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Comparison of the Performances of Biodiesel, Diesel, and Their Compound in Diesel Air Standard Irreversible Cycles

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Abstract. Biodiesel is a fuel which due to its environmental friendly and renewability properties has established a proper place among researchers. There have been several researches on this fuel. But it has not been observed in a certain research on biodiesel to demonstrate, by using numerical simulators, the behavior of this fuel in an engine which performs a specific cycle. In this research it is considered to review the irreversible cycle of biodiesel fuel and its compounds by means of thermodynamics laws and finite time thermodynamics when the biodiesel fuel is applied as the operative fluid inside the cycle. The results from numerical simulation showed that applying biodiesel fuel and its compounds in this cycle proved to have similar or in some cases even better results from the traditional diesel fuel.

Keywords: biodiesel, diesel, fuel, engine, thermodynamics cycle, air

1. Introduction.

The troubles of using fossil fuels have made researchers to think of finding replacement fuels. Since biodiesel has similar properties to the traditional diesel fuel and less environmental troubles occur from using it, is one of the main candidates for replacing diesel fuel in engines. Several researchers are experimenting on making this fuel applicable. Biodiesel is a proper fuel which is generally extracted from plant oils and animal fat along with methanol and by Trans-esterification method [1, 2, and 3].

There have been conducted vast experiments on performance of an engine while using biodiesel fuels.

Cumali Ilkilic et, al evaluated a single cylinder diesel engine while consuming biodiesel compounds derived from sunflower oil with traditional diesel. In the end it was clarified that using biodiesel compounds in comparison to use pure diesel fuel will slightly increase the brake specific consumption but at the same time greatly decrease pollutants such as CO, PM [4]. The environmental friendly trait is one the most important properties of biodiesel which is mentioned in many experiments [5, 6, and 7].

In most experiments generally in order to approximate the biodiesel properties to the traditional diesel's, the mixture of these two is applied, and it seems that 20% volume of biodiesel along with 80% of traditional diesel fuel is determined to be one of the most proper compounds of biodiesel in order to use for engines [8, 9, and 10].

The applicable aspect of biodiesel compounds in engines has been the main objective of most researches [11]. Practical experiments usually have great costs and are time-taking, which seems to be inapplicable for most researchers. One the experimental fields of biodiesel, which is used less than other fields, is the use of numerical simulation theories and cases for predicting performance engines which are working with a special cycle, while using biodiesel and its compounds. In the past two decades, using finite time thermodynamics for optimizing reversible and irreversible cycles of thermal engines has been expanded [12 and 13]. In this experiment it is considered to evaluate the performance of standard air irreversible cycle while using this

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compound as an operative fluid by means properties of a special biodiesel compound and numerical simulations.

Leff determined the thermal output of Atkinson-engine reversible cycle at the point of yielding maximum output work [12]. Ebrahimi also by using of the same method evaluated the irreversible cycle of Atkinson [12].

Chen et al used output numerical simulation and examined and compared the performance of reversible and irreversible cycles of diesel. This cycle was also evaluated by Ebrahimi under variable compression ratio and stroke length [14]. The results showed that if the compression ratio decreases from a certain limit, by increasing stroke length, the cycle output work will increase first and then decreases. Therefore, using numerical and thermodynamic simulation of fuels behavior in special cycles is a method which without requiring equipments and tools can evaluate the performance of two fuels in an engine.

2. Thermodynamics simulation of diesel standard air cycles

Figure 1 show the volume-pressure of thermodynamic process of a diesel standard air cycle where all four phases of this irreversible cycle was considered. This is the cycle which Rudolf Diesel based his engine upon it and is known as Diesel engine today.

