REDUCTION OF NOx AND SMOKE EMISSIONS ON A DIESEL ENGINE WITH INTERNAL JET PISTON USING BIO-DIESEL WITH EXHAUST GAS RECIRCULATION (EGR) TECHNIQUE

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ABSTRACT

Exhaust gas recirculation (EGR) is effective to reduce nitrogen oxides (NOx) from Diesel engines because it lowers the flame temperature and the oxygen concentration of the working fluid in the combustion chamber. However, as NOx reduces, particulate matter (PM) increases, resulting from the lowered oxygen concentration. When EGR further increases, the engine operation reaches zones with higher instabilities, increased carbonaceous emissions and even power losses. In this research, an attempt is made to reduce smoke and NOx emissions with the combined effect of turbulence inducement using internal jet piston and exhustgas recirculation (EGR). The internal jet piston which create the turbulence in the combustion chamber which enhance the complete combustion but increased NOx emissions. The NOx emissions are reduced with exhustgas recirculation.

Key words: Internal jet piston, exhaust gas recirculation, emissions, palm oil methyl ester, turbulence

I. INTRODUCTION

Compression ignition engine are preferred prime movers due to excellent drivability and higher thermal efficiency. Despite their advantages they produce higher levels of NOx and smoke emissions which will more harmful to human health. Hence stringent emission norms have been imposed. In order to meet the emission norms and also the fast depletion of petroleum oil reserves lead to the research for alternative fuels for diesel engines. Biodiesel from vegetable oils are alternative to diesel fuel for diesel engines. The use of biodiesel in diesel engines does not require any engine modification. To achieve reductions in NOx emissions, exhaust gas recirculation (EGR) can be used with biodiesel in the diesel engines. EGR is an effective technique of reducing NOx emissions from the diesel engine exhaust [1-4]. Controlling the NOx emissions primarily requires reduction of in-cylinder temperatures [2, 3]. However, the application of EGR results in higher fuel consumption and emission penalties, also EGR increases HC, CO, and PM emissions along with slightly higher specific fuel consumption [2, 3]. Abd-Alla et al [1] performed experiments on a 9.0 kW rated power dual fuel (gaseous fuel- methane with diesel as pilot fuel) mode direct injection diesel engine to study the effect of inlet air temperature by the way of mixing of hot EGR and addition of diluents gas such as CO_2 and N_2. They reported that the addition of CO_2 gas in the intake charge resulted in moderate reduction of NOx emission but unburnt hydrocarbon emission (UBHC) was increased. By increasing the intake charge temperature resulting in increase of NOx emission with decrease in UBHC, the brake thermal efficiency and power output increased due to reduced ignition delay. Also they suggested that the performance was improved at low load condition when the intake air temperature was increased.

Deepak Agarwal et al [2] conducted a test on a single cylinder DI diesel engine and measured the performance and emission characteristics with rice bran methyl ester (RBME) and its blends as fuel with EGR system. They optimized and reported that 20% biodiesel blends with 15% EGR produce the less NOx, CO and HC emissions and also improved thermal efficiency and reduced BSFC. Hountalaous et al [3] using 3D-multi dimensional model to examine the effect of EGR temperature on a turbocharged DI diesel engine with three different engine speeds, and they reported that high EGR temperature affects the engine brake thermal efficiency, peak combustion pressure, air fuel ratio and also soot emissions, and the combined effect of increased temperature and decreased O_2 concentration resulted low NOx emissions. Also they suggested that EGR cooling is necessary to retain the low NOx emissions and prevent rising of soot emissions without affecting the engine efficiency at high EGR rates. Ken Satoh et al [4] investigated on a naturally aspirated single cylinder DI diesel engine with various combinations of EGR, fuel injection pressures, injection timing and intake gas temperatures affect exhaust emissions and they found that NOx reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. NOx reduction ratio is in direct proportion to intake gas temperatures. EGR may adversely affect the smoke emission because it lowers the average combustion temperatures and reduces the oxygen intake gases, which in turn keeps soot from oxidizing. Also they suggested that for a given level of oxygen concentration the cooled EGR reduces more NOx with less EGR rates than does at hot EGR. Senthil Kumar [5] have experimentally studied the performance end emission characteristics of the DI diesel engine with internal jet piston and they reported that the smoke emissions were reduced by 8 % and nitrogen oxides emissions were increased at high load operation with diesel.

