A Comparative Evaluation of a Compressed Ignition Engine Fuelled with Nano Methyl Esters of Punnai and Waste Cooking Oil

Subramaniam D[1], Aslam Sheriff F[2], Dinesh Kumar P[3] & Rineeth G.K[4]
[1]Professor, Department of Aerospace Engineering,
Mahendra Engineering College, Namakkal, India.
[2,3 & 4] Department of Aerospace Engineering,
Mahendra Engineering College, Namakkal, India.
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Abstract - *In this experimental work focused on, the performance, emission, and combustion characteristics of Nano methyl esters of Punnai oil and Waste Cooking oil, and their diesel blends in a Compressed Ignition were experimentally tested. In the study, Nano Punnai oil methyl esters (NPOME), and Nano Waste Cooking Oil Methyl Esters (NWCOME) were prepared by the transesterification process. The Bio diesel-diesel blends were prepared by mixing 10%, 30%, 50%, and 70% of biodiesel with diesel. The effects of two nano methyl esters and their diesel blends on engine performance, combustion, and exhaust emissions are tested at different engine loads. Experimental results concluded that up to 30% of no methyl esters did not affect the performance, combustion, and emissions characteristics. On the other hand, above B30 (30% Biodiesel with 70% diesel) a reduction in performance, combustion, and emission characteristics is clear from the study.*
Keywords: *Nanoparticle Al2O3, Combustion, Emission, Methyl ester, Performance, Tranesterification.*

I INTRODUCTION

The increasing the world population is predicted to reach over 9 billion by 2050. Increasing global prices and higher energy demand have put tremendous pressure on natural energy reserves, causing their depletion. The burning of fossil fuels has several environmental implications, including an increase in Greenhouse Gas (GHG) emissions, particularly Carbon Dioxide (CO2). Over the last few decades, global primary energy consumption has increased dramatically due to rapid industrialization and higher living standards [1-5]. Fossil fuels which are polluting the environment, are economically competitive and depleted fast. The population explosion has also triggered the energy crisis. Renewable energy sources like solar, wind, nuclear, hydropower, biofuel, and biodiesel are emerging as viable alternatives and research in using them is going on in a developing stage. In the 19th century, Rudolf Christian Karl Diesel (1858-1913) ran the engine using vegetable oils as a substitute for diesel fuel [6]. The usage of biodiesel in diesel engines gives some disadvantages such as a slight decrease in fuel economy on an energy basis (about 10%), slightly greater density, fewer cloud and pour points, and higher NO_X emission. These disadvantages are avoided by using techniques such as fuel additives, modified fuel, and hybrid fuel and that results in a reduction in emissions and an improvement in engine performance [7]. The addition of nano additives with biodiesel results in better fuel properties improves combustion efficiency and reduces harmful emissions [8,9]. And also the addition of additives to diesel fuel causes a decrease in particulate emissions, a decrease in the oxidation temperature, and an increase in NO_X emission [10,11,12]. Copper Oxide (CuO) nanoparticles are insoluble in water, dissolve slowly in alcohol or ammonia solution, and are soluble in dilute acids and potassium cyanide solution. Under high temperatures, copper oxide meets with hydrogen or carbon monoxide and can restore copper metal. Nano-copper oxide is a widely used material. Our research article used Al_2O_3 as an additive to the biodiesel fuel for improving the performance, emission, and combustion characteristics.

II MATERIALS AND METHODS

Biodiesel Production Method

First, A small batch-type unit is fabricated keeping in mind the objective of the present work for producing biodiesel from all types of non-edible oils. It is very compact and can produce 5 liters of biodiesel from non-edible oils in a period of 1½ hours. The production of biodiesel is approximately 70 to 80 liters per day. It has the following advantages less cost, Easy to operate, Electronic control temperature unit, and Digital speed monitoring system. It is possible to maintain a constant speed and variable speeds, depending on the requirements.

The container and blades are made up of stainless steel. It is able to produce biodiesel with about 80 to 96% yield based on the nature of the oils and reactants.

