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6BTA 5.9 G2-1 Cummins engine performance and emission tests using methyl ester mahua (*Madhuca indica*) oil/diesel blends

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ABSTRACT

Neat mahua oil poses some problems when subjected to prolonged usage in CI engine. The trans-esterification of mahua oil can reduce these problems. The use of biodiesel fuel as substitute for conventional petroleum fuel in heavy-duty diesel engine is receiving an increasing amount of attention. This interest is based on the properties of bio-diesel including the fact that it is produced from a renewable resource, its biodegradability and potential to exhaust emissions. A Cummins 6BTA 5.9 G2- 1, 158 HP rated power, turbocharged, DI, water cooled diesel engine was run on diesel, methyl ester of mahua oil and its blends at constant speed of 1500 rpm under variable load conditions. The volumetric blending ratios of biodiesel with conventional diesel fuel were set at 0, 20, 40, 60, and 100. Engine performance (brake specific fuel consumption, brake specific energy consumption, thermal efficiency and exhaust gas temperature) and emissions (CO, HC and NOx) were measured to evaluate and compute the behavior of the diesel engine running on biodiesel. The results indicate that with the increase of biodiesel in the blends CO, HC reduces significantly, fuel consumption and NOx emission of biodiesel increases slightly compared with diesel. Brake specific energy consumption decreases and thermal efficiency of engine slightly increases when operating on 20% biodiesel than that operating on diesel.

1. Introduction

Energy demand is increasing due to ever-increasing number of vehicles employing internal combustion engines. Also, world is presently confronted with the twin crisis of fossil fuel deflection and environmental degradation. Fossil fuels are limited resources; hence, search for renewable fuels is becoming more and more prominent for ensuring energy security and environmental protection. There has been renewed interest in the use of vegetable oils for making biodiesel because it is less polluting and renewable. It is biodegradable and nontoxic, and has low emission profiles. Worldwide biodiesel production is mainly from edible oils such as soybean, peanut, coconut, sunflower and canola oils. Since, India is not self-sufficient in edible oil production, some non-edible oil seeds available in the country are required to be tapped for biodiesel production. With abundance of forest and plant based non-edible oils being available in our country such as Pongamia (Karanja), *Jatropha curcas* (Jatropha), *Madhuca indica* (mahua), *Shorea robusta* (sal), *Azadirachta indica* A. Juss (neem) and Hevea brasiliensis (rubber), no much attempt has been made to use esters of these non-edible oils as substitute for diesel except Jatropha and Karanja. Few investigators have already obtained biodiesel from some of these oils [1,3,5,10]. Mahua oil has an estimated annual production potential of 181 thousand tons in India [2,14,15]. In the light of above facts, present study was undertaken at National Institute of Technology, Surathkal (India) to determine the suitability of mahua biodiesel as a substitute for heavy-duty diesel engine.

Ramdas et al. [4] observed significant improvement in engine performance and emission characteristics for the biodiesel-fuelled engine compared to diesel-fuelled engine. Thermal efficiency of the engine improved, brake specific energy consumption reduced and a considerable reduction in the exhaust smoke opacity was observed. Schumacher et al. [9] ran 6 V 92 TA DDC heavy-duty diesel engine fuelled with soy biodiesel and its blends with diesel fuel. They reported that, fueling with bio-diesel/diesel fuel blends reduced PM, THC and CO, and increased NOx emissions. Al-Widyan et al. [11] evaluated waste vegetable

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Nomenclature

CMO	Crude mahua oil
MEMO	Methyl esters of mahua oil
BSFC	Brake specific fuel consumption
BSEC	Brake specific energy consumption
NOx	Nitrogen oxide
CO	Carbon monoxide
HC	Hydrocarbon
EGT	Exhaust gas temperature
B20	Blend with 20 % biodiesel

oil as a feedstock for biodiesel production. This research was focused on the engine performance and emission characteristics of esterified vegetable oil, when used in a diesel engine. Masjuki et al. [12] investigated preheated palm oil methyl ester in a diesel engine. Puhan et al. [16] transesterified mahua oil using methanol in presence of alkali and the biodiesel obtained was studied for fuel properties.

