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EFFECT OF AIR PREHEATING ON EXHAUST EMISSIONS IN A DI DIESEL ENGINE

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ABSTRACT

In this work diesel combustion and exhaust emission with neat diesel fuel and diesel kerosene blends are investigated in a four-stroke naturally aspirated (N/A) direct injection (DI) diesel engine. This study proposes a new air preheating system. The experimental results show that at an elevated inlet air temperature after warming up the engine, oxides of nitrogen (NO_x), carbon monoxide (CO) and engine noise decrease for medium load condition using the newly designed system. Comparatively better overall engine performance is found for medium load condition with the new set up. The reduction in emissions with the new set up may be due to significant reduction in ignition delay and better combustion because of higher inlet air temperature.

1. INTRODUCTION

As far as the fuel in diesel engines is concerned, research has been conducted to clarify the effects of fuel properties on diesel combustion and exhaust emissions. For example, sulfur content in fuels has been reduced in order to improve the acid rain problem and its reduction down to 50 ppm was set as regulations to reduce particulate levels. Other fuel properties related to the improvement of engine performance and emissions include sulfur content, aromatic content, ignitability, oxygen content, viscosity and distillation temperature [1-11]. As far as oxygen content or oxygenates, the addition of lower alcohols such as methanol and ethanol to diesel fuel was effective to reduce particulate emissions without sacrificing other emission components [12-16]. However, there were problems as the methanol has inherently poor solubility to diesel fuel and poor lubricity, and its lower ignitability made it impossible to use neat alcohols or high blending ratios in conventional diesel fuel without special measures to improve ignition. Non-alcohol organic compounds have also been investigated to improve diesel combustion and emissions. Methyl-t-butyl ether (MTBE) is a promising oxygenated fuel, which has already been used as an octane improver in gasoline. While having extremely poor ignitability like lower alcohols, MTBE may be more easily utilized in diesel engines as it has infinite solubility in diesel fuel. Another oxygenated fuel, dimethyl ether (DME) has very high ignitability, different from lower alcohols and MTBE, but its utilization in diesel engines is not easy as DME is gaseous under atmospheric conditions.

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Some reports have mentioned the effects of blending of liquid oxygenated agents to diesel fuels on diesel combustion and emissions.

Miyamoto et al [17-19] investigated eight kinds of oxygenates blended with conventional diesel fuel up to 10 vol-%. The results indicated that smoke and particulates were effectively reduced without sacrificing other emissions or thermal efficiency and that the reduction depended almost entirely on the oxygen content of the fuels.

Exhaust NOx can be reduced by in-cylinder combustion improvement [20]. This study investigated the effect of inlet air preheating on in-cylinder combustion and exhaust NOx. The influence of improved fuel properties on the exhaust NOx is also discussed. Inlet air preheating induces higher level of excitation of air particles and there is good evaporation of fuel particles and consequently ignition delay become shorter. Due to better evaporation and shorter ignition delay, there is less fuel adhering to the combustion chamber wall and therefore small amount of fuel accumulated in the combustion chamber before ignition is started which may produce low NOx emission as well as low noise and vibration [21].

In this work, a new set up has been designed for inlet air heating. The experiment has been conducted with neat diesel fuel and diesel kerosene blend in a four-stroke naturally aspirated (N/A) direct injection (DI) diesel engine.

2. EXPERIMENTAL SET UP AND PROCEDURE

The experiment was conducted in a four-stroke DI diesel engine. The specification of the tested engine is shown in Table-1. Conventional diesel fuel and diesel kerosene blend was alternatively used as fuels. The properties of the tested fuels are shown in Table-2. Figure 1 shows a schematic diagram of the inlet air preheating system. The rpm was measured directly from the tachometer attached with the engine shaft. The outlet temperature of cooling water and exhaust gas temperature was measured directly by using thermometer attached to these lines. A digital exhaust gas analyzer (Table 3) was used to measure exhaust gas emissions. Engine noise was measured at a constant distance from the engine by a sound level meter (Model CEL-228).

