

Combined Effect of Oxygen Enrichment and Emulsification Techniques on Performance, Emission and Combustion of a WCO Based CI Engine

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ABSTRACT

This work aims at studying the combined effect of oxygen enrichment and emulsification techniques on engine performance behavior of a compression ignition engine fuelled with WCO (waste cooking oil) as fuel. Used sunflower oil collected from a restaurant was chosen as fuel. A single cylinder, water cooled, agricultural oriented, diesel engine was used for the experiments. Initially tests were performed using neat diesel and neat WCO as fuels. Performance, emission, and combustion parameters were obtained. In the second phase of work, WCO was converted into its emulsion by emulsification process using water and ethanol and tested. In the third phase, the engine intake system was modified to admit excess oxygen along with air to test the engine with WCO and WCO emulsion as fuels under oxygen enriched environment. A comparative study was made at 100% and 40% of the maximum load (i.e. 3.7 kW power output) at the rated engine speed of 1500 rpm. Neat WCO resulted in reduced BTE (brake thermal efficiency), increased smoke, HC (hydrocarbon) and CO (carbon monoxide) emissions. The maximum BTE was noted as 26.2% with neat WCO, whereas it was 30.5% with diesel at the maximum power output of 3.7 kW. The smoke, emission was noted to be 75% with neat WCO and 40% with diesel. WCO emulsion resulted in improved BTE as compared to neat WCO. It was achieved as 28.2% with WCO emulsion. The smoke and NO_x values were noted to be less than neat WCO. Oxygen enrichment further improved the engine's performance with significant reduction in emissions such as smoke, HC and CO with neat WCO and WCO emulsion as fuels. 24% of oxygen concentration was found to be optimal for best operation for both WCO and WCO emulsion. At peak power output the maximum brake thermal efficiencies were noted to be 28.4% and 29.6% with neat WCO and WCO emulsion respectively for the oxygen concentration of 24%. However, NO_x increased to 685 ppm and 590 ppm with WCO and its emulsion respectively for 24% of O₂ at 100% load. From the experimental results, it was concluded that WCO could be effectively used as fuel in a single cylinder diesel engine by making stable emulsion with water and ethanol. The WCO emulsion could be used directly in the unmodified engine with superior performance and significant reduction in all emissions mainly at high power outputs. Oxygen enrichment could offer considerable improvement in BTE, significant reduction in smoke, HC and CO emissions at both power outputs with neat WCO as fuel. Oxygen enrichment could further improve the performance and reduced emissions of the WCO emulsion even at part load (i.e. 40% load). 24% oxygen concentration by volume could be recommended for optimal operation with WCO and its emulsions as fuel. Combined operation of oxygen enrichment and emulsification could achieve significant improvement in the engine performance at all operating conditions with NO_x under control using WCO as fuel.

CITATION: Masimalai, S. and Nandagopal, S., "Combined Effect of Oxygen Enrichment and Emulsification Techniques on Performance, Emission and Combustion of a WCO Based CI Engine," *SAE Int. J. Fuels Lubr.* 9(1):2016, doi:10.4271/2016-01-1265.

INTRODUCTION

Waste cooking oils (WCOs) are found very attractive to be used as alternative fuels for compression ignition (CI) engines as they are easily available, renewable and most of the properties are very close to diesel [1-3] as shown in Table 1.

However, their poor volatility, high viscosity and density make them difficult to burn completely in diesel engines. Combustion of neat WCOs in diesel engines results in inferior performance and increased HC (hydrocarbon), smoke and CO (carbon monoxide) emissions [4, 5]. Hence a number of methods have been attempted in the past to use WCO as fuel effectively in diesel engines. Preheated WCO of sunflower was tried as fuel by Pugazhvidivu et al. to investigate the performance and emission behavior of a diesel engine [6]. They

observed a significant improvement in BTE (brake thermal efficiency) by increasing the fuel inlet temperature. However they noted higher NO_x (oxides of nitrogen) with fuel preheating. Investigations carried out by Ales Hribernik et al. to study the combustion behavior of WCO and its blends with diesel fuel reported that the ignition delay of the injected fuel was more with the amount of WCO in the blend [7]. They also noted that the maximum engine power was same as diesel. Experimental study conducted by Abu Jarai et al. on a diesel engine using the blends of WCO and diesel as fuel with exhaust gas recirculation reported that the BTE was lower with the blend of WCO as compared with neat diesel at all power outputs [8]. They noted increased ignition delay and combustion duration with the blend of WCO with diesel when EGR was used.

