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Injection and Combustion of biodiesel at different blends: A review

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Abstract: In recent years, all the world is looking for alternative sources of energy to reduce emissions, Sulphur contents and use another fuel source instead of fossil fuels. Diesel engines play an important role in power generation and automotive sectors. The most common alternative fuel used in diesel engines is biodiesel. Biodiesel is suitable for diesel engines instead of petroleum diesel as the combustion of petroleum diesel produces harmful and toxic emissions. This type of fuel is very common because it is very easy to be produced and available. Biodiesel is produced by various methods from vegetable oils and animal fats. The most common method used in biodiesel production is transesterification. In this review, we will indicate injection and combustion processes of biodiesel using different blends to realize the benefits of using this fuel instead of petroleum diesel.

Keywords: Biodiesel; Diesel engine; Injection; Combustion; Emissions.

1. Introduction

It is known that biodiesel fuel is a renewable energy source that is preferred to be used instead of mineral diesel as it causes small amount of particulate matter compared to mineral diesel, but it is noticed that there is an increase of NO_X emissions. These emissions are produced as biodiesel fuel requires less time for injection compared to mineral diesel. Injection timing of biodiesel is small because biodiesel has low compressibility [1]. The increase of NO_X emissions can be overcome by many methods for example, low temperature combustion [2]. Biodiesel has a high cetane number so the ignition will be perfect when it is mixed with mineral diesel [3]. Biodiesel also decreases the amount of carbon dioxide produced by conventional diesel fuel, so it limits greenhouse effect. There are four main methods to produce biodiesel, direct use and blending of vegetable oils, micro emulsion of oils, pyrolysis of oils, and transesterification of oils [4]. Biodiesel fuel will be studied according to its injection method as injection affect many characteristics such as fuel pressure for combustion and injection timing. When biodiesel content changes, that will affect previous parameters [5]. Also, we are going to study combustion of different biodiesel blends according to heating values, different emissions, and combustion efficiency.

2. Blends of biodiesel and diesel fuels

Biodiesel is blended by various ratios with mineral diesel. For example, Jatropha is used as a potential biodiesel feedstock as we can use different blends of Jatropha biodiesel B10, B20 and B0 by using YANMAR TF 120-M diesel

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engine made by Yanmar Co. Ltd of Indonesia. It is found that the use of B10, B20 will give viscosities close to conventional diesel fuel. When biodiesel content increases, density increases, and calorific value decreases [6]. The maximum suitable blend of biodiesel with mineral diesel is B20 that does not require any modification on the engine [7]. Biodiesel produced from ethyl esters of fish oil with different blends (B20, B40, B60, and B80) is blended with diesel fuel with temperatures from 298 K to 573 K. it is found that both cloud point and pour point of biodiesel reduce when we reduce percentage of biodiesel. Dynamic viscosity of biodiesel at different values of shear stress is studied, it is found that biodiesel acts as Newtonian fluid and its dynamic viscosity increases with reducing temperature [8].

Biodiesel from corn and soybean is blended with diesel fuel with ratio of 20% biodiesel (C20 and S20) in single cylinder direct injection diesel engine. The injection pressure was 180, 190 and 200 bar as the effect of injection pressure on engine performance for this technology is studied and compared to diesel fuel. It is noticed that biodiesel blends should be heated until 60-80 ℃ before injection to reduce its viscosity. It is found that the more the injection pressure increases, the more the performance increases, as brake specific fuel consumption reduces and brake efficiency increases, so the most perfect performance was at 200 bar [9]. Some researchers have used a percentage of alcohol with diesel and biodiesel fuels. For example, they used biodiesel (45%)-methanol (10%)-diesel (45%), biodiesel (40%)-methanol (20%)-diesel (40%), biodiesel (45%)-ethanol (10%)-diesel (45%) and biodiesel (40%) -ethanol (20%)-diesel (40%) blends and they found that using alcohols increases brake specific fuel consumption, CO and HC emissions but decreases NO emissions. It is noticed that CO and HC emissions are reduced with using methanol blends, while NO emissions are reduced with using ethanol blends [10]. In some studies, alcohols such as ethanol is used in biodiesel blends to enhance solubility with diesel and reduce emissions, so it is recommended to use ethanol in compression ignition engines with biodiesel and diesel fuel [11]. Also, vegetable oils are added to improve efficiency, emission and lubricity properties. They also have a higher heat of combustion and cetane number so they give us perfect combustion [11]. Low concentration blends of rapeseed oil as a biodiesel fuel (specially B20 and lower blends) gave high performance and brake thermal efficiency of engine, it reduced combustion emissions but it is noticed that this oil has a negative effect on brake specific fuel consumption [12]. When using a common rail direct injection system and different EGR rates with various blends of palm oil biodiesel (B0, B10, B20, B30, and B100), it is found that using B30 and 10% EGR rate at injection timing of 24° CA BTDC reduces PM and NO_X emissions [13]. 20% palm-based biodiesel is studied for various compression ratios. The more the compression ratio increases, the more brake thermal efficiency increases and ignition delay period decreases [14].