Since heat transfer depends upon area, the area of heat transfer between exhaust and inlet pipes was extended as far as possible. To accomplish this, the maximum length of exhaust pipe was surrounded by inlet air passage so as to extract maximum quantity of heat from exhaust gases. To reduce heat transfer to atmosphere from inlet air, inlet passage was insulated by plaster of paris whose heat resistivity is comparatively higher. Figure 2 shows the heat transfer phenomenon. Overall heat transfer from exhaust gas to inlet air was calculated by the following equation [22]:

$$q = UA\Delta T_{overall} \tag{1}$$

where,

A = area of heat flow,

U =overall heat transfer co-efficient and

ΔT=difference between average exhaust gases temperature (T_E) and average inlet air temperature (T_A)

U can be evaluated by the following equation:

$$U = \frac{1}{R_1 + R_2 + R_3}, \; R_1 = \frac{1}{h_i A_i}, \; R_2 = \frac{\ln(r_0 - r_i)}{2\pi k l}, \text{ and}$$

$$R_3 = \frac{1}{h_o A_o}$$

The overall heat transfer coefficient is calculated based on the inside area of the exhaust pipe. Setting the value of U in the above equation we have the following equation for q.

$$q = \frac{T_E - T_A}{1/h_i A_i + \ln(r_0/r_i)/2\pi k L + 1/h_0 A_0} \tag{2}$$

where,

h_i = convection heat transfer co-efficient of exhaust gases

h_0= convection heat transfer co-efficient of inlet air

k = thermal conductivity of exhaust pipe material

A_o, A_i = outlet and inlet heat transfer area respectively

r_0, r_i = outer and inner radius of the exhaust pipe respectively

L= length of heat transfer area

Table 1. Specification of tested diesel engine

Items	Specification
Type	1-cylinder, 4-stroke
Bore x Stroke	95 x 115 mm
Rated output	10 KW/2000 rpm
Compression ratio	20:1
Type of cooling	Water evaporative type
Injection pressure	14 MPa

Table 2. Properties of tested fuels

Tested fuels	Dist. temp. 90% (°C)	Cal. Value (MJ/kg)	Density (g/cc)	Cetane no.
Diesel	336	42.74	0.830	50
Kerosene	170	43.0	0.740	39

Table 3. Specification of gas analyzer

Items	Specification
Type	IMR 1400 Digital, portable
Calibration	Automatic zero point calibration after switch on calibration time 1 minute
Fuels	Oil light, natural gas, town gas, coal gas, liquid gas, coal and wood dry.
Gas probe	Heated probe with PTC resistor temperature 65ºc (Thermocouple Ni-Cr)
Gas hose	3-Way-Hose, Length 3.5 m
Air-probe	Integrated current sensor
Dust filter	Cellpor-filter, 4 micron
Operating temperature	-10 ºC to + 40 ºC
Power supply	Main 230V/50-60 Hz

3. RESULTS AND DISCUSSIONS

3.1 Effect of inlet air preheating on diesel combustion and emissions-

Figure 3 shows the effect of inlet air preheating on NOx emission. Without preheating, the inlet air temperature was recorded as 32°C and with preheating, the inlet air temperature was set at 55°C by controlling the exhaust gas valve. The data was taken at medium load condition. Engine load means the load on engine shaft. From this load, brake output power, brake torque and brake mean effective pressure (BMEP) can be calculated. Here conventional diesel fuel was used as test fuel. It is seen from the Figure that with the increase in engine speed, NOx emission increases for both systems. But compared to without preheating, a significant reduction in NOx emission was found when the air