The outcome of combustion, performance, and emission characteristics of a diesel engine using when alumina oxide nano additive blended with Punnai oil methyl ester and waste cooking oil methyl ester as a fuel has been studied. Biodiesels are produced from punnai oil and waste cooking oil by transesterification process. The fuel properties of pure Diesel, NPOME (80% Diesel + 20% POME +50ppm Al_2O_3 nanoparticles), and NWCOME (80% Diesel + 20% WCOME +50ppm Al_2O_3 nanoparticles) have been studied and compared to ASTM standard test methods for biodiesel.

Table 1: Specifications of Al2O3 nanoparticles

1	Chemical name	Aluminum oxide
2	Nanoparticle size	<50 nm
3	Color	white
4	Purity	>99.9%
5	Surface area	58 m^2/g

Production of Methyl Esters of Bio Diesel from Raw Punnai Oil, and Waste Cooking Oil

Methanolysis of triglycerides is represented in Equation (1).

$$\begin{array}{llcll} CH_2\text{-COO-R} & CH_3OH & & \text{R-COO-}CH_3 & CH_2\text{-OH} \\ | & | & & | & | \\ CH\ \text{-COO-R} & +CH_3OH & \xleftrightarrow{\text{Catalyst}} & \text{R-COO-}CH_3 & +CH\text{- OH} \\ | & | & & | & | \\ CH_2\text{-COO-R} & CH_3OH & & \text{R-COO-}CH_3 & CH_2\text{-OH} \end{array} \quad (1)$$

Triglyceride + 3 Methanol 3 Bio diesel + Glycerol

Trans-Esterification Process

The author reported that Biodiesel can be extracted from straight vegetable oil, animal oil/fats, tallow, and waste cooking oils [13]. There are three basic routes available for producing biodiesel from oils and fats:

- Base catalyzed transesterification of the oil.
- Direct acid-catalyzed trans-esterification of the oil.
- Conversion of the oil into fatty acids and then converted as biodiesel.

Trans-esterification is the process, in which the triglycerides (fat/oil) react with an alcohol to form esters and glycerol. A triglyceride has a glycerin molecule as its base containing three long chains with fatty acids attached. The characteristics of the fat are evaluated by the nature of the fatty acids attached to the glycerin. The property of the fatty acids can affect the characteristics of the biodiesel. During the esterification process, the triglyceride reacts with alcohol in the presence of a strong alkaline-like sodium hydroxide catalyst. The reaction carried out between alcohol and fatty acids, forms the mono-alkyl ester, or biodiesel, and crude glycerol. In most, biodiesel production alcohol like methanol or ethanol is used (methanol produced methyl esters, and ethanol produced ethyl esters) and is base catalyzed by either potassium or sodium hydroxide. Potassium hydroxide has been found to be more suitable for ethyl ester biodiesel production; either base can be used for the methyl ester.

Table 2: Engine Specification

Make	Kirloskar AV 1
Type	Four-stroke, single-cylinder, vertical, water-cooled
Bore	80 mm
Stroke	110 mm
Speed	1500 rpm
Power	3.7 kW (5 h.p)

Figure 1: Photograph View of Test Rig Setup

Table 3: Specifications of Al2O3 Nanoparticles

Blend (%)	Nano Methyl esters			
	Kinematic Viscosity @ 40 °C (cSt)	Specific Gravity	Flash Point (°C)	Calorific Value (kJ/kg)
NPOME	3.43	0.847	72	41,478
NWCOME	3.35	0.842	68	41,512
DIESEL	3.20	0.838	54	42,800

Table 4: Abbreviations

1	NPOME	80% Diesel + 20% Punnai oil Methyl Ester +25ppm Al2O3 Nanoparticles
2	NWCOME	80% Diesel + 20% Waste Cooking Oil Methyl Ester +25ppm Al2O3 Nanoparticles
3	POME	Punnai Oil Methyl Ester
4	WCOME	Waste Cooking Oil Methyl Ester
5	BTE	Brake Thermal Efficiency
6	BSFC	Brake-Specific Fuel Consumption
7	CO	Carbon Monoxide
8	CO2	Carbon Dioxide
9	HC	Hydrocarbon
10	NOX	Oxides Of Nitrogen
11	HSU	Hartridge Smoke Unit
12	HRR	Heat Release Rate