3. Injection characteristics of biodiesel blends

At first, we said in the introduction that biodiesel fuel requires small time for injection as it has low compressibility, so it is very important to study the effect of bulk modulus (the inverse of compressibility) on injection timing. It is found that the increase of biodiesel pressure after injection is very fast, because the bulk modulus of biodiesel is high. It is also noticed that it passes through injector nozzles immediately as it has high sound velocity. The viscosity is high, so the leakage of pump is reduced. These previous properties cause fast injection of needle for biodiesel fuel. Injection technology greatly affects NO_X emissions. For example, common rail injection type produces more emissions compared to mechanically controlled fuel injection type [7].

3.1. Injection pressure of biodiesel

The increase of injection pressure for biodiesel can improve atomization and combustion so the brake thermal efficiency is going to increase, but this increase of pressure also increases NO emissions. The increase of the brake thermal efficiency with the increase of injection pressure at different timing is shown in **Fig. 1.** [15]. When using moringa oleifera biodiesel blended with diesel fuel in a common rail direct injection system under various pressure range (300 bar to 600 bar), it is noticed that the highest brake thermal efficiency can be gotten at B20 at maximum injection pressure and advanced injection timing, but it produced high CO emissions. Also, it is noticed that using biodiesel only produces low carbon monoxide, high carbon dioxide emissions and maximum brake thermal efficiency [16]. Soybean biodiesel is tested by numerical method with high injection pressure and ambient pressure using fluent software. It is found that the more the injection pressure increases, the more the initial velocity of injected fuel increases so the spray characteristics are going to be improved. Increasing injection timing will decrease the Sauter mean diameter [16]. When using multi chambered piston in diesel engine in a single cylinder direct injection diesel engine for Jatropha biodiesel, it is found that 200 bar pressure for B20 gives the best result for combustion, brake thermal efficiency and specific fuel consumption. **Fig. 2.** Shows that 200 bar injection pressure was the optimum condition for both brake thermal efficiency and specific fuel consumption [17]. On using Roselle biodiesel blends (RB20, RB40 and RB100) with conventional diesel in a single cylinder diesel engine under different pressures (180, 200, 220, 240 and 260 bars) and different loads (25%, 50%, 75%, 100%), it is found that RB20 blend at 180 bar gives high brake thermal efficiency than other blends at 260 bar due to perfect mixing and complete combustion. At full load, it is noticed that the more the injection pressure increases, the more the brake specific fuel consumption decreases [18].