2. Experimental

2.1. Composition of mahua oil

The basic composition of any vegetable oil is triglyceride, which is the ester of three fatty acids and glycerol. The fatty acid composition of mahua oil is summarized in Table 1.

2.2. Biodiesel production

Vegetable oils have to undergo the process of transesterification to be usable in IC engines. Biodiesel is an alternative fuel, which has a correlation with sustainable development, energy conservation, management, efficiency and environmental preservation. In transesterification, mahua oil was chemically reacted with an alcohol in the presence of a catalyst to produce vegetable oil esters. Glycerol is produced as a by-product of the reaction.

The mixture is stirred continuously and then allowed to settle under gravity in a separating funnel. Two distinct layers form after gravity settling for 24 h. The upper layer was ester and lower layer was of glycerol. The lower layer is separated out. The separated ester was mixed with some warm water (around 10% volume of ester) to remove the catalyst present in the ester and is allowed to settle under gravity for another 24 h. The ester was then blended with mineral diesel to be used in CI engine.

2.3. Fuel properties

The fuel properties were determined and are listed as given below in Table 2, for crude mahua oil (CMO), methyl ester of mahua oil (MEMO) and diesel.

Table 1
Composition of mahua oil.

Properties	Values (wt.%)
Oleic	41.0–51.0
Palmitic	16.0–28.2
Stearic	20.0–25.1
Linoleic	8.9–13.7
Arachidic	0.0–3.3

Table 2
Fuel properties of diesel oil, mahua oil and methyl ester of mahua oil.

Properties	Diesel	Raw mahua	MME
Density (kg/m^3)	850	924	916
Specific gravity	0.85	0.924	0.916
Kinematic viscosity at 40 °C (Cst)	3.05	39.45	5.8
Calorific value (kJ/kg)	42,800	37,614	39,400
Flash point (°C)	56	230	129
Fire point (°C)	63	246	141

2.4. Experimental setup

The present study was carried out to investigate the performance and emission characteristics of methyl ester of mahua oil and its blends in a Cummins 6 BTA 5.9 G2-1, 158 HP, and turbocharged engine. The values were compared with baseline data of diesel fuel. The engine was coupled to a POWERICA A.C. Generator is set and loaded by electrical resistance to apply different engine loads. The specification of the engine is demonstrated in Table 3. The voltage, current and power developed by engine were directly displayed on control panel. The layout of experimental test rig and its instrumentation is shown in Fig. 1.

2.5. Experimental procedure

The engine was first started by a battery with diesel as fuel and it was allowed to reach its steady state (for about 10 min). The test fuels used during this program were neat (100%) biodiesel, a neat (100%) diesel fuel, and blends of 20, 40, and 60 percent biodiesel by volume in the diesel fuel. Selected properties for fuels are listed in Table 2.

The engine was sufficiently warmed up and stabilized before taking all readings. The performance of the engine and emissions were studied at variable loads corresponding to the load at maximum power at an average speed of 1500 rpm. After the engine reached the stabilized working condition, the load applied, fuel consumption, brake power and exhaust temperature were measured from which brake specific fuel consumption, brake specific energy consumption and thermal efficiency were computed. The emissions such as CO, HC, and NOx were measured using an automotive emission analyzer QRO-402 exhaust gas analyzer. These performance and emission characteristics for different fuels are compared with the result of baseline diesel. Each test was repeated thrice to obtain a reasonable value.

Table 3
Engine specification.

Make	Cummins (2005)
Model	6 BTA 5.9 G2-1
No. of cylinders	6 In line
Aspiration	Turbocharged After cooled
Bore and stroke	102 mm × 120 mm
Displacement	5.9 lits
Input prime	100 kW
Specific fuel consumption @100% load	158 gms/bhp.h
BHP	158
Speed	1500 rpm
Compression ratio	17.6:1
Governor	Mechanical “A2”
Batter capacity	12 Volts mechanical
Lube oil specification	15W40