III RESULTS AND DISCUSSION

Brake Thermal Efficiency

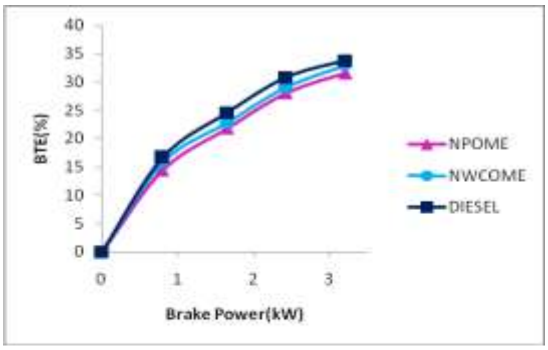

Figure 2: The Variation of Brake Power Versus Brake Thermal Efficiency

The variation of brake power versus Brake Thermal Efficiency (BTE) of the Nano additive of POME and WCOME at full load for diesel, and bio-diesel–diesel blends is shown in Figure 2. The brake thermal efficiency increases with an increase in loads for all tested fuels. Brake thermal efficiency is slightly lower than NPOME and NWCOME compared to diesel at all loads. Among NPOME, NWCOME, and diesel the brake thermal efficiency becomes 32.06%, 33.12%, and 34.0% respectively. It is almost closer to the diesel fuel at full load condition. This may be due to better spray characteristics and dissolved oxygen in esters of NPOME, and NWCOME blends in the combustion chamber; it leads to effective utilization of air resulting in complete combustion. The brake thermal efficiency gradually decreases with an increasing percentage of blends. This is due to the high viscosity of the blended fuels inhibiting the proper atomization, fuel vaporization, and combustion. This reason agreed with the previous researcher [14, 15]. Brake thermal efficiency acquired from biodiesel was lower compared with diesel. This reduction of brake thermal efficiency is due to poor spray properties, higher viscosity, and lower calorific value. Figure 2 shows brake thermal efficiency for 50 ppm fuel blends due to the high calorific value of nano fuels combined with better combustion characteristics of nanoparticles such as a higher surface-to-volume ratio that allows more amount of fuel to react with air to enhance the brake thermal efficiency. Another reason is 50 ppm blends give a high calorific value [16, 17, 18].

Brake-specific fuel consumption

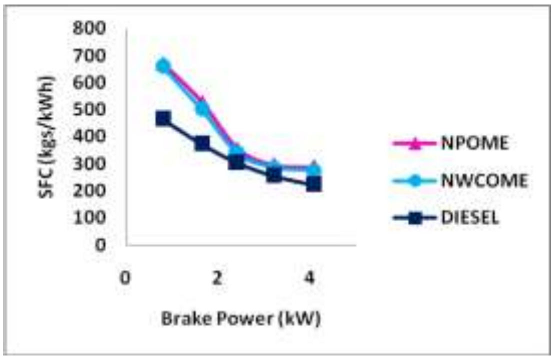

Figure 3: Variation of Brake Specific Fuel Consumption

Performance is the quantity of fuel used per unit of power production, which is known as BSFC. As the brake power increased, the BSFC showed a decreasing trend. Figure 3 shows the BSFC against various brake power. BSFC is the fuel consumption and utilization generally, diesel-biodiesel has a higher BSFC than diesel, mainly because the calorific value of diesel-biodiesel fuel is lower than that of diesel when the engine output is constant, resulting in the need to consume more fuel to maintain the same power [19]. The researchers found that adding nanomaterials to the fuel to improve the engine's BSFC was a good method [20, 21]. In this research work the effect of adding various nano-additives to diesel-biodiesel on BSFC. Prepared nano-fuel blends by dispersing three different nanoparticles (Al_2O_3, CNT, and TiO_2) into diesel-biodiesel fuel blends. The result of the BSFC decreases as the speed increases, and the fuel with nano-additives is significantly lower at the higher load, especially additives containing Al_2O_3 will achieve superior results. The nanoparticles with diesel-biodiesel were able to resolve obstruction and atomization and improve the air-fuel mixture. In addition, these nanoparticles all increase the surface area to volume ratio, which leads to better combustion and lowers fuel consumption, better air-fuel mixture, and better homogenization at higher injection pressures, resulting in a faster heat release rate [22, 23, 24].