The main objective of the present research is to investigate the effect of exhaust gas recirculation and internal jet piston with palm oil methyl ester blends and diesel fuel. For this experimental study 15% EGR has been taken as optimized quantity from the literature.

II. MATERIALS AND METHODS

A. Preparation of Palm Oil Methyl Ester

Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar in size to the molecules of the species present in diesel fuel. The process takes place by reacting the vegetable oil with an alcohol in the presence of catalyst. Methyl esters are preferred as methanol is non hygroscopic and is less expensive than other alcohols. In general, due to high value of free fatty acids (FFA) of palm oil, acid catalyzed transesterification is adopted However, FFA of the feedstock used in this work is less and hence alkali catalyzed transesterification process is employed for the conversion of palm oil into ester. The palm oil is preheated in a reactor to remove the moisture. Sodium methoxide is prepared by dissolving sodium hydroxide in methanol. Methoxide is mixed with preheated oil and the reaction carried out under nominal speed stirring by a magnetic stirrer and at a constant reaction temperature of 60°C for 1 hours. After 8 hours of settling period, ester separates as an upper layer and glycerol settles at bottom separated by decantation. These esters is washed with warm water to remove impurities and separated.

Experimentally the process parameters are optimized. The optimum proportions are for one litre of palm oil, the requirement of methanol and NaOH are 200 ml and 6.75g respectively. With this proportion from one litre of palmoil, 920 ml of palm oil methyl ester (POME) was produced. The important properties of palm oil, POME and diesel are given in Table 1.Table 2 shows the properties of POME blends.

B. Exhaust Gas Recirculation

Fig.1 shows the exhaust gas recirculation (EGR) set up in the test engine used for controlling the NOx emissions.EGR is an effective technique of reducing NOx emissions from the diesel engine exhaust. EGR involves replacement of oxygen and nitrogen of fresh air entering in the combustion chamber with the carbon dioxide and water vapor from the engine exhaust. The recirculation of part of exhaust gases into the engine intake air increases the specific heat capacity of the mixture and reduces the oxygen concentration of the intake mixture. These two factors combined lead to significant reduction in NOx emissions. EGR (%) is defined as the mass percentage of the recirculated exhaust (MEGR) in total intake mixture.

C. Experimental Setup

The performance and exhaust emission tests were carried out in a constant speed, direct injection diesel engine. The engine specifications are given in table.1. The engine was coupled to a electrical dynamometer. Two separate fuel tanks were used for the diesel fuel and POME. The fuel consumption was determined by measuring the time taken for a fixed volume of fuel to flow into the engine. The exhaust gas emissions are measured by the AVL 444 five gas analyzer was used and the smoke emissions are measured by Bosch smoke meter.