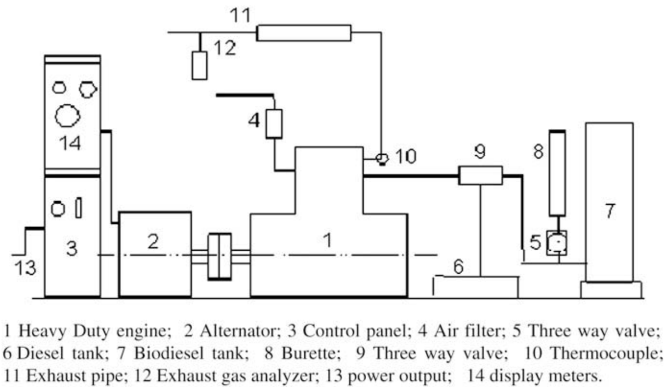

Fig. 1. Layout of experimental setup with instrumentation. (1) Heavy-duty engine; (2) alternator; (3) control panel; (4) air filter; (5) three way valve; (6) diesel tank; (7) biodiesel tank; (8) burette; (9) three-way valve; (10) thermocouple; (11) exhaust pipe; (12) exhaust gas analyzer; (13) power output; and (14) display meters.

3. Results and discussions

3.1. Fuel properties

After pretreatment and transesterification, the colour of crude mahua oil (CMO) changed from yellow to reddish yellow and on an average 80% of recovery of biodiesel was possible. The various fuel properties of CMO and mahua biodiesel were determined. The characteristics of biodiesel are close to mineral diesel, and, therefore, biodiesel become a strong candidate to replace the mineral diesel if need arises. The CMO, however, was found to have much higher values of fuel properties, especially viscosity, thus restricting its direct use as a fuel for diesel engine.

3.2. Engine performance

Biodiesel has low heating value (10% lower than diesel) on weight basis, because of presence of substantial amount of oxygen in the fuel but at the same time, biodiesel has a higher specific gravity (0.916) as compared to diesel (0.85), so overall impact is approximately 5% lower energy content per unit volume. The engine performance with mahua biodiesel was evaluated in terms of brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency and exhaust gas temperature at different loading conditions of the engine.

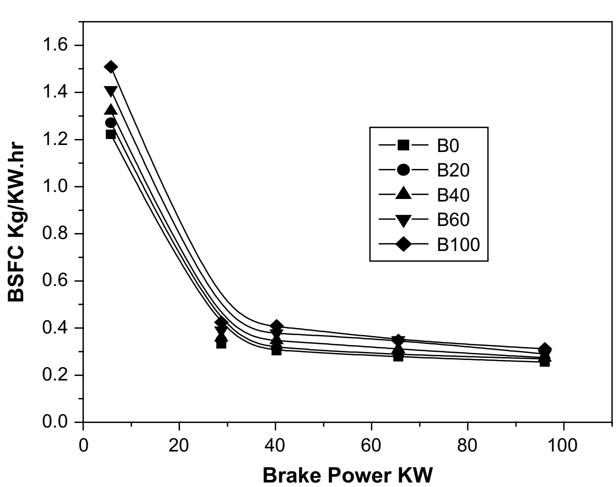

Fig. 2. Comparison of brake specific fuel consumption with brake power for diesel, methyl ester of mahua oil and its blends.

3.2.1. Brake specific fuel consumption

The BSFC of Cummins engine obtained for different fuels is shown in Fig. 2 as a function of load for C.R. of 17.6:1. The BSFC in general, was found to increase with increasing proportion of B100 in the fuel blends with diesel, whereas it decreases sharply with increase in load for all fuels. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads.

As the BSFC was calculated on weight basis obviously higher densities resulted in higher values for BSFC. As density of biodiesel was higher than that of diesel, which means, the same fuel consumption on volume basis resulted in higher BSFC in case of 100% biodiesel. The higher densities of biodiesel blends caused higher mass injection for the same volume at the same injection pressure. The calorific value of biodiesel is less than diesel. Due to these reasons, the BSFC for other blends were higher than that of diesel. Similar trends of BSFC with increasing load in different biodiesel blends were also reported by other researchers [2,5,7,8] while testing biodiesel obtained from Karanja, mahua and Honge oils. Different trends are observed by researchers [1].

3.2.2. Brake specific energy consumption

Brake specific energy consumption (BSEC) is a more reliable criteria compared to BSFC for comparing fuels having different calorific values and densities. The variation in BSEC with load for all fuels is presented in Fig. 3. In all cases, it decreased sharply with increase in percentage load for all fuels. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads.