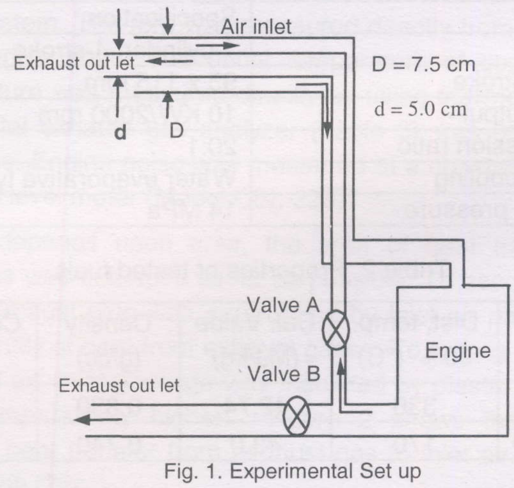

Fig. 1. Experimental Set up

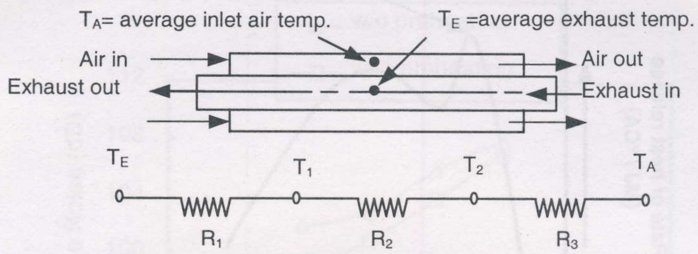

Fig. 2 Heat transfer phenomena

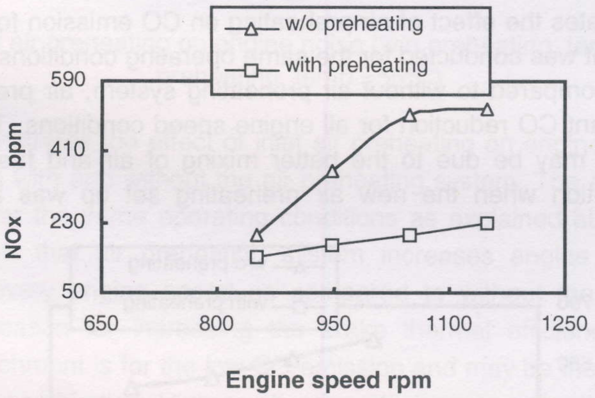

Fig. 3 Effect of air preheating on NOx emission (w/o preheating, temp = 32°C, with preheating, temp. = 55°C)

was preheated. This remarkable reduction in NOx emission may be caused by the reduction in ignition delay, and lower combustion temperature, which reduce engine emissions. The present investigation has no provision to measure inside cylinder temperature. To investigate cylinder inside temperature, authors calculated adiabatic flame temperature and NOx emission. The calculated results indicated (results not shown) that with the increase in inlet air temperature, the peak of the premixed combustion is lower; as a result the degree of heterogeneous combustion is improved. It is well known that the lower peak of the premixed combustion experiences lower flame temperature. Lower flame temperature gives lower NOx emission. Figure 4 shows the rate of heat release (ROHR) versus crank angle curve.

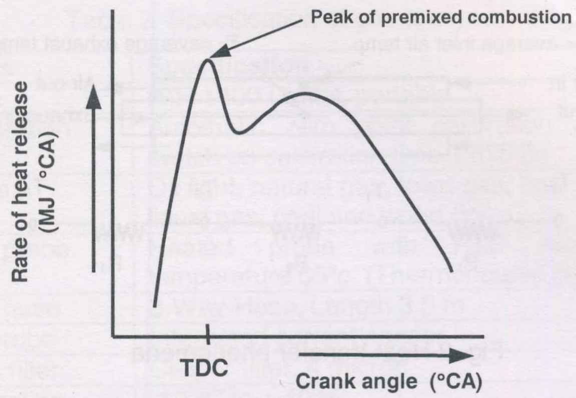

Fig. 4 ROHR versus crank angle curve

Figure 5 illustrates the effect of air preheating on CO emission for both systems. The experiment was conducted for the same operating conditions as explained in Figure 3. As compared to without air preheating system, air preheating system shows significant CO reduction for all engine speed conditions. The reduction in CO emissions may be due to the better mixing of air and fuel, which results better combustion when the new air preheating set up was attached to the engine.

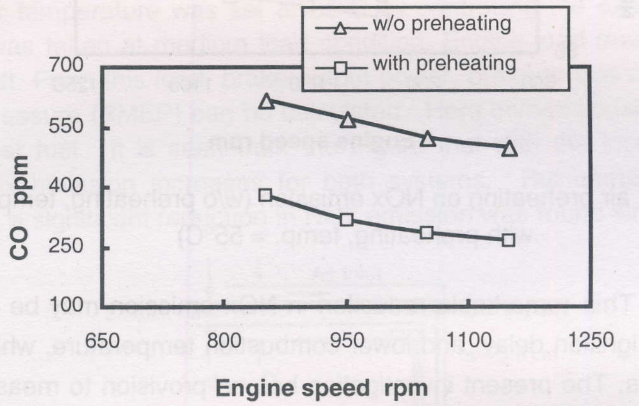

Fig 5 Effect of air preheating on CO emission (w/o preheating, temp.=32°C, with preheating, temp.=55°C)

