blends and the error variation is found to be within 1.3%. The performance and emission results with the onboard fuel metering system are provided in Figures 5 and 6 respectively. The results of nitric oxide emissions are in accordance to the previous studies [7-10]. The possible threats due to biodiesel usage are the depletion of ozone layer due to higher NO<sub>x</sub> emission, smog formation in presence of hydrocarbon emanating from other sources and land availability. Both NO<sub>x</sub> and smoke are observed to increase with increase in load conditions. The presence of fuel-bound oxygen will tend to suppress the smoke emissions [11]; however in the current work the biodiesel blended diesel has yielded higher smoke emission. Thus the developed system had precisely blended the fuel, during the engine operation. The metering system satisfies the required flow rate to operate

the engine. The time taken for fuel to into mixing chamber is decreasing with increase in biodiesel blend as both the fuel meet at the three-way slip which increases the pressure. The pressure developed increases flow rate of fuel into the mixing chamber.



**Fig. 5** Engine performance parameters (a) Brake thermal efficiency and (b) Fuel consumption



**Figure 6.** Engine emission characteristics (a) Nitric oxide and (b) Smoke

#### 4. Conclusion

The developed system has all the advantages to meet the requirements of onboard fuel metering and sensing in a vehicle. In case of blending, the developed system has demonstrated its performance with minimal error. The system has added benefit as it can allow for change in features with help of software using the microcontroller design. Thus the driver can alter the proportion of biofuel blend anytime by just using a switch, which can be mounted on the steering wheel.

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### Annexure

**Table A.1** Equipment's and Controllers details used for measurements

S. No.	Parameter	Instrument	Measurement range and accuracy
1	Brake torque	Eddy current dynamometer (Magtrol make)	0-560 (Nm @ 2390 rpm)
2	Speed	Pulse sensor	0-10000 (rpm)
3	Fuel flow rate	Burette-stop watch arrangement	---
4	Air flow rate	U-tube manometer	---
5	Nitric oxide	Electrochemical (Horiba)	0-5000 (ppm)
6	Exhaust smoke	AVL Smoke meter	0 – 10 (FSN)
7	Fuel density	Hydrometer	700 – 1000 (kg/m <sup>3</sup> )
8	Fuel viscosity	Viscometer	0 – 50 (cSt)

**Table A.2** Measurements uncertainty

S. No.	Parameter	Uncertainty
1	Speed (rpm)	± 3.43
2	Brake torque (Nm)	± 2.10
3	Fuel time (s)	± 0.45
4	Air time (s)	± 0.54
5	Nitric oxide (ppm)	± 7.00
6	Smoke (FSN)	± 0.30
7	Brake power (kW)	± 0.29
8	Fuel consumption (kg/s)	± 0.45
9	Brake thermal efficiency (%)	± 1.13