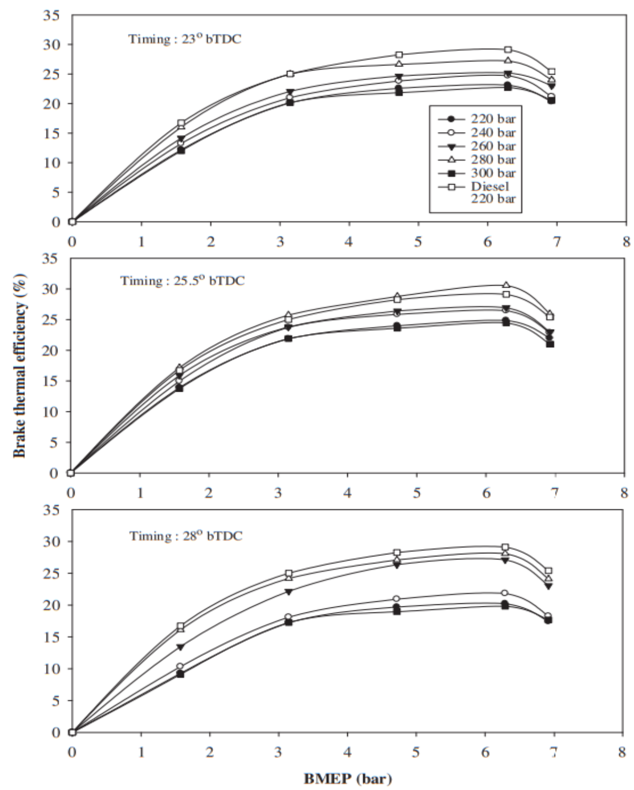

Fig. 1. Brake thermal efficiency versus injection pressure at different timing.

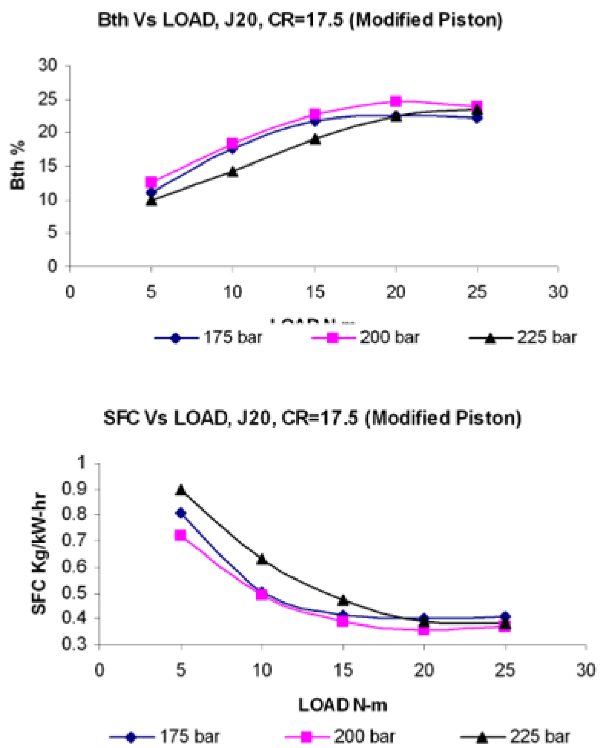

Fig. 2. Effect of different three pressures on SFC and BTE at different loads.

3.2. Injection timing of biodiesel

We said that injection of biodiesel requires less time compared to conventional diesel as it has high bulk modulus [1]. After injecting methanol and biodiesel directly in a compression ignition engine with making some advance in methanol injection and using two-stage split-injection strategy for methanol , HC, CO, and NO_X emissions are reduced [16]. When using diesel and two biodiesel fuels namely karanja and coconut, it is found that NO_X can be reduced by restoring the start of injection of biodiesel to mineral diesel. With adding coconut to the karanja, bulk modulus is going to decrease and then delay the start of injection [19]. B20 Mahua methyl ester in a single cylinder diesel engine with different static injection timings (19°,21°,23°,25°,27° bTDC) at different operating pressures of (225, 250, 275 bar) is tested. It is noticed that when using 275 bar as high pressure improves the performance, it is required to retard static injection timing to 21° bTDC to limit emissions without affecting performance. The delay of injection timing decreased NO_X emissions but increased smoke intensity. This increase of smoke intensity can be overcome by increasing injection pressure. Delay of injection timing by 2.5 CAD causes a reduction of NOx emission without increasing in smoke density or decreasing in brake thermal efficiency [13]. Delay of injection timing lowers marginally ignition delay, peak in-cylinder temperature and maximum heat release rate and thereby reduces NOx emission. (21° bTDC) increases the performance, combustion and emission characteristics because of better mixing and improved combustion [20].

