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ORIGINAL ARTICLE

Application of zero-dimensional thermodynamic model for predicting combustion parameters of CI engine fuelled with biodiesel-diesel blends

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Abstract Biodiesel from non-edible vegetable oil seems to be a promising alternate for petro-diesel in the present energy scenario. This study analyses the experimental and theoretical effects on the blends of Bee Wax biodiesel with straight diesel on combustion parameters. A zero-dimensional mathematical model is developed to analyse the rise in in-cylinder pressure along with Wiebie's heat release correlations, ignition delay, gas dynamics model, heat transfer model and frictional model. The combustion parameters include in-cylinder pressure rise, net heat release and rate of pressure rise are investigated and found to be higher for straight diesel and deteriorated with the increase in blends of BWB. The theoretical simulation also supports the experimental data with constant injection timing, speed and compression ratio.

1. Introduction

Honey and beekeeping have a long history in India with oldest records in the form of paintings by prehistoric man in the rock shelters. With the development of civilization, honey acquired a unique status in the lives of human beings. The recent past has witnessed a revival of the industry in the rich forest regions along the sub-Himalayan mountain ranges and the Western Ghats, where it has been practiced in its simplest form. Several natural plant species provide nectar and pollen to honey bees. Thus, the raw material for production of honey is available free from nature. Beehives neither demand additional land space nor do compete with agriculture or animal husbandry for any input. Beekeeping constitutes a resource of sustainable income generation to the rural and tribal farmers providing valuable nutrition in the form of honey, protein rich pollen, brood and beehive wax.

During the 1980s, an estimated one million beehives had been functioning under various schemes of the Khadi and Village Industries Commission with the development of apiculture using the indigenous bee, Apis cerana, Apis mellifera, which gained popularity in Jammu & Kashmir, Punjab, Himachal Pradesh, Haryana, Uttar Pradesh, Bihar and West Bengal. Wild honey bee colonies of the giant honey bee and the oriental beehive have also been exploited for collection of

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Nomenclature

θ	crank angle (in °)
Cr	compression ratio
Crl	connecting rod length
V_{swept}	swept volume (in mm^3)
BDC	bottom dead centre
TDC	top dead centre
D	bore diameter (in mm)
l	stroke length (in mm)
DI	direct injection
C–H–O	carbon hydrogen oxygen equilibrium system
FTT	finite temperature thermodynamics model
bTDC	before top dead centre
EGT	exhaust gas temperature in degree celsius
U	internal energy (in joules)
W	work done (in kW)
C_v	specific heat at constant volume (in kJ/kg K)
x	mass fraction
t_i	starting time of injection (in s)
t_g	starting of combustion (in s)
p_o	stagnation pressure (in bar)
k	specific heat ratios for gasses
h_c	coefficient of heat transfer (in W/m^2)
υ	velocity of gasses (in m/s)
V_p	mean piston speed (in mm/s)
BWB 10	beeswax biodiesel 10% straight diesel 90%
BWB 20	beeswax biodiesel 20% straight diesel 80%
CA	crank angle (in °)
HRR	heat release rate (in J/CA)

honey. Both natural and cultivated vegetations in India constitute an immense potential for development of beekeeping. About 500 flowering plant species have been identified as major and minor sources of nectar and pollen. In the recent years the exotic honey bee has been introduced representing a wide variety of bee fauna that can be utilized for the development of honey industry in the country. There are several types of indigenous and traditional hives including logs, clay pots, wall niches, baskets and boxes of different sizes and shapes. India, potentially produces about 120 million bee colonies discharging over 1.2 million tons of honey and 15,000 tons of beeswax. Organized collection of forest honey and beeswax using improved methods results in an additional production of at least 120,000 tons of honey and 10,000 tons of beeswax [22].

Internal combustion engines, mainly compression ignition engines are used in transportation industries. They are also used in power production and agricultural applications as well. CI engines operate at relatively higher efficiency when compared with spark ignition engines, due to their higher compression ratio. Currently, investigations are carried out to reduce the diesel emission and provide cleaner and more efficient engine systems. Biodiesels will be a key in achieving the above goal and thermodynamic simulation of the internal combustion engines providing enhanced knowledge to understand and configure new engines technologies.

Simulation is the process of creating a virtual system to understand the properties of real time system without physical interventions. The development in the field of computers has opened the doors of computational environment. Diesel engine simulation models are classified into three categories, namely zero-dimensional single zone models, quasi-dimensional multi zone models and multi-dimensional models in which zero-dimensional models provide the essence of thermodynamic property of a system modelled. On the other hand, the multi-dimensional models resolve the space of modelled system on a fine grid thus providing special information. However, computational time and coding constraints keep this model away from consistently using them in-design optimization process. Combustion process of compression ignition engine is a complicated phenomenon based on thermodynamic models that incorporate the energy equation for closed system and species conservation equation that predicts the heat release pattern and pressure of the system. Working fluid undergoes a continuous change in its thermodynamic state through the series of the engine operational cycles which mainly consists of constant pressure suction, adiabatic compression, constant pressure combustion, isentropic expansion and constant pressure exhaust events where the thermodynamic states are to be computed with the help of programs for diesel operating cycle.

Many researchers conducted experiments based on mathematically modelling of engine fuelled with bio-diesel for predicting the performance and combustion parameters. A few of them are discussed below. Ramadhas et al. studied the theoretical model for rubber seed oil methyl ester fuelled engine and analysed effect of relative air fuel ratio and compression ratio on the engine performance for different fuels. They used single zone thermodynamic model for predicting the performance of compression ignition engine by considering fundamental assumption about cylinder charge, specific heats to solve energy equation and also Hohenberg equation in heat transfer [1].

Raut theoretically modelled a compression ignition engine depending on the characteristics of fuel using thermodynamic model for predicting the properties of working substance in suction, compression, power and exhaust strokes during the engine operation. The model predicted the performance of compression ignition engine in terms of brake power and brake thermal efficiency for all fuels and also calculated the volume as a function of crank angle by taking cylinder bore, stroke length of the engine and length of the connecting rod. The author used Wiebie heat release model to analyse the heat release pattern of the engine and Pflaum equation to predict the heat transfer coefficient and heat lost to the walls of the engine [14]. Rakopoulos et al. elaborated the two zone models for DI diesel engine with the use of mass, energy and state equations for determining the local temperature and pressure. Also, the author applied chemical equilibrium scheme for C–H–O system to predict the exhaust gas composition and used simulation model for various loads and compression ratios along with Annand's equation for determining the heat transfer coefficient. The authors have also elaborated the use of fuel

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