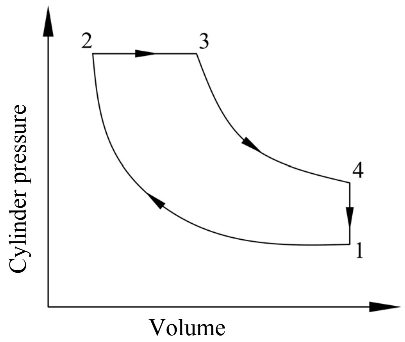


Figure. 1: cylinder pressure based on volume in a diesel standard air cycle

Specific heat generally is considered constant by most researchers in diesel standard air cycle, but in an actual engine this amount is not constant and generally the specific heat is considered only as a function of temperature. Since in engine work range, the temperature varies between 300 to 2200 K, these changes could be considered linear with temperature [15]. Therefore, these two equations are introduced for determining the specific heat:

$$C_v = b + kT \quad (1) \qquad\qquad C_p = a + kT \quad (2)$$

Where, a, b, and k are constant and Cv and Cp are mole specific heat at constant volume and pressure, respectively. It is obvious that gas mole constant could be calculated from the following equation:

$$R = C_p - C_v = a - b \quad (3)$$

During the process of $2 \rightarrow 3$ which is constant pressure process, the fluid is heated which could be calculated from the following equation:

$$Q_{in} = M \int_{T_2}^{T_3} C_p dT = M \int_{T2}^{T3} (a + kT) dT = M \left[a(T_3 - T_2) + 0.5k(T_3^2 - T_2^2) \right] \quad (4)$$

And during the $1 \rightarrow 4$ process which is a constant volume process, the fluid inside the cylinder will release an amount of heat which output heat from this system can be determined from the following equation:

$$Q_{out} = M \int_{T_1}^{T_4} C_v dT = \int_{T_1}^{T4} (b + kT) dT = M \left[(b(T_4 - T_1) + 0.5k(T_4^2 - T_1^2) \right] \quad (5)$$

Since the existing equations were considered only for reversible conditions, the adiabatic amount was considered constant in all of them. But in this experiment, since all processes occur at irreversible conditions, the specific heat amounts depend on the fluid's temperature. Therefore, using reversible adiabatic equations directly is not possible. In order to make these equations applicable at irreversible conditions, an engineering approximation was used. If an irreversible process was considered as an infinite amounts of small processes, the adiabatic ratio of each phase (for example i to j) could be determined as constant. Since in each considered small phase the temperature and volume change as much as dT and dV, thus the temperature-volume adiabatic equation for an irreversible process (with variable adiabatic ration) can be determined from the following equation:

$$TV^{r_c-1} = (T + dT)(V + dV)^{r_c-1} \tag{6}$$

For each small phase (for example i to j):

$$k(T_j - T_i) + b\ln(\frac{T_j}{T_i}) = -R\ln(\frac{V_j}{V_i}) \tag{7}$$

So, the isentropic process of $1 \rightarrow 2$ and $3 \rightarrow 4$ can be rewritten based on (7) as follows:

$$k(T_2 - T_1) + b\ln\left(\frac{T_2}{T_1}\right) = R\ln r_c \tag{8}$$

$$k(T_3 - T_4) + b\ln(\frac{T_3}{T_4}) = R\ln(\frac{r_c}{\beta}) \tag{9}$$

Where, in these equations r_c is compression ratio, and ß=V_3/V_2. In this study, in order to make conditions closer to the reality, the heat losses from heat transfer to outside of the cycle were noted. It could be presumed that heat loss from the cylinder wall is proportionate to the average temperature of fluid inside the cylinder and chamber wall. Therefore, the heat given to a fluid during an actual cycle can be calculated from the following equation [16]:

$$Q_{in} = M\left[A - B(T_2 + T_3)\right] \tag{10}$$

Where, in this equation A and B are constant amounts which are related to the heat transferred to walls and combustion.

Given amount of T_1 from (8), T_2 could be calculated. So by equaling (4) and (10) the following equation is derived:

$$A - B(T_2 + T_3) - a(T_3 - T_2) - 0.5k(T_3^2 - T_2^2) = 0 \tag{11}$$

Placing T_2 in (11), T_3 is achieved. Then, by placing T_3 in (9), T_4 is also achieved. Finally, given T_1, T_2, T_3, and T_4, the amount of cycle work could be calculated from the following equation:

$$W = Q_{in} - Q_{out} = M\left[a(T_3 - T_2) + 0.5k(T_3^2 - T_2^2) - b(T_4 - T_1) - 0.5k(T_4^2 - T_1^2)\right] \tag{12}$$

Also, the amount of cycle's heat output can be calculated as follows:

$$\eta = 1 - \frac{Q_{outn}}{Q_{in}} = 1 - \frac{b(T_4 - T_1) + 0.5k(T_4^2 - T_1^2)}{a(T_3 - T_2) + 0.5k(T_3^2 - T_2^2)} \tag{13}$$

