

High FFA Rubber Seed Oil as an Alternative Fuel for Diesel Engine – An Overview

¹S.Senthil Kumar, ²K.Purushothaman

¹Research Scholar, Anna University, Chennai, India

²Professor and Head, Department of Mechanical Engineering,
St. Peter's College of Engineering and Technology Chennai, India

Abstract: The large increase in number of automobiles in recent years has resulted in great demand for petroleum products. With crude oil reserves estimated to last only for few decades. Many countries import more crude oil causes huge foreign exchange out-go on the one hand and increasing exhaust emission on the other. Therefore there has been an active search for alternate fuels like biodiesel to provide a suitable diesel substitute for internal combustion engines. The Rubber seed oil based bio-diesel offer a very promising alternative to diesel. The acid value for Rubber Seed oil is high. Two step esterification i.e acid catalyzed esterification followed by alkaline catalyzed transesterification is developed to produce biodiesel from high FFA Rubber Seed Oil. The engine fueled with diesel and blends of Rubber seed oil based bio-diesel. The objective of the present study is investigating the use of blends of Rubber seed oil based bio-diesel on performance and emission characteristics of a diesel engine compared to that of diesel. Engine performance with biodiesel does not differ greatly from that of diesel fuel. The experimental results proved that the use of Rubber seed oil based biodiesel is viable alternative to diesel.

Index Terms - Rubber seed oil, FFA, Blend, Engine performance, Exhaust Emissions

I. Introduction

The large increase in industrialization and motorization in recent years has resulted in great demand for petroleum products. Petroleum based fuels are obtained from limited reserves. The price of conventional fossil fuel is too high and has added burden on the economy of the importing nations. With crude oil reserves estimated to last only for few decades, there has been an active search for alternate fuels. The combustion of fossil fuels increases As energy demands increase and fossil fuels are limited, research is directed towards alternative fossil fuels are limited, research is directed towards alternative.

The depletion of crude oil would cause a major impact on the transportation sector. directed towards alternative renewable fuels. The main advantages of using this alternative fuel are its renewability, biodegradability and better quality of exhaust gases. It is technically competitive and environmentally friendly alternative to conventional petro diesel fuel for use in CI engines. The use of biodiesel reduces the dependence on imported fossil fuels which continue to decrease in availability and affordability. Using Biodiesel can help to reduce the world's dependence on fossil fuels and which also has significant environmental benefits. The ozone (smog) forming potential of biodiesel hydrocarbons is less than diesel fuel. Sulfur emissions are essentially eliminated with pure biodiesel. The exhaust emissions of sulfur oxides and sulfates (major components of acid rain) from biodiesel are essentially eliminated compared to diesel.

Biodiesel reduces the health risks associated with petroleum diesel. Biodiesel emissions show decreased levels of polycyclic aromatic hydrocarbons (PAH) and nitrated polycyclic aromatic hydrocarbons (nPAH), which have been identified as potential cancer causing compounds. Biodiesel is the first and only alternative fuel to have a complete evaluation of emission results and potential health effects submitted to the U.S. Environmental Protection Agency (EPA) under the Clean Air Act Section 211(b). For these reasons, several campaigns have been planned in many countries to introduce and promote the use of biodiesel

Vegetable oils for biodiesel production vary considerably with location according to climate and feedstock availability. Generally the most abundant vegetable oil in a particular region is the most common feedstock. Biodiesel can be produced from food grade vegetable oils or edible oils like nonfood grade vegetable oils or non edible oil, animal fats and waste or used vegetable oils. Most of the biodiesel were prepared from edible oil like soybean (de Oliveira, 2005), rapeseed (Jeong and Park, 1996), sunflower (Vicente, et al., 2004), safflower (Meka, et al., 2007), canola (Singh, et al., 2006), palm (Darnoko and Cheryman, 2000; Cheng, et al., 2004) and fish oil (El Mashad, et al., 2006). The price of edible oils is very high as compared to diesel and we use edible oils for biodiesel production leads food oil crisis. In India, bio fuels research cannot be based on edible vegetable oils, since India is a net-importer of edible vegetable oils. This increases the overall production cost of the biodiesel production. The above problem can be solved by using cheapest, low cost non edible oils such as *Jatropha*, *Pongamia*, *Madhuca*, *Castor*, *Karanja*, *Linseed*, *Cotton seed*, *Rice bran*, *Azadirachta* and *Rubber Seed* as feed stocks for biodiesel production. However one of the main problems of vegetable oil use in diesel engine is their higher kinematic viscosity due to which problems occur in pumping and atomization, ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc. The direct use of vegetable oils as fuel can cause numerous engine problems like poor fuel atomization, incomplete combustion and carbon deposition on fuel injector and engine fouling (Sridharan and Mathai, 1974; Encinar et al., 2002; Williamson, A. M.; Badr, O., 1998; Karaosmanoglu, F.; et al., 2000). This is due to the presence of higher viscosity (about 11-17 times higher than petroleum diesel) of vegetable oils. Hence, straight vegetable oils have to be modified to bring their combustion related properties closer to diesel. Hence the viscosity of vegetable oils can be reduced by several methods which include blending of oils micro emulsification, pyrolysis and transesterification (Ma and Hanna, 1999).