Figure 6 depicts the effect of air preheating on engine noise using with and without the attachment under conditions mentioned earlier. It is clearly evident from the Figure that air preheating system reduces engine noise for all engine speed conditions as compared to without air preheating system. There is a relationship among peak of premixed combustion, NOx emission and engine noise. Lower peak experiences smoother combustion (explained in Figure 3), which results lower NOx emission. Smooth combustion leads to lower engine noise.

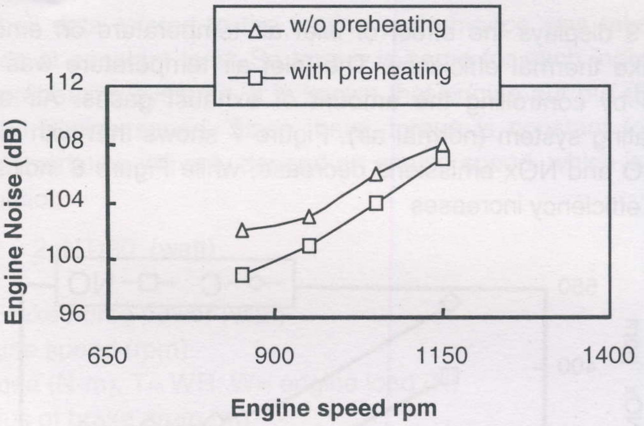

Fig. 6 Effect of air preheating on engine noise (w/o preheating, temp.=32°C, with preheating, temp.=55°C)

Figure 7 demonstrates the effect of inlet air preheating on engine brake thermal efficiency using with and without the air preheating system. The experiment was conducted under the same operating conditions as explained above. It is seen from the Figure that air preheating system increases engine brake thermal efficiency for every engine speed as compared to without the air preheating system. The reason for increasing the brake thermal efficiency with the air preheating attachment is for the low CO emission and may be the high degree of heterogeneous combustion. High combustion efficiency may be the other reason for brake thermal efficiency improvement.

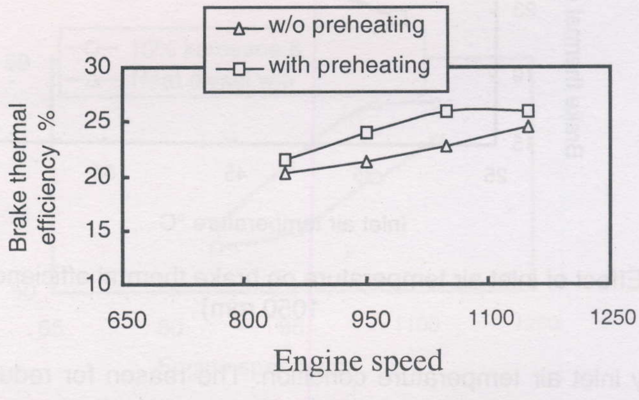

Fig. 7 Effect of air preheating on efficiency (w/o preheating, temp.=32°C, with preheating temp.=55°C)

Figure 8 and 9 displays the effect of inlet air temperature on emissions (CO, NOx) and brake thermal efficiency. The inlet air temperature was varied from 32°C to 60°C by controlling the amount of exhaust gases. Air at 32°C was without preheating system (normal air). Figure 7 shows that with air preheating attachment, CO and NOx emissions decrease, while Figure 8 indicates that the brake thermal efficiency increases

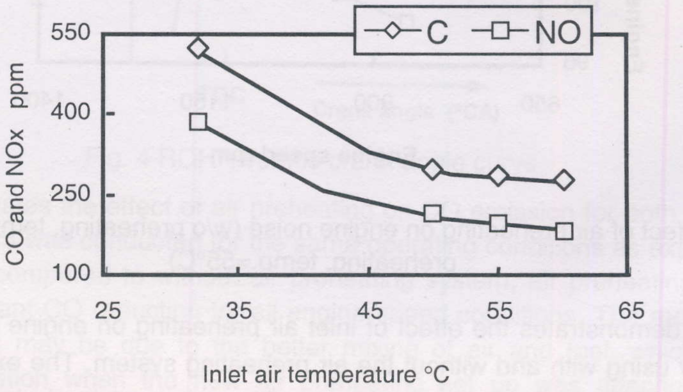

Fig. 8 Effect of inlet air temperature on engine CO and NOx emissions (Engine speed 1050 rpm).