Table 1. Properties of Fuels

Properties	Diesel	WCO
Density at 20°C(kg/m ³)	840	870
Lower Heating Value (kJ/kg)	42490	39600
Viscosity (cSt) @ 30°C	4.59	45
Flash Point (°C)	52-96	218
Cetane Number	45-55	40
Boiling Point (K)	436-672	657
Stoic A/F ratio (mass)	14.5	12.5
Carbon residue (%)	0.1	0.54
Sulphur content (% wt)	0.049	0

Transesterification of WCO in to its methyl or ethyl esters (called as biodiesel) is considered as the most effective method of using WCO in diesel engines [9-11]. A winter road test performed by Merve Cetinkaya et al. on an automotive engine using WCO biodiesel as fuel reported that the torque and brake power output with WCO biodiesel were 3-5% less than that of diesel fuel [9]. They explained that the lower specific heating value of biodiesel was the reason for that difference. Investigations made on the performance, emission and combustion behavior of a LHR (low heat rejection) engine using WCO oil in crude form and biodiesel form by Chowdary et al. reported improvement in performance with WCO in biodiesel form in the LHR engine [10]. Experimental study performed by Joonsik et al. reported lower heat release rate and longer ignition delay with WCO biodiesel as compared to commercial diesel [11]. Though biodiesel is very attractive, transesterification process involves complex chemical reactions. In addition it is a time consuming and expensive process [12]. It also results in certain by products such as glycerol and fatty acids which cannot be used as fuel in engines. The other drawback of using biodiesel in diesel engine is the result of higher NOx emissions [13].

Fuel emulsification is considered as an easy and effective ways of combusting slow burning vegetable oils such as WCO completely and rapidly in diesel engines. Emulsification is an easy process. It involves no complex chemical reactions. In addition, no by products are obtained from emulsification unlike fatty acids and glycerol from transesterification process. The added advantage of emulsified fuel is the simultaneous reduction of smoke and NOx emissions when used as fuel in diesel engines. Earlier studies on emulsions of animal fat and vegetable oils reported significant improvement in engine performance with simultaneous reduction of smoke and NOx emissions [14-16]. Emulsions could also reduce the HC and CO emissions mainly at high power outputs. However past studies revealed poor part load performance with emulsions as fuel [14]. It was also recommended that oxygen enrichment technique could solve the problem of poor part load performance of the engine. In addition, oxygen enrichment could offer significant improvement at performance and considerable reduction in smoke, HC and CO emissions at high power outputs also. The problem of high NOx emissions could be compensated by using emulsions of oils. Earlier studies revealed that the combined effect of emulsions and oxygen

enrichment significantly improved the performance and reduced the emissions drastically including NOx using water diesel emulsions as fuel [17].

Though a number of methods have been attempted in the past to improve the performance of WCO as fuel in diesel engines, past studies indicates that still there is a need for further research in solving the problem of very high smoke emissions of using WCO as fuel. It is noted that earlier research works revealed limited analysis on the use of WCO emulsions as fuel for diesel engines. Investigations on the combined effect of oxygen enrichment and emulsification of WCO in diesel engines on performance, emission and combustion behavior were not reported elsewhere. Hence an attempt was made on an agricultural purpose diesel engine using emulsification of fuel, oxygen enrichment and hydrogen induction to use WCO effectively as fuel. A comparative study was made on all the methods. The following methods were compared on engine performance, emission and combustion characteristics at 100% and 40% of the maximum load (power output i.e.3.7 kW).

1. Neat diesel
2. Neat WCO
3. Emulsion of WCO
4. Oxygen enrichment with WCO as fuel with 24% of oxygen concentration
5. Oxygen enrichment with WCO Emulsion as fuel with 24% of oxygen concentration

TEST ENGINE SET-UP AND EXPERIMENTS CONDUCTED

The test engine used for the study is a single cylinder, 4-Stroke water-cooled, direct injection, agricultural diesel engine. The complete engine specifications are presented in Table 2 and the engine experimental setup and instruments used can be seen in Figure.1.

Table 2. Engine Details

Make	KIRLOSKAR - AV 1
General Details	4S, CI, Water-cooled, Naturally aspirated, single cylinder engine
Bore & Stroke	88 mm × 110 mm
Compression Ratio	16:1
Rated Power output	3.7 kW at 1500 rev/min
Injector opening Pressure	200 bar
Displacement Volume	630 cc
Connecting rod length	165.3 mm
Fuel Injection Timing	27 ° Before Top Dead Center