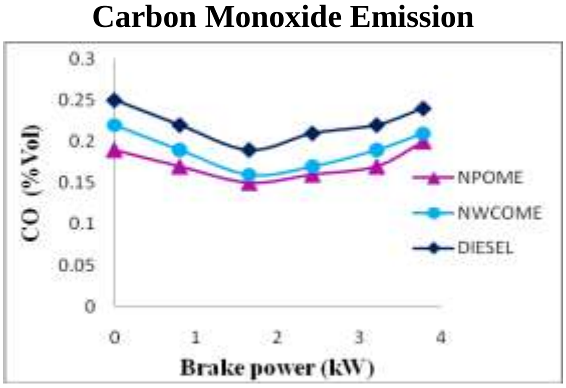

Figure 4: Variation of CO Emissions with Brake Power

The variations of CO emissions with brake power for diesel, bio diesel–diesel blends, with nano additive ofPOME and WCOME are shown in Figure 4. CO formation is due to the insufficient oxygen and time in the combustion chamber during the combustion process.From the graph the minimum and maximum CO produced was 0.15–0.25% at part load to full load condition. The CO emission of diesel at maximum load is 0.24% whereas NPOME is 0.2% andNWCOME is 0.21%. The negative effect due to high viscosity and small increases in specific gravity may suppress the complete combustion process, which produces higher CO emission. [25]. CO emission critically depends on theair fuel ratio relative to stoichiometric, insufficient oxygen and time during the combustion process. From Figure 4 shows carbon monoxide emissions for the nano additive fuel blends are lower thanDieselfuel. In general compression ignition engines work with a lean mixture and hence CO emissions would be lower. This could be possibly attributed to the enriched ignition characteristics of nano particles leading to high catalytic activity due to their higher surface to volume ratio, improving the mixing rate of fuel and air [26, 27].

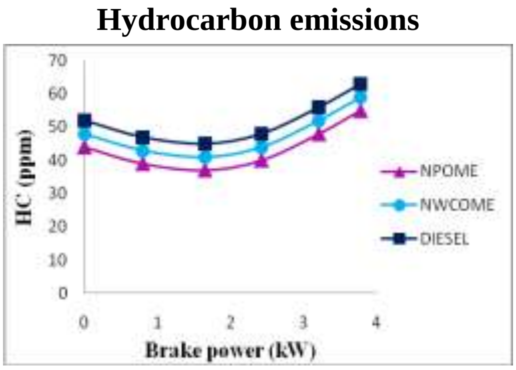

Figure 5: Variation of HC Emissions with Brake Power

The variations of HC emissions with engine load for diesel, bio diesel–diesel blends, with and without nano additive ofPOME and WCOME are shown in Figure 5. Hydrocarbon emissions of all the blends are lower in partial load, but increases at higher load. This is due to theavailability of relatively less oxygen for the reaction when more fuel is injected into the cylinder at higher load.The hydro carbon emission of diesel at maximum load is63 ppm, whereas NPOME and NWCOME is 55 ppm and 59ppm. HC emission of NWCOMEis closer than diesel. This is due to the fact that cetane number of ester based fuels is higher than that of diesel. The effects of shorter delay period results in lower HC emission. In addition, the intrinsic oxygen contained by the esters and increasing oxygen content resulting in better combustion were responsible for the reduction in HC emission, [28]. Unburned fuel is caused for producing HC emission. Hydrocarbon emissions for the nano additive fuel blends are lower than diesel fuel. This is due to perfect mixing of fuel with air and increasing the oxidation process. Another reason was nano additive blended fuel having higher surface to volume ratio [29, 30].

Carbon Dioxide Emissions

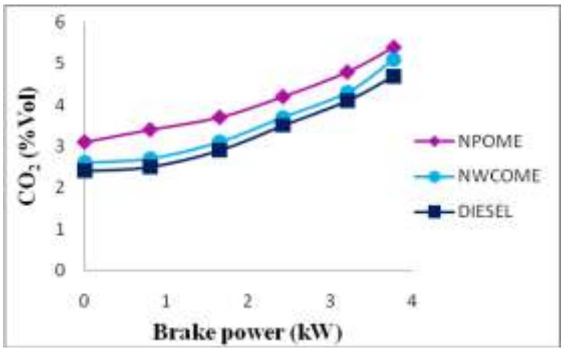

Figure 6: Variation of CO_2 Emissions with Brake Power

The lower percentage of blends nano additive of POME and WCOMEemits almost closer amount of CO_2 in comparison with diesel. This is due to low carbon content in biodiesel and has a lower elemental carbon to hydrogen ratio than diesel fuel. Using NPOME and NWCOMEthere is a slight increase in CO_2 emission at higher power, which is due to higher oxygen content of methyl esters.This is due to the lower content of fuel blend. Al_2O_3nano particles properly blended with fuel blends and air, which promotes the better combustion leading to higherCO_2 emissions than blend[31, 32]. Diesel fuel, NPOME and NWCOMEemits CO_2 as 4.7%, 5.4% and 5.1% respectively at maximum load.