The BSEC for B20 was observed lower than diesel. In case of B40, B60, and B100, the BSEC was higher than that of diesel. This reverse trend was observed due to lower calorific value with increase in biodiesel percentage in the blends. Different trends of BSEC with increasing load in different biodiesel blends were also reported by some researchers [1,4,13] while testing biodiesel obtained from linseed, mahua, and rice bran oils.

3.2.3. Brake thermal efficiency

The variation of brake thermal efficiency with load for different fuels is presented in Fig. 4. In all cases, it increased with increase in

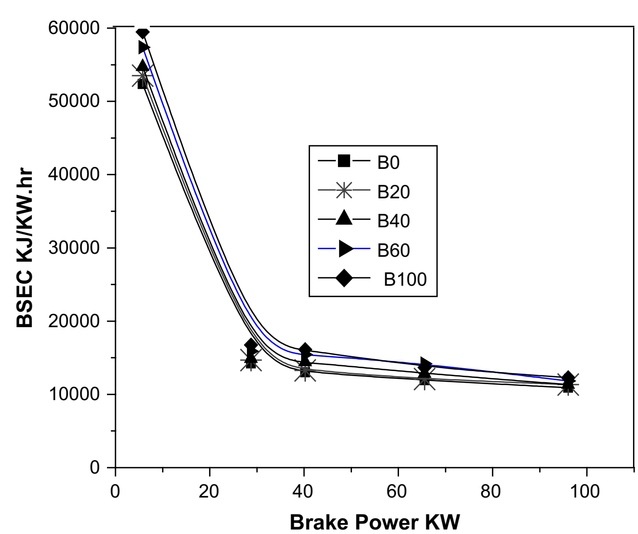

Fig. 3. Comparison of brake specific energy consumption with brake power for diesel, methyl ester of mahua oil and its blends.

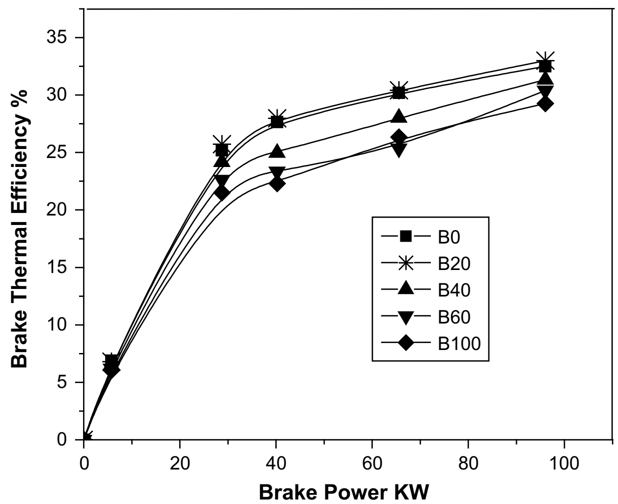

Fig. 4. Comparison of thermal efficiency with brake power for diesel, methyl ester of mahua oil and its blends.

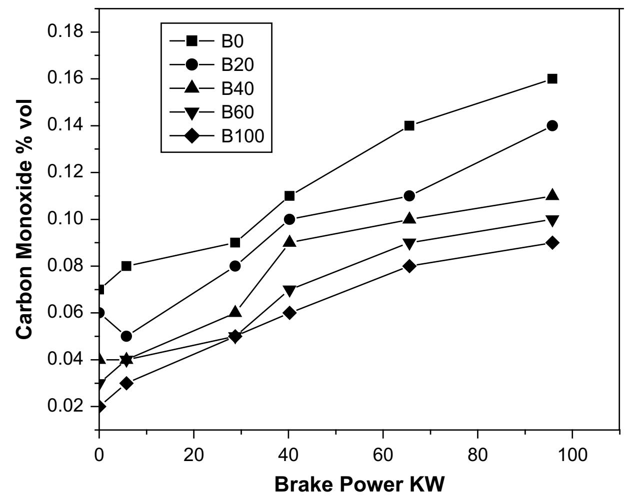

Fig. 6. Comparison of carbon monoxide with brake power for diesel, methyl ester of mahua oil and its blends.