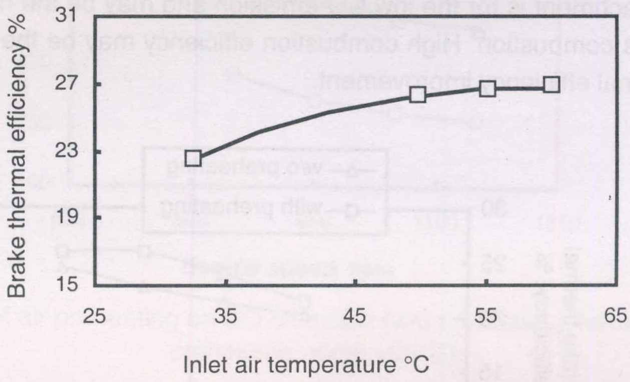

Fig. 9 Effect of inlet air temperature on brake thermal efficiency (engine speed 1050 rpm)

for every inlet air temperature condition. The reason for reduction in emissions (CO, NOx) and improvement in brake thermal efficiency is caused by the improvement in combustion efficiency and better degree of heterogeneous combustion as explained earlier in Figures 3, 5 and 7.

In this study all data related to the engine performance was taken at different engine speeds at constant load. So torque is same for each individual run with and without preheating systems. It is known that engine out put (BHP) depends on torque and engine speed. Since, here, torque is constant for all runs, so engine out put variation will only depend on engine speed, which is shown by the following equation:

$$BHP = 2\pi NT/60 \text{ (watt)} \qquad (3)$$

where,

BHP: brake horse power (watt)

N: engine speed (rpm)

T: Torque (N-m), T= WR: W= engine load (N)

R: radius of brake drum (m)

So, for a certain engine speed out put is same for with and without preheating systems

Figure 10 shows the effect of inlet air preheating at different engine speeds on NOx emission with neat diesel fuel and diesel kerosene blend. Here conventional diesel fuel and diesel kerosene blend (10% by volume) are used as tested fuels. Without heating, the inlet air temperature was recorded as 32°C and with heating, the inlet air temperature was set at 55°C. The data was taken at medium load condition. For both fuels, NOx emission increases with engine speed. It is seen from the Figure that NOx emission for 10% kerosene blend is comparatively lower than that of neat diesel fuel at various engine speeds though diesel kerosene blend is lower grade fuel. This lower NOx emission may be caused by the reduction in ignition delay and combustion temperature, which also reduce engine emissions. When the attachment is fixed to the engine, better combustion may be expected due to the heating of incoming air, which is the dominating factor even though kerosene possesses lower cetane number.

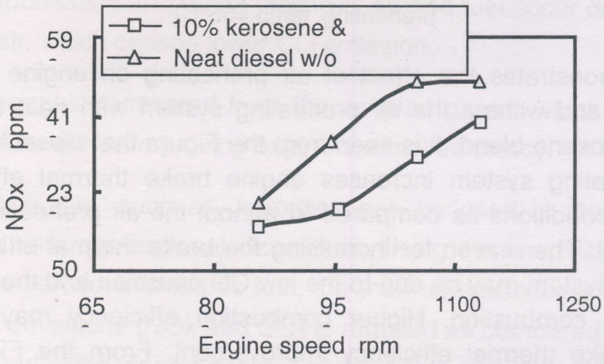

Fig. 10 Effect of engine speed on NOx emission with neat diesel fuel using no preheating attachment and diesel kerosene blend with air preheating (w/o preheating, temp.=32°C, with preheating, temp.=55°C)

Figure 11 illustrates the effect of air preheating on CO emission for both systems with neat diesel fuel and diesel-10% kerosene blend at different engine speeds. The experiment was conducted for the same operating conditions as explained in case of Figure 10. During combustion, CO formation is reduced with engine speed for both arrangements due to the increase of air squish in combustion chamber as well as better air fuel mixing. From the Figure it is clear that CO emission is remarkably lower for diesel-10% kerosene blend with air pre heating system as compared to the neat diesel fuel at every engine speed. This reduction in CO emission may be due to the better air-fuel mixing in the combustion chamber, which leads to improved combustion. Beyond certain engine speed reduction of CO emission and difference in CO formation is not significant due to over lean mixture of air fuel at higher engine speed. However, the experiment was not conducted up to that speed.