Oxides of Nitrogen Emissions

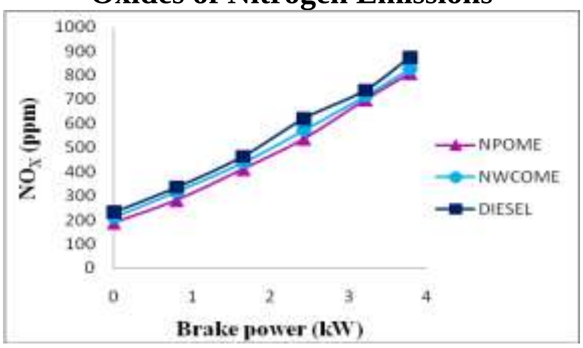

Figure 7: Variation of NO_X Emissions with Brake Power

The variations of NO_X emissions with engine load for diesel, bio diesel–diesel blends, withnano additive ofPOME and WCOME are shown in Figure 7. It is observed that the NO_X emissions increase with increase in loads for all fuel blends. This is due to increase in combustion temperature whereas there is an increase in the amount of fuel burned with load.NO_X emissions of NPOME and NWCOME are lower than diesel cause of high viscosity fuel gives poorer atomization and poorer combustion leads to lower combustion temperature [33, 34]. NO_X formation is fully dependent on the combustion temperature. In general the NO_X emission varies linearly with the increasing load. As the load increases, the overall fuel–air ratio increases and then the temperature increases in combustion chamber [35]. Due to complete combustion of the fuel with using nano additives and increasing the combustion chamber temperature, which in turns leads to increasing in NO_X.Diesel fuel, NPOME and NWCOME emits asNO_Xas 875 ppm, 808 ppm and 827 ppm respectively at maximum load.

Smoke Opacity

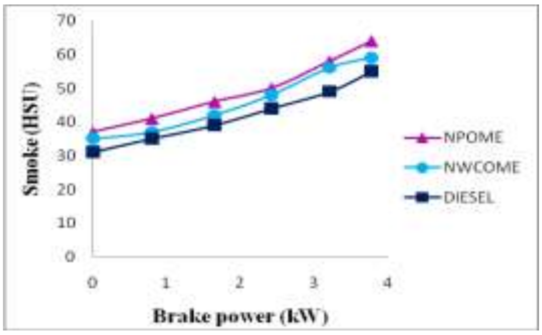

Figure 8: Variation of Smoke with Brake Power

The variations of smoke emissions with engine load for diesel, bio diesel–diesel blends, with nano additive ofPOME and WCOME are shown in Figure 8. For all the blends, the smoke increases with increase in loads.The combustion duration and ignition delay increases the gas-phase emissions compared with the lower blends [36].The Smoke emission was formed due to higher viscosity and lower volatility can result in poor mixture formation in which biofuel was used in DI diesel engine [37, 38, 39]. The smoke emissions of nano additive fuel blends are higherthan diesel fuel. Due to the shortened ignition delay, higher surface to volume ratio results in a perfect mixture formation, quick evaporation rate and improved ignition characteristics of nano additives. Because NOX and smoke are trade off [38, 39, 40].Diesel fuel, NPOME and NWCOME smoke as55HSU59 HSU and 64 HSU respectively at maximum load.

