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Optimization of combustion bowl geometry for the operation of kapok biodiesel – Diesel blends in a stationary diesel engine

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HIGHLIGHTS

- The combustion bowl geometry has been optimized for the use of KME in a diesel engine.
- TRCC, TCC and HCC were considered as probable combustion bowl geometries.
- With HCC and TCC, B25 and B50 were found to be the optimum blends, respectively.
- B50 showed a 5.2% increase in BTE than diesel with TCC.
- CO and smoke were reduced by 15.7% and 7.8%, respectively, for B50 with TCC.

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ABSTRACT

The purpose of this research work is to optimize the combustion bowl geometry of a single cylinder stationary diesel engine for the effective operation of KME (kapok methyl ester) – diesel blends. Considering that the reported design modification would render the benefit of adaptation of higher blends of KME, in this study, two different combustion chamber geometries such as TRCC (trapezoidal combustion chamber) and TCC (toroidal combustion chamber) were chosen in addition to the convention design of HCC (hemispherical combustion chamber). In the experimental investigation, suitable blends such as B25 (25% KME + 75% diesel), B50 (50% KME + 50% diesel), B75 (75% KME + 25% diesel) and B100 (100% KME) were tested in a diesel engine with various combustion chamber geometries as mentioned above. Based on the results obtained from this study, TCC was shown to exhibit better performance and emission than TRCC and HCC for all test blends. Further, when compared to diesel, B25 and B50 were found to be the optimum blends with HCC and TCC, respectively, while TRCC seldom evinced better engine characteristics for any of the blends. Categorically, B50 showed a 5.2% increase in BTE (brake thermal efficiency) than diesel with TCC, whereas emissions such as CO (carbon monoxide) and smoke were reduced by 15.7% and 7.8%, respectively, with a comparable NO_X (nitrogen oxides) emission with diesel. Similarly, combustion for B50 with TCC was found to be better than diesel, manifesting an increase in maximum heat release rate that that of diesel. Conclusively, from the experimental study, TCC was recognized as an ideal choice of combustion chamber design for the operation of blends up to B50 in a diesel engine.

1. Introduction

In the history of engine development, engine manufacturers are very keen to design the combustion chamber meticulously, as it is the key component ascertaining the engine combustion, performance and emission. Typically, combustion chamber design will have an effect on air/fuel mixing process and an improved air/fuel mixing will help achieve enhanced fuel burning rate [1,2]. Therefore, in the design process, care should be taken to develop a combustion chamber, which could enhance the air/fuel mixing and the subsequent combustion process. With these considerations, in the past, researchers have been nursing several options to decide on the shape of the combustion chamber and figure out an optimal design. Right from the development of simple design of open combustion chamber, researchers have realized the implementation of re-entrant type, swirl combustion chambers, pre-combustion chambers and so on [3,4]. In the past, there have been many revelations on the impact of different combustion chamber designs on

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the engine characteristics when using conventional diesel [5–7]. With some general trend and insights obtained for diesel fuel with a variety of combustion chambers, the effect of combustion chamber geometry when using biodiesel is worth of an investigation.

Biodiesel, a renewable fuel produced from vegetable oils of various origins, are long chain esters of fatty acids with higher molecular weight and complex molecular structure [8,9]. It is a matter of fact that though 20% of biodiesel with diesel has been standardized to be used in a diesel engine without any modifications [10,11]. With the advent of biodiesel as probable substitute for diesel, research on the optimization of diesel engine to make higher blends amenable for it is imperative. Considering the distinct properties of biodiesel, researchers have asserted modification of either the engine operating or design conditions as a pertinent strategy to adapt higher blends biodiesel in a diesel engine more effectively. In an analogy, the modification of engine design parameters is considered to be an enviable strategy than the parametric study with engine operating parameters, given the design modifications would better counter the distinct properties of biodiesel so as to help enable the use of higher blends of biodiesel [12,13]. In particular, design modification strategy of optimizing the combustion bowl geometry is regarded to be more beneficial and applicable, as it enhances the fuel/air mixing and the combustion processes. [14,15].