load. This was due to reduction in heat loss and increase in power with increase in load. The maximum thermal efficiency for B20 (32.5%) was higher than that of diesel. The brake thermal efficiency obtained for B40, B60 and B100 were less than that of diesel. This lower brake thermal efficiency obtained could be due to reduction calorific value and increase in fuel consumption as compared to B20. This blend of 20% also gave minimum brake specific energy consumption. Hence, this blend was selected as optimum blend for further investigations and long-term operation. Based on the results it can be concluded that the performance of the engine with biodiesel blends is comparable to that with diesel, in terms of brake thermal efficiency. The maximum value of BTE for B20 is comparable with the maximum values of 32% for B10 and 34% for B20 by other researchers [4] when tests are conducted on MEMO and LOME, respectively.

3.2.4. Exhaust gas temperature

The variations of EGT with respect to engine loading are presented in Fig. 5. In general, the EGT increased with increase in engine loading for all the fuel tested. The mean temperature increased linearly from 180 °C at no load to 425 °C at full load condition with an average increase of 15% with every 25% increase in load. This increase in exhaust gas temperature with load is obvious from the simple fact that more amount of fuel was required in the engine to generate that extra power needed to take up the additional loading. The exhaust gas temperature was found to increase with the increasing concentration of biodiesel in the blends. The mean EGTs of B20, B40, B60 and B100 were 7%, 9% 10% and 12%, respectively, higher than the mean EGT of diesel. This could be due to the increased heat loss of the higher blends, which are also evident from, their lower brake thermal efficiencies as compared to diesel.

Similar findings were obtained by other researchers [1,2,4,5,6] while testing different biodiesel.

3.2.5. Carbon monoxide

Variation of CO emissions with engine loading for different fuel is compared in Fig. 6. The minimum and maximum CO produced

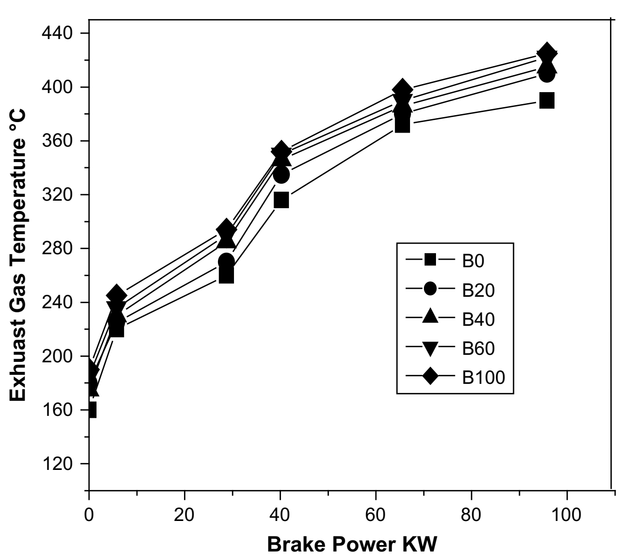

Fig. 5. Comparison of exhaust gas temperature with brake power for diesel, methyl ester of mahua oil and its blends.

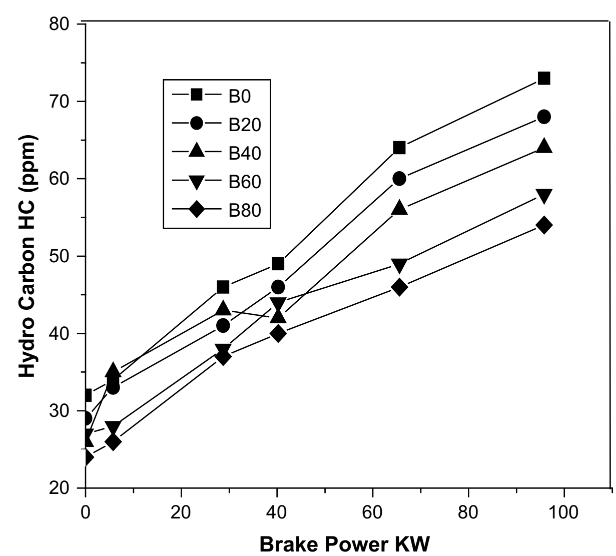

Fig. 7. Comparison of hydrocarbon with brake power for diesel, methyl ester of mahua oil and its blends.

