ABSTRACT

The rapid depletion of fossil fuel reserves, rising energy demand and stringent emissions norms have driven global efforts toward sustainable, cost-effective alternatives to conventional diesel. Waste cooking oil (WCO), owing to its low cost and for environmental benefits, presents a viable renewable option; however, limitations related to its physicochemical properties restrict its direct use in diesel engines. To overcome these limitations without resorting to complex, energy-intensive transesterification processes, the present investigation explores the feasibility of diesel–preheated waste cooking oil (PWCO)–n-octanol ternary blends as an alternative fuel for compression-ignition engines, with the objective of improving combustion behavior, engine performance and exhaust emission characteristics.

Initially, the viscosity-temperature characteristics of WCO were evaluated and a preheating temperature of 70 °C was selected, resulting in a viscosity reduction from 34.25 cSt to 12.5 cSt. Based on fuel property constraints, a minimum 50% diesel replacement target and the cost lower than diesel, suitable blend compositions were identified. Three ternary blends, D50W40O10, D50W35O15 and D50W30O20, along with a binary blend (D50W50), were prepared and characterized. The fuel properties of all blends satisfied the limits prescribed by ASTM, EN and Indian standards and were found to be more economical than diesel.

Engine experiments were conducted on a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine rated at 10 kW, operated at a constant speed of 1500 rpm under varying load conditions. Combustion analysis revealed that the D50W40O10 blend exhibited the most advanced and efficient combustion, with the lowest mean ignition delay (15.73 °CA), earlier combustion phasing (CA10 = 0.34 °CA, CA50 = 13.84 °CA, CA90 = 32.05 °CA) and the shortest total combustion duration (40.32 °CA). Peak cylinder pressure varied from approximately 36 bar at no load to 72 bar at full load for all fuels, while the peak heat release rate increased with engine load, reaching approximately 207 J $°CA^{-1}$ at full load. Brake thermal efficiency increased and fuel consumption decreased with increase in engine load, peaking at approximately 75% load. However, the blends exhibited slightly higher fuel consumption than diesel due to their lower calorific value. Compared to diesel, the blends exhibited higher CO and HC emissions, but significantly lower NO_X and smoke opacity due to charge-cooling effects and the presence of fuel-bound oxygen. The higher CO_2 emissions further indicate enhanced overall oxidation and improved combustion completeness despite localized incomplete combustion.

The combined effects of engine load and n-octanol concentration on performance and emission characteristics were studied using a full factorial experimental design coupled with response surface methodology, yielding $R^2 > 0.97$, CoV% < 10% and adequate precision > 4. Validation tests confirmed that the developed regression models predicted the responses with errors below 8%. Multi-objective optimization identified D50W30O20 at 65% engine load as the optimal condition (desirability 0.988). With reference to diesel, this blend reduced CO, NO_X, HC and smoke emissions by 5.70%, 33.56%, 12.24% and 22.85%, respectively, while maintaining comparable BTE, with CO_2 emissions increased by 8.72% and a cost reduction of 8.82%.

Overall, the study demonstrates that WCO, when judiciously blended with diesel and n-octanol, can serve as a technically feasible, economically attractive and environmentally sustainable alternative fuel for diesel engines, enabling effective waste utilization, emission reduction and reduced dependence on fossil fuels without extensive fuel processing.

Keywords: Waste cooking oil; n-Octanol; Diesel engine; fuel properties; Combustion characteristics; Performance; Exhaust emissions, Response surface methodology