3.3. Injection spray of biodiesel

According to injection of biodiesel inside combustion chamber, one of the most important parameter that should be studied is the development of fuel spray inside the combustion chamber. Injection parameters are determined by experimental method using a glass injection chamber and high speed camera using mechanically controlled M injection system. The results are compared with numerical simulation results. When injection of diesel and biodiesel fuels are compared by this technology, it is found that the spray penetration of biodiesel is longer and narrower than diesel fuel as shown in **Fig. 3,** as biodiesel has high efficiency, sound velocity, and a higher bulk modulus. When using biodiesel, there will be ignition delay as it has a high flash point and low evaporation compared to diesel fuel [21]. Spray properties of biodiesel blending with di-n-butyl ether (DBE15, DBE30) that are shown in **Fig. 4.** were studied by light intensity level such as spray tip penetration, spray cone angle, maximum spray width and spray tip velocity were used to compare under different injection pressures and ambient pressures. The spray tip penetration with DBE decreased while spray cone angle and maximum spray width increased.

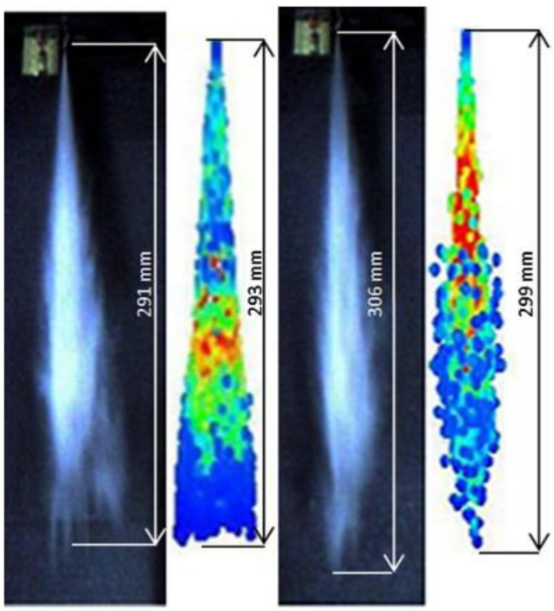

Fig. 3. Experimental and numerical results of spray jet at 500 rpm pump speed for diesel (left) and biodiesel (right).

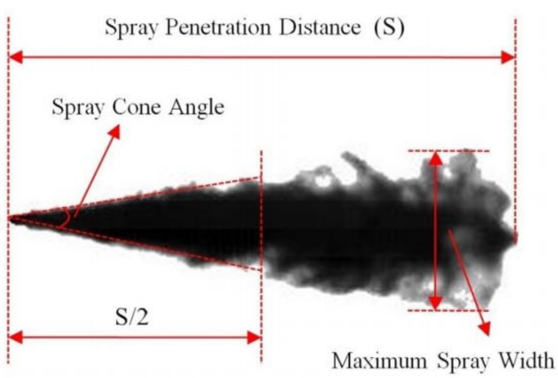

Fig. 4. Parameters of spray characteristics

It is shown that light intensity of biodiesel was the narrowest, but the light intensity level of biodiesel-DBE blends was similar to that of diesel. Biodiesel fuel was proved to have poor gas-fuel mixing property, but it increased with added with DBE [22]. After using multi- ple-injection technology by a single cylinder diesel engine with a displacement volume of 373.33 cm3 and a compression ratio of 17.8. The injected spray before BTDC 25° developed to the piston hole region, and then spread out through the wall of the piston. This angle of injection made the charge propagate to the piston lib. The spray injected after BTDC 25° flowed into the squish and crevice regions. The delay of injection timing of BTDC 30° decreases combustion pressure and rate of heat release as the majority of injected spray was distributed in the squish, crevice regions, and piston bowl area. This retardation also increases soot, HC, and CO emissions due to the incomplete combustion. on comparing injection modes, multiple-injection has higher IMEP than the single-injection and pilot injection strategy with a small quantity for the first injection provided a higher IMEP than the split injection mode as the combustion duration of the second injection was longer than that of the split injection. The long combustion duration produced a high combustion pressure and work amount in the expansion stroke. Multiple-injection system proved that low injection timing produces a decrease of soot, HC, and CO emissions and an increase of NOx emissions. large particles decreased compared to a single-injection combustion. [23].