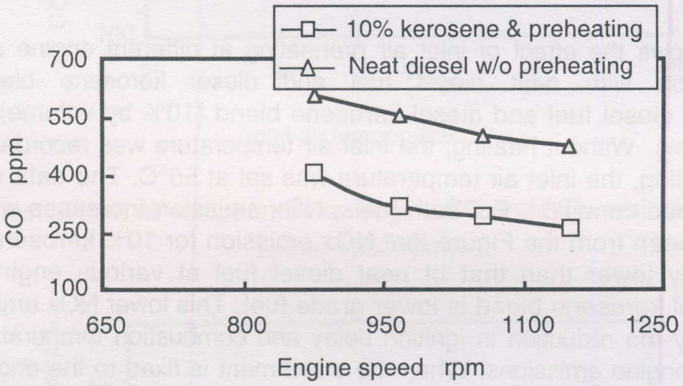

Fig. 11 Effect of engine speed on CO emission with neat diesel fuel using no attachment and diesel kerosene blend with air preheating (w/o preheating, temp.=32°C, with preheating, temp.=55°C)

Figure 12 demonstrates the effect of air preheating on engine brake thermal efficiency with and without the air preheating system with neat diesel fuel and diesel-10% kerosene blend. It is seen from the Figure that diesel kerosene blend with air preheating system increases engine brake thermal efficiency for all engine speed conditions as compared to without the air preheating system with neat diesel fuel. The reason for increasing the brake thermal efficiency with the air preheating system may be due to the low CO emission and the high degree of heterogeneous combustion. Higher combustion efficiency may be the other reason for brake thermal efficiency improvement. From the Figure it is also evident that at higher engine speed, brake thermal efficiency is near about same for both the systems because at higher engine speeds, duration of premixed combustion is shorter, which is more dominating factor than inlet air temperature.

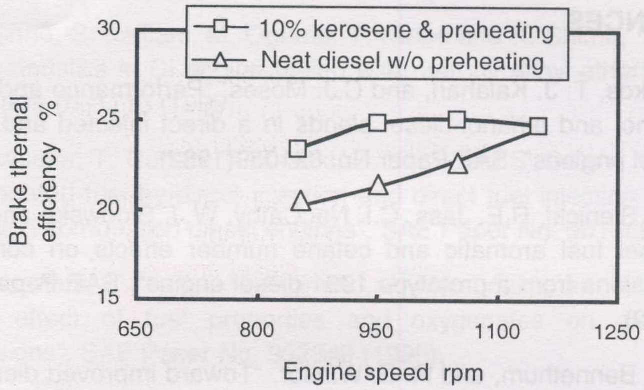

Fig. 12 Effect of engine speed on brake thermal efficiency with neat diesel fuel using no attachment and diesel kerosene blend with air preheating (w/o preheating, temp.=32°C, with preheating, temp.=55°C)

4. CONCLUSIONS

In this work an air preheating system has been designed, and fabricated and its effect has been tested on diesel combustion and exhaust emissions. The results of this work may be summarized as follows:

1. A new air preheating set up has been constructed. Higher inlet temperature for the new set up reduces the peak of the premixed combustion as well as shortening the ignition delay. This causes lower NOx emission. Uniform or better combustion is obtained by preheating the inlet air, which eventually reduces engine noise.

2. Easy vaporisation and better mixing of air and fuel occur due to warm up of inlet air, which causes lower CO emission.

3. Heat energy is recovered from the exhaust gases, which causes lower heat addition, thus improving engine thermal efficiency.

4. Low grade fuel, such as, kerosene can be used in diesel engine by blending with conventional diesel fuel. Using the air preheating system and 10% kerosene blend as fuel, the thermal efficiency is improved and exhaust emissions (NOx and CO) is reduced as compared to neat diesel fuel without using air preheating system.

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