3. Numerical Simulation and Results

Due to data from resources [15] to [19], the following amounts were selected for numerical analysis:

$$\beta = 1.5 - 3 \quad B = 25\frac{J}{mole.K} \quad A = 60000\frac{J}{mole} \quad T_1 = 280 - 340K \quad M = 1.57 \times 10^{-5}\,kmole$$

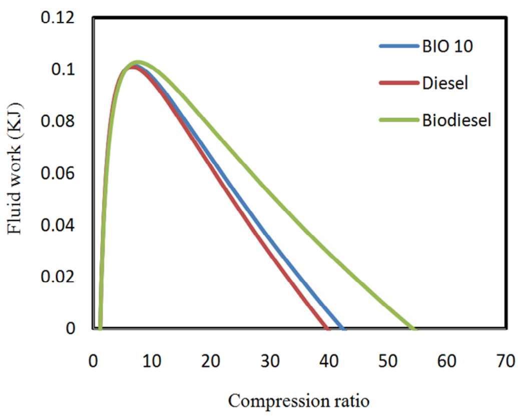
Table 1 shows the specific heat constants for diesel, biodiesel, and BIO10 (including 80% diesel and 20% biodiesel). Considering that biodiesel fuel can be made from a vast range of oils, it should be reminded that the parameters selected for the biodiesel used in this study are from a biodiesel derived from canola oil [20].

Table. 1: specific heat constants from diesel, biodiesel, and BIO10 fuels

a	b	k	Fuel Type
29.9776	20.1442	005372.0	Diesel
28.161	20.3266	0.008175	Biodiesel
28.0151	20.1807	0.005932	BIO10

Then by using numerical simulation the effect of different parameters on cycle performance was evaluated. Also cycle performances while using different fuels and their compounds were compared.

As shown in figure 2, the maximum fluid's work for biodiesel fuel is higher than diesel and BIO10 fuels; also the maximum work of fluid for biodiesel happens at higher compression ratio. And generally the biodiesel work which occurs at higher compression ratios is higher than diesel and BIO10. Consequently, in order to replace biodiesel fuel as an operative fluid in diesel cycle, in order to obtain higher amount of work than diesel fuel, the system must operate under higher compression ratios.



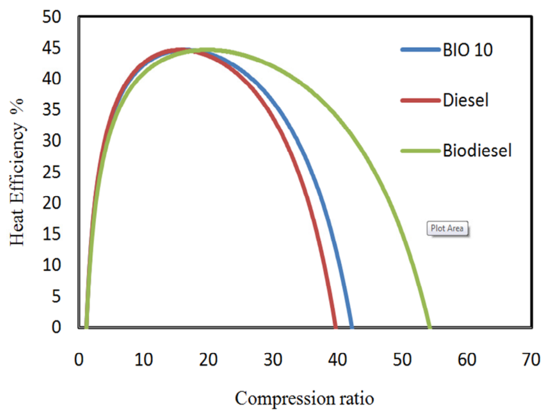
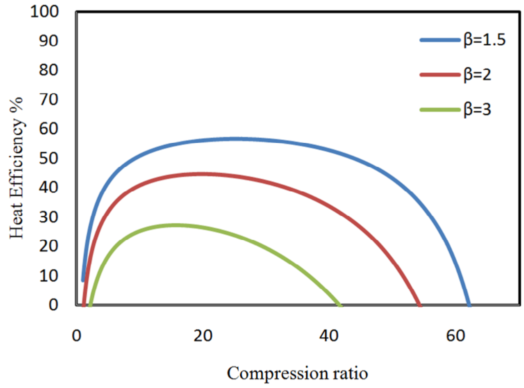


Figure 2 – Fluid work versus compression ratio for diesel, biodiesel, and BIO10 fuels

Figure 3 – Heat efficiency versus compression ratio for diesel, biodiesel, and BIO10 fuels