II. Rubber Seed Feed Stock For Bio Diesel Production:

Natural rubber producer in the world are Thailand (35%), Indonesia (23%), Malaysia (12%), India (9%), and China (7%). Normal seed production yields vary from 70 to 500 kg/ha/year [1] while the annual rubber seed production potential in India is about 150 kg per hectare [2].

Ramadhas et al. demonstrated that methyl esters of rubber seed oil could be successfully used in existing diesel engines without any modifications. Lower concentrations of biodiesel blends improved thermal efficiency. At higher concentrations of biodiesel in the blend, there was a reduction of smoke density in exhaust gas [2].

Rubber seed oil is oil extracted from the seeds of rubber trees. Rubber seed as a waste product from rubber plantations, Rubber (*hevea brasiliensis*) tree starts to bear fruits at four years of age. Each fruit contain three or four seeds, which fall to the ground when the fruit ripens and splits. Each tree yields about 800 seeds (1.3 kg) twice a year.[3]



A rubber plantation is estimated to be able produce about 800- 200 kg rubber seed per ha per year (Siriwardene and Nugara, 1972), and these are normally regarded as waste. According to a study conducted by the rubber board, on an average, a healthy tree can give about 500 g of useful seeds during a normal year and this works out to an estimated availability of 150 kg of seeds per hectare. The price of rubber seeds is around one Indian rupee per kg. Rubber seeds are produced mostly in Kerala (southern most state of India), the processing of rubber seeds is concentrated in Tamilnadu (another southern state). The production and utilization of these oils are low at present because of their limited end usage. At present rubber seed oil does not find any major application and hence even the natural production of seeds itself remains underutilized.

The rubber seeds were cracked and the kernels (52.5% of seed weight) were dried in the oven at 100°C for 20 hours. The crude rubber seed oil was extracted from kernels by hydraulic press machine and was about 10% of seed weight. The extracted crude rubber seed oil usually contains sediment of kernel and moisture. The crude rubber seed oil should be cleared from adulterants before the acid esterification process in order to avoid the imperfection of the process.

2.1 Properties of Rubber seed oil

Fuel Property	Diesel	Rubber Seed Oil
Kinematic viscosity in CS	7.956	6.0
Flash point in 0C	65	72
Density in g / cc	0.892	0.86
LCV in KJ / kg	34589	44000
Pour point 0 C	20	12
Cetane number	56	45

2.2 Fatty Acids in Rubber seed oil

Fatty acid	Nomenclature	Percent
<u>Palmitic</u>	C16:0	10.2 %
<u>Stearic</u>	C18:0	8.7 %
<u>Oleic</u>	C18:1	24.6 %
<u>Linoleic</u>	C18:2	39.6 %
<u>Linolenic</u>	C18:3	16.3 %

2.3. Economics of Biodiesel:

The major economic factor to consider for input costs of biodiesel production is the feedstock (price of seed, seed collection and oil extraction, transport of seed and oil), which is about 75–80% of the total operating cost. Other important cost related factors are labour, methanol and catalyst for biodiesel conversion for straight vegetable oil, which must be added to the feedstock. Cost recovery will be through sale of oil cake and of glycerol (Mulugetta,2009). The volatile oil prices due to increased demand have necessitated for continuous research and development into the biodiesel sector so as to increase the production of biodiesel of suitable quality and at reasonable price so that it can compete with diesel fuel.