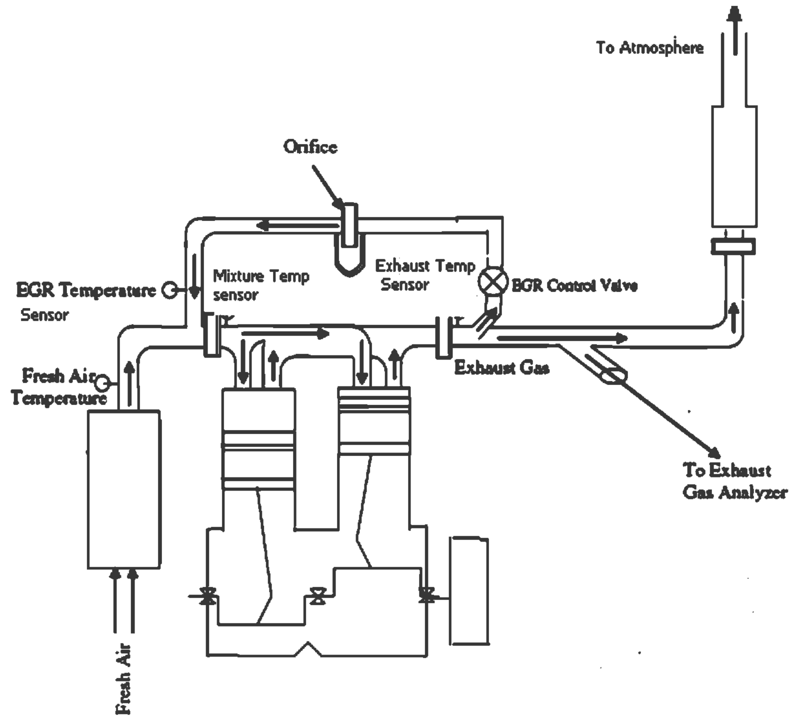

Fig. 1. Schematic view of experimental setup

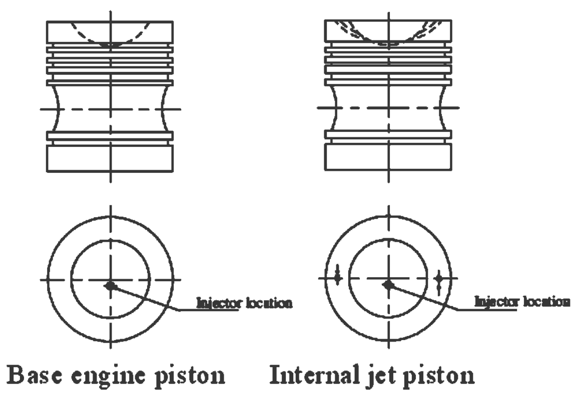

Fig. 2. Base engine piston and Internal jet piston

Table 1. Properties of diesel, palm oil and its methyl ester

S. No	Properties	Diesel	Palm oil	POME
1	Density (kg/m3)	830	910	885
2	Viscosity(mPa-s) @40°C	3.32	38.23	4.18
3	C V(MJ/Kg)	44	36.543	38.5
4	Cetane no	56	42	45
5	Flash point (°C)	50	325	142

Table 2. Properties of methyl ester blends

Properties	Density (Kg/m^3)	Viscosity (mPa-s)	C.V (MJ/kg)
B-20	832	3.92	42.038
B-40	834	3.94	41.827
B-60	836	3.96	41.615

Table 3. Test engine specifications

Engine	Kirlokar, Vertical engine
Type	Single cylinder, water cooled
Bore Diameter,mm	80
Stroke Length,mm	110
Brake Power	3.68KW
Compression Ratio	16:1
Speed	1500rpm
Fuel injection	23° before TDC

D. Methodology

The diesel engine is a type of internal combustion engine; more specifically, it is a compression ignition engine, in which the fuel is ignited by being suddenly exposed to the high temperature and pressure [2] of a compressed gas, rather than by a separate source of ignition, such as a spark plug, as is the case in the gasoline engine The tests were first carried out for the basic engine configuration having a piston with a hemispherical cavity with diesel and biodiesel blends in the ratio of 20:80, 40:60 and 60:40 with exhaust gas recirculation (10% EGR).Then the another test were carried out by using internal jets which are provided by fabricating the piston with two diametrically opposite holes of 3 mm diameter in the plane of piston crown with diesel and biodiesel blends of POME with exhaust gas recirculation (10% EGR). The results of these measurements were compared with the baseline diesel fuel.

III. RESULTS AND DISCUSSION

Engine tests were carried out using diesel at 1500 rpm and different EGR rates of 5%, 10% and 15% with diesel blends with base engine piston and internal jet piston in order to study the effect of EGR on performance and emissions of a diesel engine. Higher amount of smoke in the exhaust is observed when the engine is operated with EGR compared to without EGR. Smoke emissions increases with increasing engine load and EGR rates.EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of PM and reducing NOx emissions from diesel engine. Using biodiesel in diesel engine, smoke is decreased with increase in NOx. Thus, biodiesel with EGR can be used to reduce NOx and smoke intensity simultaneously. The performance and emission data of the internal jet piston were analyzed for thermal efficiency, BSFC, exhaust gas temperature, HC, CO, NOx and smoke emissions. The measured values were compared with base engine piston with diesel fuel.