4. Biodiesel combustion

The most important property should be studied in biodiesel combustion is cetane number that gives us an indication of ignition of the fuel. Generally, biodiesel has high cetane number compared to conventional diesel. This number depends on distribution of fatty acids in the original oil or fat from which it was produced [24]. Cetane number of biodiesel changes with the change of physical properties of fuel and carbon chain length [25]. Biodiesel is known as it has lower heating value compared to diesel fuel as it has lower content of oxygen, that may causes Incomplete combustion [18]. Biodiesel is used by different blends with diesel fuel B30, B50, and B70 in a single cylinder diesel engine at speed of 1400 rpm. The results shown that while increasing biodiesel content, there is a decrease in CO, HC emissions and brake thermal efficiency but increase in brake specific fuel consumption and NO_X emissions. It is found that there is a decrease in cylinder pressure as biodiesel has low calorific value compared to mineral diesel. [24]. When using Low-temperature combustion for biodiesel, it is noticed that the time of ignition delay increases and ignition temperature decreases with increasing of biodiesel content [2]. After injecting biodiesel with different blends in a single-cylinder high-speed direct-injection compression ignition engine, it is found that premixed combustion affects the rate of heat released and this rate decreases with the delay of injection timing. It is noticed that the increase of biodiesel content causes a delay of ignition and heat release rate. It is noticed that when using biodiesel blends with fossil diesel, soot luminosity will reduce and also NO_X emissions due to premixed combustion mode [26]. There are many methods are used to reduce NO_X emissions such as exhaust gas recirculation method that produces high emissions of HC, CO, CO_2, smoke and brake thermal efficiency. Another method is selective catalytic reduction and lean nitrogen traps that require high cost space for exhaust pipes but it does not affect other emissions or brake thermal efficiency. Low temperature combustion is another way to reduce NO_X emissions but it is noticed that it reduces brake thermal efficiency and increases CO and HC emissions. Other methods are modifying fuel composition and adding fuel additives to increase cetane number. The last three methods are very suitable for reducing NO_X emissions without increasing any other emissions [27].

4.1. Combustion performance of biodiesel

With comparing combustion of B5, B10, B20, B50, B80 and B100 to conventional diesel to study the combustion efficiency for different air flowrate. It is noticed that biodiesel has high combustion efficiency level than mineral diesel at low energy level. Combustion efficiency is decreases with the increase of air flow as it is affected by low exhaust gas temperature as shown in **Fig. 5a**. from **Fig. 5b**, it is noticed that diesel efficiency is slightly higher than diesel but biodiesels were efficient. than diesel at lower energy. [28]. While using biodiesel of rubber seed oil in a single cylinder direct injection engine, biodiesel gave better combustion efficiency than petroleum diesel at low to medium engine speeds but brake specific fuel consumption was higher than diesel fuel. At high speeds, it is noticed that combustion efficiency is lower than petroleum diesel [29]. Combustion of soybean biodiesel fueled with diesel is studied using water blends of 10% and 20%. It is found that the calorific value of biodiesel is less than diesel so the brake specific fuel consumption is high. Water emulsification with soybean biodiesel is used to enhance the performance of the engine. 10% gave us best results according to performance and emission [30]. Euro V diesel fuel, biodiesel, and ethanol–biodiesel blends (BE) were tested in a 4-cylinder direct-injection diesel engine, it is noticed that the combustion properties of ethanol–biodiesel blends have enhanced slightly with 5% ethanol in biodiesel (BE5) with a reduction of NOx and particulate emissions [31].

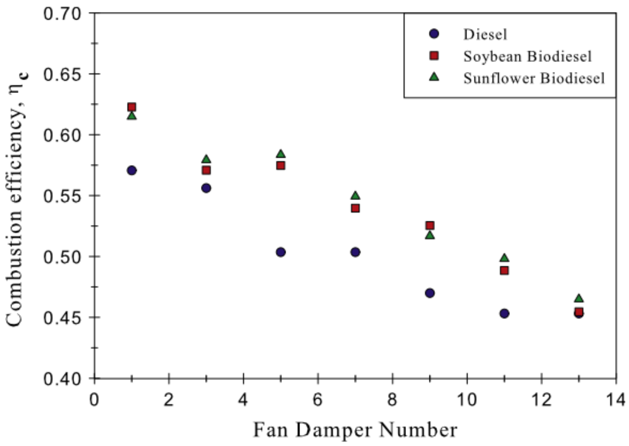

Fig. 5a. Combustion efficiency vs fan damper number at 827 kPa of diesel and biodiesels.