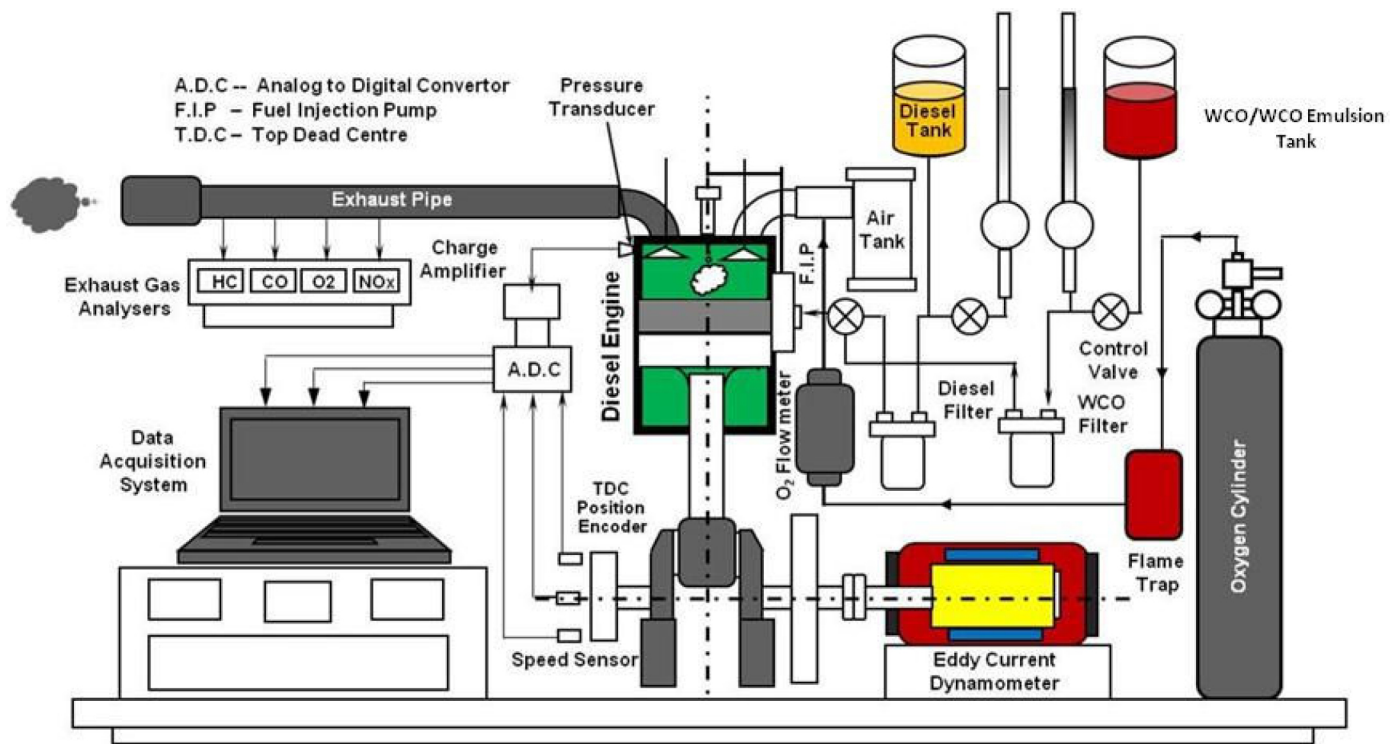


Figure 1. Engine Experimental Setup

An eddy current dynamometer (BENZ SYSTEMS) was used for varying the power output and measuring torque of the engine. The intake manifold of the engine was modified to accommodate excess oxygen. A separate oxygen cylinder was used for storing pure oxygen (with 99.8% purity) at 160 bars and supplying excess oxygen to the engine. The oxygen from the cylinder was passed through a regulating valve to the gas flow meter, the flame trap and flame arrester and to the intake manifold. The gas flow meter was used for measuring oxygen flow rate. An AVL crank position encoder was used to give signals at TDC. An air cooled piezo electric pressure sensor (KISTLER 6613CA integrated with a charge amplifier) in conjunction with an AVL INDISMAST combustion analyzer was used for obtaining cylinder pressure diagrams.

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Cylinder pressure data obtained from 100 consecutive cycles were recorded by the data acquisition system and the signals were processed by the specially developed AVL software to obtain combustion parameters like peak pressure, maximum rate of pressure rise, heat release rate etc. The fuel flow rate was measured on the volumetric basis using a burette and stop watch. An AVL five gas analyzer which works on the non dispersive infrared principle was used for measuring HC, CO and NO in the exhaust. Smoke levels were obtained by using a standard AVL smoke meter. Test was conducted on the engine for all the fuels at the rated speed of 1500 rpm with two different power outputs (i.e. loads) such as 100% (3.7 kW brake power at 23.6 Nm torque) and 40% (1.48 kW brake power at 9.4 Nm torque). During the entire investigation the injection timing was set at 27° before TDC (optimum timing for all the fuels). Readings for engine speed, torque, exhaust gas temperature and fuel flow rate were recorded for obtaining performance parameters. Cylinder pressure histories with crank angle were obtained to study the engine combustion parameters.

EMULSION PREPARATION AND OXYGEN INDUCTION SYSTEM

Water in oil indirect emulsion of WCO was prepared by mixing WCO with water in the presence of the emulsifier (span 80) and co surfactant (ethanol). To study the stability of the emulsions different formulations shown in Table 3 were made by varying the water, oil surfactant and co surfactant. The prepared emulsions were kept at room temperature without stirring. The homogeneity was oil and water of all formulations was checked every day. From the stability test, it was found that the optimum emulsion contained 80% of WCO, 10% of water, 5% of ethanol, and 5% of surfactant. This mixture composition was stable for a long period of time (i.e. for 20