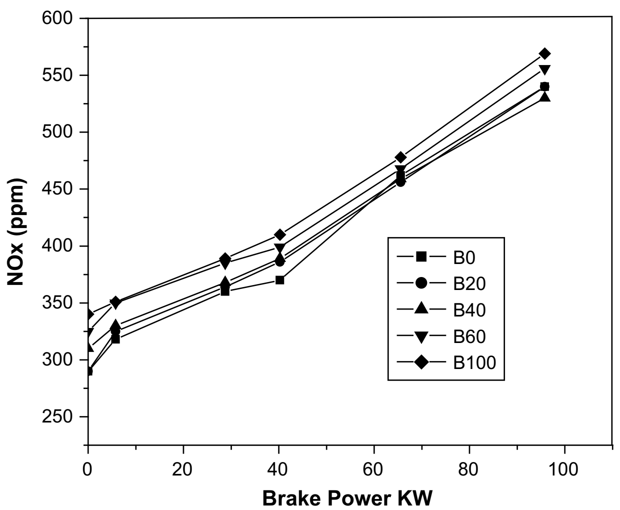

Fig. 8. Comparison of NOx with brake power for diesel, methyl ester of mahua oil and its blends.

was 0.02–0.16 %. These lower CO emissions of biodiesel blends may be due to their more complete oxidation as compared to diesel. Some of the CO produced during combustion of biodiesel might have converted into CO_2 by taking up the extra oxygen molecule present in the biodiesel chain and thus reduced CO formation. It can be observed from Fig. 6 that the CO initially decreased with load and latter increased sharply up to full load. This trend was observed for all the fuel blends tested. Initially, at no load condition, cylinder temperature might be too low, which increase with loading due to more fuel injected inside the cylinder. At elevated temperature, performance of the engine improved with relatively better burning of the fuel resulting in decreased CO.

3.2.6. Hydrocarbon

It is seen in Fig. 7 that there is a significant decrease in the HC emission level with blends of methyl ester of mahua oil as compared to pure diesel operation. There is a reduction from 74 ppm to 50 ppm at the maximum power output of 96 kW. These reductions indicate that more complete is combustion of the fuels and thus, HC level decreases significantly.

3.2.7. Nitrogen oxides

The NOx values as parts per million (ppm) for different fuel blends of diesel and B100 in exhaust emissions of Cummins 6 BTA 5.9 G2-1 are plotted as a function of load in Fig. 8. The amount of NOx produced for B20–B100 varied from 290 to 540 for diesel. From this Fig. 8 it can be seen that the increasing proportion of biodiesel in the blends was found to increase NOx emissions slightly (11.6%) when compared with that of pure diesel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which facilitated NOx formation. In general, the NOx concentration varies linearly with the load of the engine. As the load increases, the overall fuel-air ratio increases resulting in an increase in the average gas temperature in the combustion chamber and hence NOx formation, which is sensitive to temperature increase. The NOx level was found to be directly related to the exhaust gas temperature while it was inversely related to the smoke and CO values.

4. Conclusions

Based on the results of this study, the following specific conclusions were drawn:

- The fuel properties of mahua biodiesel were within limits except calorific value; all other fuel properties of mahua biodiesel were found to be higher as compared to diesel.
- The brake specific fuel consumption increased and brake thermal efficiency decreased with increase in the proportion of biodiesel in the blends. A reverse trend was observed with increase in engine load.
- The amount of CO and HC in exhaust emission reduced, whereas NOx increased with increase in percentage of mahua biodiesel in the blends. However, the level of emissions increased with increase in engine load for all fuels tested.
- The performance and emission parameters for different blends were better compared with diesel.
- The emission levels of CO and HC in heavy-duty engines are less compared with small engines.

From these findings, it is concluded that mahua biodiesel could be safely blended with diesel up to 20% without significantly affecting the engine performance (BSFC, BSEC, EGT) and emissions (CO, HC and NOx) and thus could be suitable alternative fuel for heavy-duty engines.

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