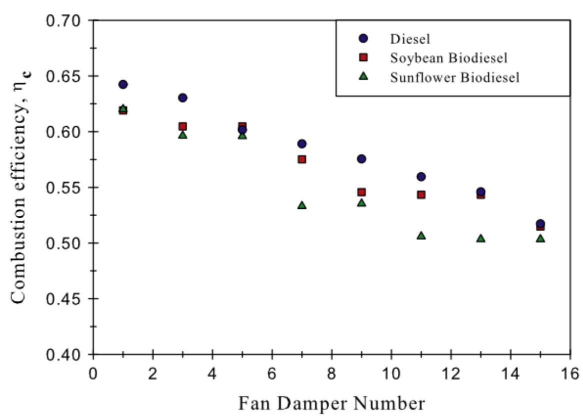

Fig. 5b. Combustion efficiency vs fan damper number at 1375 kPa of diesel and biodiesels.

1.1. Combustion chamber for biodiesel

As we know that biodiesel has a high viscosity and low volatility compared to mineral diesel, biodiesel combustion needs different technology to make turbulence for the charge and give efficient combustion process. Biodiesel made from Jatropha is used in multi-chambered piston single cylinder diesel engine, it is found that this modified piston (that is shown in **Fig. 6**) produces high efficiency combustion and low emission [17]. Injection timing of biodiesel and combustion chamber geometry greatly affect combustion efficiency. For example, when using a blend of 20% Pongamia Oil Methyl Ester (POME) by volume in ultra-low sulfur diesel (B20), in a single cylinder Direct Injection (DI) diesel engine equipped with pistons having Hemispherical and Toroidal Re- entrant Combustion Chamber (TRCC) geometries (**Fig. 7**), it is found that brake specific fuel consumption increases and brake thermal efficiency decreases in standard diesel engine but when using re-entrant combustion chamber, results improved because of better air movement and charge mixing so the performance initially improves and then decreases with delay injection timings. This modification reduced carbon monoxide emission and increased combustion efficiency because of high mixing. It is also noticed that this reduction of emissions increases again with delay of injection timing due to poor initial phase of combustion [20].

Fig. 6. (a) Standard piston (b) multi-chambered piston.

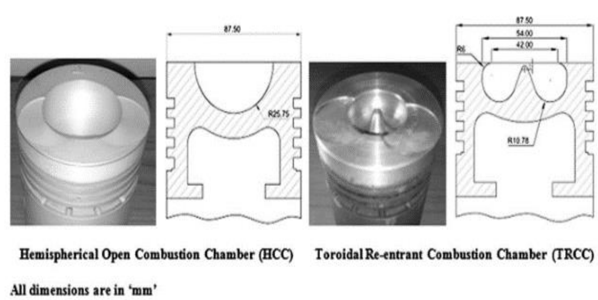

Fig. 7. Different combustion chambers used

2. Conclusion

At the end of studying injection and combustion of biodiesel, we have depicted the following points.

- When comparing combustion of biodiesel with petroleum diesel, biodiesel produces low particulate matters, CO, and HC emissions but the most common problem of biodiesel is NO_X emission. Biodiesel can be used in diesel engine without any modification for the engine until its percentage with petroleum diesel does not exceed 20%. If it exceeds this value, there will be some modification.
- The increase of injection pressure of biodiesel can improve combustion and brake thermal efficiency but also it increases NO_X emissions. Injection timing of biodiesel requires less time compared to diesel as it has high bulk modulus (low compressibility). Injecting a percentage of methanol with biodiesel directly in the combustion chamber can improve emissions.
- B20 for most biodiesel fuels was proved to give optimum results for both injection and combustion characteristics, so it is recommended to used 20% biodiesel and 80% diesel to get the best results.
- The spray penetration of biodiesel is longer and narrower than diesel fuel as biodiesel has high efficiency, sound velocity, and a higher bulk modulus. The spray tip penetration of biodiesel with DBE decreased while spray cone angle and maximum spray width increased.
- There are many methods are used to reduce NO_X emissions such as exhaust gas recirculation method, selective catalytic reduction, low temperature combustion, and modifying fuel composition and adding fuel additives to increase cetane number. The last three methods are very suitable for reducing NO_X emissions without increasing any other emissions.
- Compared to diesel fuel, biodiesel is noticed to have high specific fuel consumption and low brake thermal efficiency.

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