The air flow and the associated flow fields in the bowl and squish region are interconnected, and the engine performance, combustion and emission characteristics are different for different shapes of combustion chamber [16,17]. In order to study the effect of combustion chamber geometry on engine performance and emission for the operation of biodiesel, few researchers have performed experimental investigation with various combustion bowl geometries. In this regard, Jaichandar and Annamalai [18] carried out engine experimental testing with three types of combustion chamber geometries in the form of hemispherical, toroidal and shallow combustion chamber without altering the compression ratio of the engine. From their investigation, among the three combustion chambers, toroidal combustion chamber was observed to evince better performance and emission, due to its geometric consideration. Further, due to the improvement in combustion process and presence of oxygen within biodiesel, the gaseous emissions such as CO (carbon monoxide), HC (hydrocarbon) and smoke were reported to be reduced, with an increase in NO_X (nitrogen oxides) emission. In-order to study the effect of re-entrant combustion chamber design over the hemispherical, toroidal and shallow combustion chamber design, Jaichandar and Annamalai [19], in another study, conducted an experimental study in a diesel engine using the B20 blend of pongamia biodiesel. As a notable mention, in re-entrant combustion chamber, the lip of the combustion chamber protrudes beyond the wall surface of bowl and this was reportedly facilitated to increase the engine performance and emission on account of better air/fuel mixing process. From the experimental engine test results, toroidal combustion chamber discerned higher BTE (brake thermal efficiency) than re-entrant combustion chamber and interestingly, BTE of the re-entrant combustion chamber was found to be flanked between toroidal and hemispherical combustion chamber. Due to better mixture formation and the subsequent hot combustion environment, HC, CO and smoke emission were reported out to be lower for toroidal as well as re-entrant combustion chamber than conventional hemispherical combustion chamber, while NO_X emission was pointed out to be higher.

The literature review divulges that optimization of combustion bowl geometry is an appropriate strategy for the adaptation of higher blends of biodiesel in a diesel engine. Despite the fact that more than 350 species of vegetable oil based fuels have been evolved, only few studies have resorted to modify the combustion bowl geometry for using biodiesel. Therefore, an extensive database with optimization of combustion bowl geometry when using biodiesel would be of a notable contribution. In this backdrop, in the current study, we have made an attempt to optimize the combustion bowl geometry for the operation of biodiesel, KME (kapok methyl ester) in a diesel engine. The choice of this biodiesel stems from the fact that feedstock used for the synthesis of biodiesel is a waste and in-edible product, and is only at the beginning stage of development. With these considerations, KME produced by transesterification process was blended in suitable proportions with diesel and operated in a diesel engine with three different combustion chamber geometries viz TRCC (trapezoidal combustion chamber), HCC (hemispherical combustion chamber) and TCC (toroidal combustion chamber). Finally, the optimum combustion chamber design for a suitable blend has been identified in respect of better engine performance, combustion and emission characteristics.

2. Experimental methodology

These days, for research studies, there is a growing interest in the adoption of single cylinder diesel engine generator for testing alternate renewable fuels like alcohols, vegetable oils and biodiesel, owing to the flexibility in handling as well as the ability to operate at desired operating and loading conditions for long hours. Therefore, in the current research study, a single cylinder constant speed diesel engine (genset), enabling variation of operating and design parameters, has been used to experimentally investigate kapok biodiesel – diesel blends. The engine, which is a naturally aspirated one, is configured to operate at a default compression ratio of 17.5, with a capacity to produce a maximum power output of 5.2 kW. The experimental setup and arrangement entailed in the current study on the optimization of combustion chamber geometry using KME – diesel blends have been depicted in Fig. 1. Herein, mechanical type fuel injection system has been used, with the fuel injection timing and pressure of 23° CA (crank angle) BTDC (before top dead center) and 220 bar, respectively. The detailed specifications of the engine are shown in Table 1.

The quantity of fuel consumed by the engine, for each and every loading condition, is measured manually by a burette and stopwatch. The air flow rate is held constant, which is ensured by the pressure column in the manometer attached to the orifice meter. The major gaseous emissions measured in the current study are HC, CO, O_2 (oxygen) and NO_X. Arguably, the reason for the occurrence of these emissions are general and depends up on the type

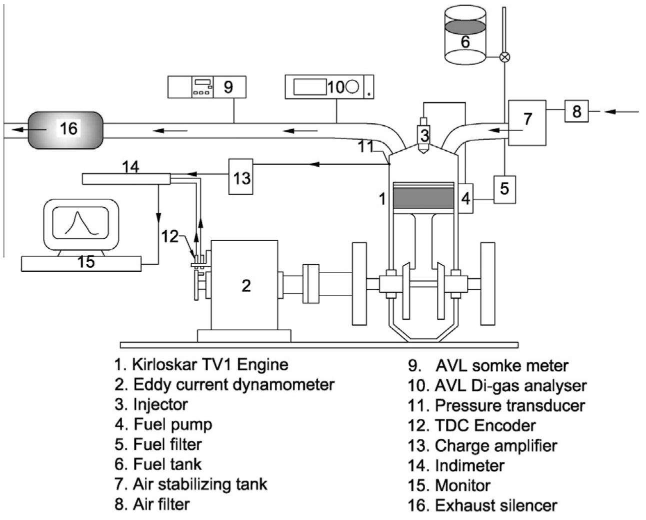

Fig. 1. Schematic diagram of the engine experimental setup and arrangement.