According to figure 3, it could be found that the maximum heat efficiency for all three fuels is approximately equal, but this maximum amount is achieved in different compression ratios. This ratio for diesel, BIO10, and biodiesel fuels are 12, 15, and 17, respectively. This can be a great guide in designing biodiesel engines. Also, as seen for the cycle work, while using biodiesel fuel in order to achieve higher engine outputs, higher compression ratios are required. In next figures the effect of β parameters on work and heat efficiency for biodiesel fuel was evaluated. This parameter in actual applications represents the amount of piston movement inside cylinder during the time that the fluid was heated. Therefore, smaller β shows shorter piston movements inside cylinder. As observed in figures 4 by increasing β, the amount of work done by the fluid at equal compression ratio decreases. So, in designing engines based on diesel cycle, in order to obtain higher work, heat transfer phase to operative fluid must be done at lowest time possible, or the piston must have minimum displacement inside cylinder. But figures 5 show how heat efficiency variations in relation with compression ratio at different β's. According to obtained figures, it is specified that for achieving to higher outputs at constant compression ratio, one must decrease β. It should be noted that by decreasing β for achieving maximum heat efficiency, the compression ratio must be increased, but at lower β's and around maximum output, the figure curve becomes approximately linear, thus, in this range with small changes in compression ratio, no significant change occurs at heat efficiency amount, and this can be a proper factor in designing engines based on diesel cycle for using biodiesel. Therefore, bigger range of compression ratio changes can be considered in designing, which will result in various options for designers.



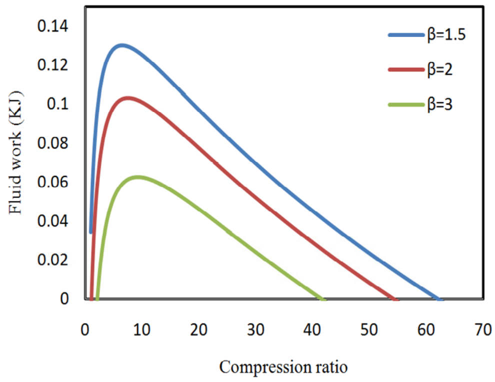


Figure 4 – Fluid work versus heat output for biodiesel

Figure 5 – Heat efficiency versus compression ratio for biodiesel β’

Figures 6 show work done versus heat efficiency at different β's. As it can be seen in these figures, decreasing β, increases maximum work done by the operative fluid and the other important issue is that the maximum work can be achieved at higher heat efficiency, and this is a positive point while designing engines.

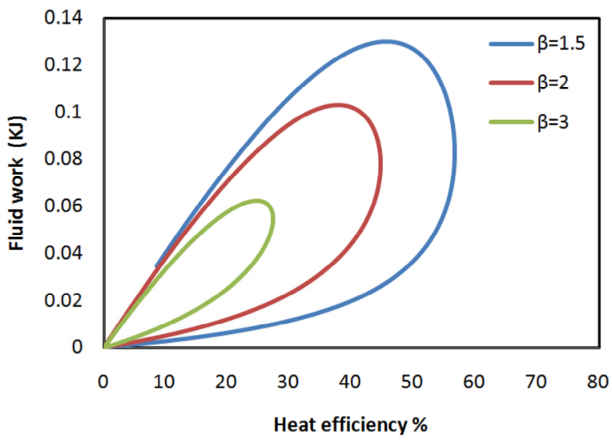


Figure.6 – Fluid work versus heat output for biodiesel fuel at different β's

4. Results

In this study a model for diesel standard air irreversible cycle by considering irreversible parameters such as heat transferred to cylinder wall, entering fluid temperature, and the linear dependence of specific heat to the temperature, was introduced. Fluid work changes and heat efficiency by using numerical calculations by changing irreversible parameters according to compression ratio were evaluated. Results showed that by considering the heat transferred to cylinder wall, entering fluid temperature and variable specific heat have apparent influences on heat output and fluid work of the cycle.

Also, according to obtained equations and figures it can be observed that biodiesel derived from canola oil and its 20% compound with traditional diesel fuel, while being used in diesel standard air cycles, has similar and in some case even better results from traditional diesel fuel. This means that by using the clean biodiesel fuel in addition to decreasing the pollutants, theoretically, output and the amount of the generated work inside cycle would be around the traditional diesel fuel. These results are comparable with the results from the practical experiments on applying biodiesel in engines. Results obtained from this study are a proper guide for designing and evaluating actual internal combustion engines and are also a good guide for designing engines that are basically designed for application of biodiesel as an operative fluid.

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