Economical feasibility of biodiesel depends on the price of the crude petroleum and the cost of transporting diesel to long distances to remote markets in India. Further, the strict regulations on the aromatics and sulphur contents in diesel fuels will result in higher cost of production of conventional diesel fuels. The reason for high biodiesel prices are the limited availability of biodiesel feed stocks. The biodiesel program in any country has a time lag between policy planning and actual implementation this is especially applicable to India where biodiesel is proposed to be made from non oils. Presently, the availability of these oils is very limited and the price of such oils is higher than petro-diesel.

For successful launch of biodiesel availability of oil on large scale has to been at reasonable price and abundance availability of biodiesel feed stocks. The Ministry of Petroleum and Natural Gas announced the biodiesel purchase policy in October 2005. The Policy provided for the purchase of biodiesel at 20 specified purchase center in 12 different states in India /litre (inclusive of taxes/duties) from January 2006. This price was subject to review every six months. The last price revision of biodiesel was done in December 2006, when it was fixed at Rs 26.5 (Altenburg et al., 2008).

The Indian government also announced, on 23rd Dec attractive incentives to encourage bio fuels plantation in wastelands and to utilize indigenous bio-mass feed stocks for production of bio addresses the issues across the entire value chain from plantations, and processing to marketing of bio fuels. India's new policy on biofuels blending at least 20 percent bio fuels in diesel and petrol by 2017. This implies that 13.38 million tons of biodiesel will be required. Rubber seed oil based biodiesel is viable alternative to diesel [4].

III. Production of Biodiesel

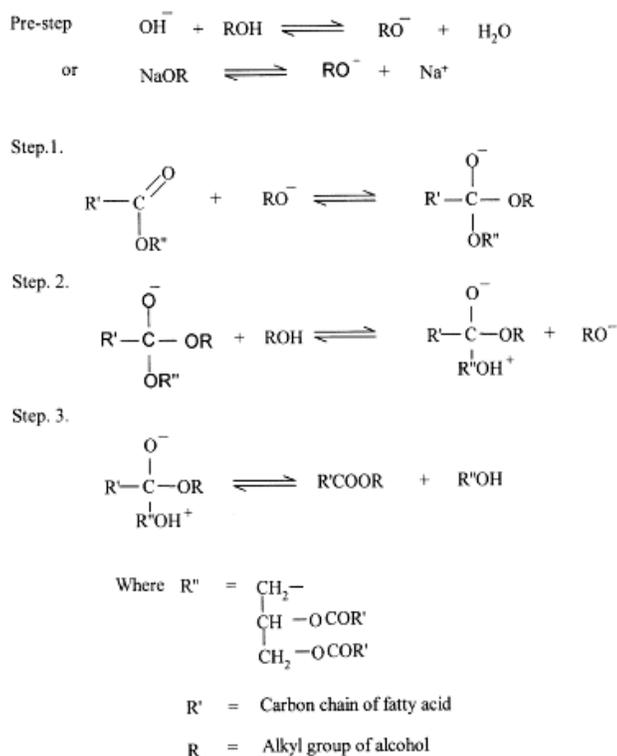
Rubber seed containing high amount of free fatty acids (FFA). Biodiesel is commercially produced from the refined edible vegetable oils by alkaline-catalyzed esterification process. This process is not appropriate for production of biodiesel from Rubber Seed oil because of their high acid value. Hence two step esterification method is developed to produce biodiesel from high FFA Rubber Seed Oil.[5],[12]. Production of biodiesel from high FFA Rubber Seed Oil consists of acid-catalyzed pretreatment followed by an alkaline catalyzed transesterification [6]-[7]. The first step of the process is to reduce FFA content in vegetable oil by esterification with methanol and acid catalyst. The second step is transesterification process, in which triglyceride (TG) portion of the oil reacts with methanol and base catalyst to form ester and glycerol. The acid catalyst is generally sulfuric acid [8], [9], while the base catalyst is usually sodium or potassium hydroxide. Product from the reaction is separated into two phases by gravity [10], [11].