Variation of Heat Release Rate

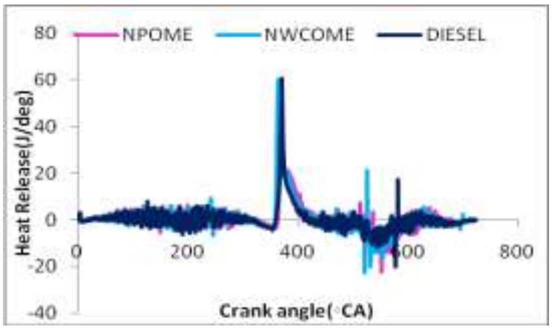

Figure 9: HRR Versus Crank Angle at Full Load

The HRR measures how quickly fuel's chemical energy is released during burning. Figure 9 shows the variationof HRR against crank angle at various fuel injection pressures. Therefore, compared to pure diesel, the NPOME and NWCOME have lower peak pressure and maximum rate of pressure rise due toits slightly higher viscosity and inferior volatility [41]. It is observed that HRR of the heat release rate ofbiodiesel and nano additive fuel samples is reduced as a result of degradation in the formulation of the air-fuelmixture due to excessive viscosity [42]. NWCOME showed higher HRR compared NPOMEbut lower thandieselat standardfuel injection pressures. Longer ignition delay results in a higher net heat release and faster combustionthan the premixed stage when Al_2O_3 nanoparticles are added [43].

Variation of In-Cylinder Pressure

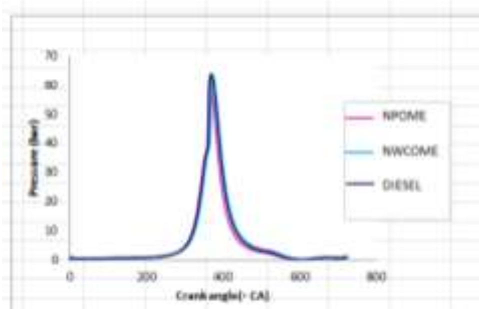

Figure 10: In-Cylinder Pressure Versus Crank Angle at Full Load

According to the Law of Conservation of energy is facilitated by understanding of pressure changes within the internal combustion engine. Figure 10 depicts In-Cylinder pressure at various fuel injection pressures at full load. In-Cylinder pressure of the fuel samples were reduced with increase in fuel injection pressures. At standard fuel injection pressures of 200bar, In-Cylinder pressure of diesel and NPOME and NWCOME are 61.22, 61.23 and 61.26 bar respectively but at 180 bar fuel injection pressures, In-Cylinder pressure of diesel and NPOME and NWCOME are 63.72, 63.45 and 63 bar respectively. NPOME and NWCOME have a lower in-cylinder pressure than diesel due to the fuel's influence on the premixed combustion phase. Due to the air-fuel mixture's poor preparation due to excessive viscosity, the biofuel’s peak in-cylinder pressure and peak heat release rate are lower [42]. In cylinder pressure of 63.72bar with diesel observed at 180 bar which is slightly higher than NPOME and NWCOME. This may be due to fuels that have higher Al_2O_3 nanoparticle ignition properties and improved surface area to volume ratios, which start burning earlier and reduce peak pressure compared to diesel [43].

IV CONCLUSION

Based on the experimental test results the following conclusions were drawn.

- The fuel properties of NPOME and NWCOME are closer to diesel.From the experimental study NWCOME Blended fuel is the best fuel ratio compared to other fuel.
- Among NPOME, NWCOME and diesel the brake thermal efficiency becomes 32.06%, 33.12% and 34.0% respectively.

- The CO emission of diesel at maximum load is 0.24% whereas NPOME is 0.2% andNWCOME is 0.21%
- The hydro carbon emission of diesel at maximum load is 63 ppm, whereas NPOME and NWCOME is 55 ppm and 59ppm.
- Diesel fuel, NPOME and NWCOME emits as NOX as 875 ppm 808 ppm and 827 ppm respectively at maximum load.
- Diesel fuel, NPOME and NWCOME smoke as 55 HSU 59 HSU and 64 HSU respectively at maximum load
- Aluminium Oxidenano additive (50 ppm) present in the NWCOME fuel blends leads to slight improvement in the brake thermal efficiency and lowering the fuel consumption.
- NPOME and NWCOME reduced HC, CO and smoke emissions up to compared with Diesel. It may be due to enhanced surface to volume ratio and improving the mixing rate of fuel and air in the combustion chamber.
- The NO_X emission was found to be slightly increased with the addition of 50 ppm Al_2O_3 with biodiesel.Bio-diesel from WCOME with nanoadditive (50 ppm) is quite suitable as alternate fuel for diesel engine.

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