A. Brake Thermal Efficiency

Figure. 3 shows the variation of brake thermal efficiency of diesel and biodiesel blends (POME) with base engine piston and internal jet piston respectively. It is observed from the figure that the brake thermal efficiencies are increased with increase in load. The brake thermal efficiencies are increased for internal jet piston for diesel. The brake thermal efficiencies are 29.79% and 30.56% for base engine piston and internal jet piston respectively at full load. This may be due to higher turbulence inducements, which results better air fuel mixture formation, resulting higher brake thermal efficiency. The brake thermal efficiencies are increased with increasing concentration of bio diesel blends due to the higher oxygen present in the bio diesel and induced turbulence in the combustion chamber at full load conditions.

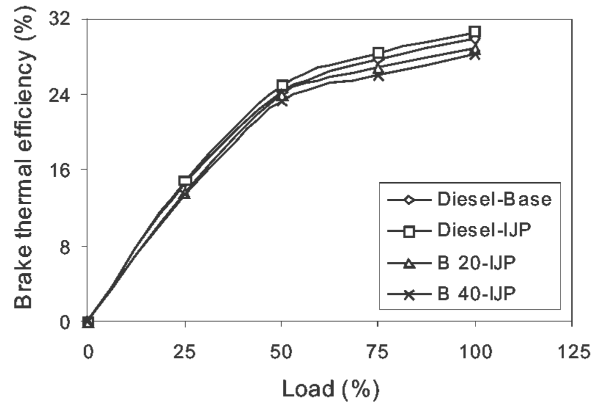

Fig. 3. Brake thermal efficiency with Load

Figure. 4 shows the variation of brake thermal efficiency of diesel and biodiesel blends (POME) with and without EGR using base engine piston and internal jet piston respectively. The brake thermal efficiencies are decreased with increase in EGR rates for diesel and biodiesel blends with both the piston operation at full load conditions. It is observed from the figure that the brake thermal efficiencies are slightely decreased for 5% EGR and 1-2% for 10% EGR and 2-3.5% for

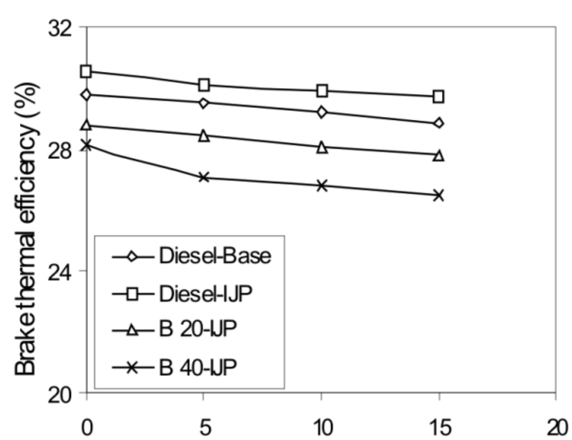

Fig. 4. Brake thermal efficiency with EGR rate

15 % EGR for diesel and biodiesel blends with internal jet piston compared with base engine piston without EGR at full load conditions. This may be due to insufficient oxygen content available for combustion while increasing EGR rates.

B. Brake specific fuel consumption (BSFC)

Figure. 5 shows the variation of brake specific fuel consumption of diesel and biodiesel blends (POME) with and without EGR using base engine piston and internal jet piston respectively. The brake specific fuel consumptions are increasing with increase in EGR rates. The brake specific fuel consumptions are increased with increasing concentration of biodiesel blends when the engine is operated with EGR .This may be due to lower oxygen available for combustion at full load with EGR, and lower calorific value of the biodiesel, resulting more fuel is required to get the required power out put.