3.1 Acid Catalyzed method

In this method high FFA content of non-edible oils are reduced below 3% by using acid pretreatment. It comprises the preheating of oil samples in water bath at 60 °C for 30 min. The acid catalyst mixture (10 ml H₂SO₄ mixed with 200 ml methanol/ liter oil samples) was added to preheated oil samples and it kept in water bath for 3-4 hrs at 60 °C. After the reaction, the sample shows two distinct layer such as upper ester layer and lower glycerol layer. The lower glycerol layer was decanted and the upper layer was measured and stored for further study (for alkali catalyzed method).

3.2 Alkali/Base catalyzed method

For this study the pretreated (acid treated) oil samples were heated, addition of alkali catalyst mixture (7.5 gram KOH with 200 ml Methanol/liter oil samples).



The mixture was shaken and incubated to water bath at 60 °C for 1-2 hrs. Finally the samples show two distinct layers as that of acid catalyzed method. The top layer was measured and it was saved for purification process.

3.3 Purification of product

After transesterification the ester layer may contain unreacted catalyst, methanol and residual glycerol. These impurities were removed by hot water treatment. The water washing method was continued (4-6 times) until the water layer becomes clear. For this process equal amount of hot distilled water was used to remove the impurities.

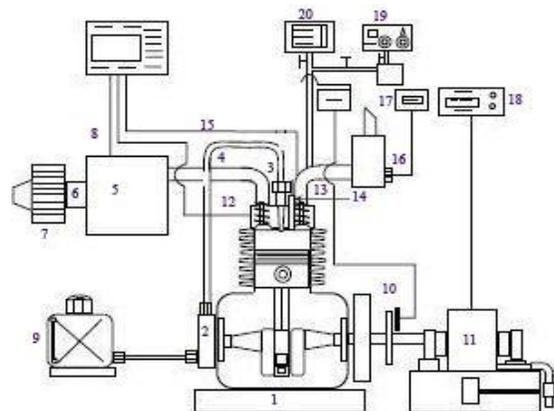
3.4 Drying of product

After the completion of purification process the ester layer may contain some amount of water and methanol. This should be removed before the commercialization of fuel. Because methanol reduces the flash point of fuel and it have corrosive nature to fuel hoses. Water content is responsible for the growth of biological organisms and it also increases the acid value of fuel. Hence the ester layer was heated in hot plate with stirrer at 100°C for 15 to 30 min to remove the water and methanol content present in the product (biodiesel). Finally the dried biodiesel fuel was saved.

IV. Experimental setup

Schematic diagram of experimental set-up

1. Engine
2. Fuel injection pump
3. Fuel injection nozzle
4. Intake manifold
5. Intake air surge tank
6. Air flow meter
7. Air cleaner
8. Intake air temp sensor
9. Fuel tank
10. Crank angle detector
11. Electric dynamometer
12. Coolant temp sensor
13. Exhaust manifold



14. Compression pressure
15. Exhaust gas transducer temp sensor
16. Air-fuel ratio sensor
17. A/F meter
18. Dynamometer control panel
19. Gas analyzer
20. Smoke meter

4.1 Test engine

Test engine used in the experiments is a single cylinder four-stroke, naturally aspirated, constant speed compression ignition engine. Engine was tested at a rated speed of 1500rpm. The exhaust gas was sent to the smoke meter and gas analyzer to measure smoke intensity, CO, CO₂, etc. The readings taken during each set of experiments was used for the calculation of brake specific consumption, thermal efficiency, and other engine characteristics.

4.2. Experimental procedure

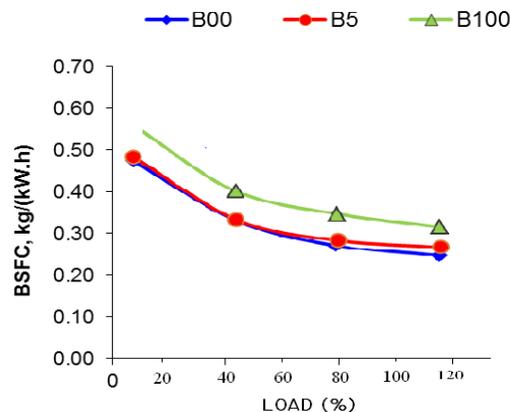
Before starting the engine experiments, the fuel tank, engine oil level, coolant and other proper conditions of the test engine were checked. And the test engine was started by lower engine speed until achieving the stable idling condition. Then the engine speed was increased gradually up to 1500 rpm. At the same time, the dynamometer, all analyzers and meters for measurements were switched on and the proper preparations and settings for measurements were carried out as the recommended methods by the makers' instruction manuals. When the test engine got stable condition and preparations and settings for the measurements were finished the experiments were started. The type of experiment is a study state engine test. The applications of loads were five levels and they were 20%, 40%, 60%, 80% and 100% loads respectively. The engine speeds at all load levels were adjusted for constant engine speed and fixed at 1500 rpm. In each load levels, the measurements of intake air, fuel consumption, intake air temperature, exhaust gas temperature, engine coolant temperature, air fuel ratio, fuel injection timing, combustion pressure, crank angle, hydrocarbon (HC) emission, carbon monoxide (CO) emission and smoke emission were carried out and recorded the data.

The same conditions, methods and procedures were used for both the experiments of biodiesel and diesel fuels. Bxx represents the percentage of ester (xx %) used in the mixture, i.e. 10% ester in the blend is represented by B10. Three types of fuel were used to run the diesel engine to obtain data for comparing engine performance, including exhaust gas emissions, and to conduct endurance tests. The fuels used were: neat biodiesel fuel (B100), diesel fuel (B00) and a blend of 5 percent biodiesel by volume with diesel fuel (B5). Differences in Cetane number (CN), viscosity, low heating value (LHV) and density influences the performance, exhaust gas emissions and wear of diesel engines. The viscosity of B100 was significantly higher than B00. Higher viscosities affect the atomization and combustion process and raise the potential for the formation of engine deposits and higher exhaust gas emissions levels [13].

V. Results And Discussions

5.1. Brake Specific Fuel Consumption with load

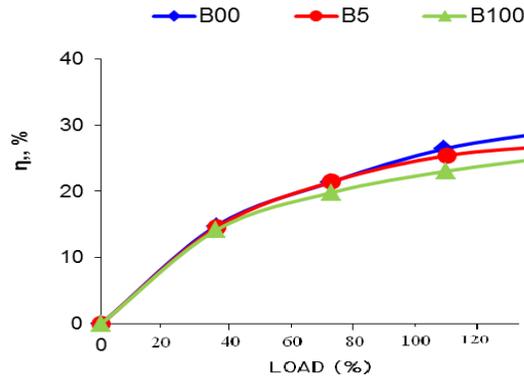
Brake specific fuel consumption is the rate of fuel consumption divided by the rate of power production. Brake specific fuel consumptions descend from lower to higher load level. It is related with brake thermal efficiency. The Brake specific fuel consumption of B00 was lower compared with both B5 and B100 biodiesel. The higher Brake specific fuel consumption value of the biodiesel fuels can be attributed to lower heating value and higher viscosity. The fact that diesel has 11%



higher caloric value, lower viscosity and better volatility than biodiesel ensures better fuel atomization and results in better combustion of the fuel as it is injected into the combustion chamber. Thus, less B00 fuel is needed to provide an equivalent amount of energy.

5.2. Brake Thermal Efficiency and load

Brake thermal efficiency is the ratio of brake power output to power input. Differences in thermal

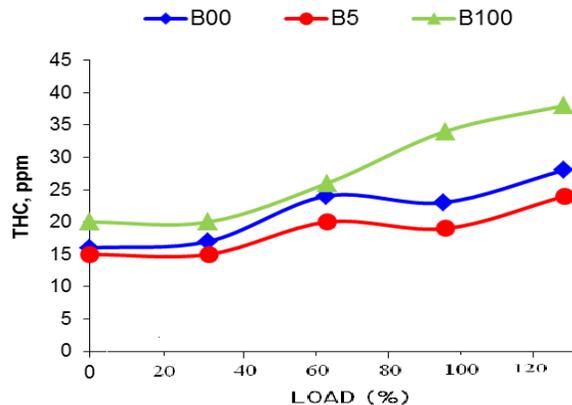


efficiency were small at low load values, but became more obvious at higher load. The percentage differences of thermal efficiency for B100 and B5 compared with diesel fuel were respectively: -9.66 and -3.68%. A significant drop in efficiency was found with pure biodiesel when compared with diesel. This may be attributed to the poorer combustion characteristics of methyl esters due to higher viscosity. The largest reduction was for B5% and -3.68%.

5.3 Engine Exhaust Gas Emissions

5.3.1 Total hydrocarbon

Total hydrocarbon was measured by emission test for various blends of biodiesel and diesel at the rated engine speed of 1500 rpm under various load conditions. From figure it is evident that THC emissions increased for all fuels as the load increased. This trend is due to the presence of fuel-rich mixtures at higher loads.

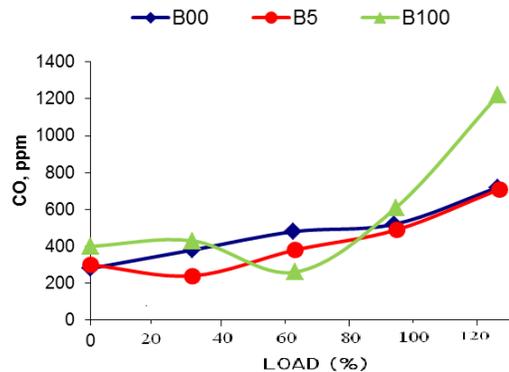


The percentage differences of THC emission for B100 and B5 compared with diesel fuel were respectively: 27.78% and -13.89%. B100 produced the highest THC emission. Higher viscosity of the biodiesel results in less complete combustion, so increasing THC emission. Correction may require changes in injection pressure and/or injection timing. B5 fuel produced lower THC emission than diesel fuel. This is probably due to the effect of the internal oxygen content of biodiesel fuel in the B5 blend tending to improve combustion. Increase of THC was due to insufficient combustion, caused by deposits and injector clogging.

5.3.2 Carbon Monoxide

Generally CO is generated when there is not enough oxygen to convert all carbon to CO₂, some fuel does not get burned and some carbon ends up as CO [14]. Figure shows the percentage differences of CO emission for B100 and B5 compared with diesel fuel were respectively: 20.83% and -12.50% .

It is noteworthy that, B5 produced less CO emission than B00 under all load conditions. Since Rubber Seed Biodiesel is an oxygenated fuel, it results in better combustion of blended biodiesel fuel and a resultant decrease in CO emissions, providing that the proportion of biodiesel is not sufficient to significantly increase the



blend viscosity above that of B00. However, in case of B100, CO emission produced were higher than for diesel at the highest load level or at load levels approaching full load. The higher viscosity of B100 results in poorer combustion and higher CO emission especially at higher load levels.

VI. Conclusions

In this study, the production of methyl ester from crude rubber seed oil has been successfully performed. The acid esterification-alkaline transesterification reaction was adopted. The first step of the process is to reduce FFA content in vegetable oil by esterification with methanol and acid catalyst. The second step is transesterification process, in which triglyceride (TG) portion of the oil reacts with methanol and base catalyst to form ester and glycerol.

Various blends of biodiesel, diesel fuel are tested in diesel engine and its performance emission characteristics are analyzed.

The main conclusions from this research can be summarized as follows.

- BSFC for B5 fuel was comparable to that of diesel fuel. The BSFC was significantly higher (23%) than for diesel fuel. Brake thermal efficiency of B5 blend was better than B100 but still less than diesel, due to the lower calorific value of Rubber Seed Biodiesel than diesel.
 - The B5 blend produced lower exhaust emissions including CO, THC and smoke opacity. Emissions for B100 were significantly higher than diesel (20.83% CO, 27. opacity after endurance test) because of poorer atomization due to high viscosity and poorer combustion due to the low heating value of RSB. According to results of CO and smoke emissions, it appears that the most favorable working condition of B100 fuel is at 200 kPa and 1500 rpm due to reduction of those emissions.
 - Rubber Seed Biodiesel reduced wear of fuel-contact engine components due to its better lubricity.
 - Pure Rubber Seed Biodiesel and B5 reduce deposits on the cylinder head but Rubber Seed Biodiesel increases deposits on the piston due to the high concentration of unsaturated fatty acids in the carbon chain.
 - B5 does not significantly affect the lubricating oil viscosity.
- Overall the results indicate that Rubber Seed biodiesel can be used as a partial substitute for diesel fuel.

- A 5 % blend of Rubber Seed Biodiesel with diesel fuel can be used to fuel diesel engines providing comparable performance, reduced emissions, wear reduction of engine components and neutral effect on lubricating oil.
 - No significant engine modifications are required.

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