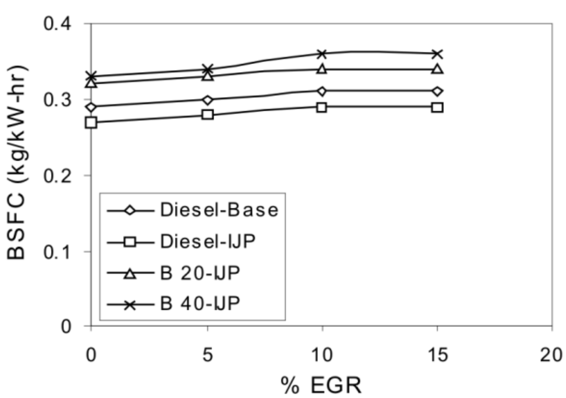

Fig. 5. BSFC with EGR rate

C. Exhaust gas temperature

Figure. 6 shows the variation of exhaust gas temperatures of diesel and biodiesel blends (POME) with and without EGR using base engine piston and internal jet piston respectively. It is observed that the exhaust gas temperatures are increases with increasing biodiesel blends and diesel without EGR.But, the exhaust gas temperature was found to be lower for while increasing EGR rates for both the piston operation with diesel due to lower availability of oxygen for combustion and higher specific heat of intake exhaust gas air mixture. The internal jet piston operated egine gives lower exhaust gas temperature for biodiesel blends with EGR.

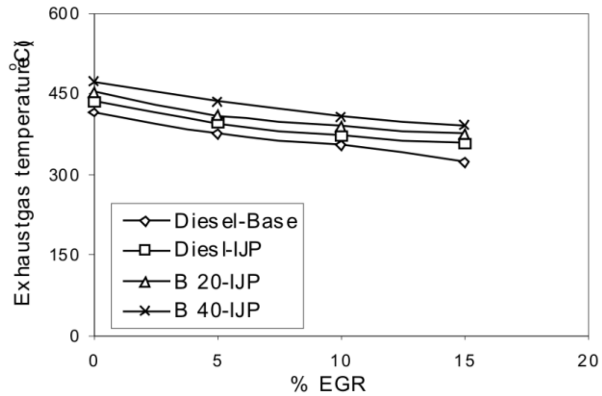

Fig. 6. Exhaust gas temperature with EGR rate

D. Hydrocarbon emissions (HC)

Figure.7 shows the variation of hydrocarbon emissions of diesel and biodiesel blends (POME) with and without EGR using base engine piston and internal jet piston respectively. The UBHC increases with increases with increasing EGR rates, because of lower oxygen available for combustion results rich mixture. This results incomplete combustion, thus increase in hydro carbon emissions for both the fuels. It is observed that the hydro carbon emissions are lower for internal jet piston operation with all EGR rates due to the induced turbulence in the combustion chamber by the internal jets, which results better air fuel mixing, resulting lower hydrocarbon emissions.

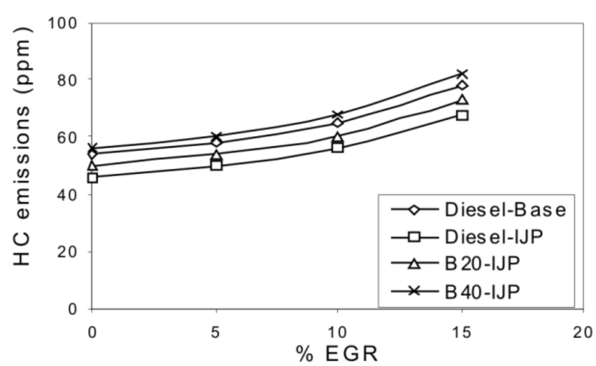

Fig. 7. Hydro carbon emissions with EGR rate

E. Carbon monoxide emissions (CO)

Figure. 8 shows the variation of CO emissions of diesel and biodiesel blends (POME) with and without EGR using base engine piston and internal jet piston respectively. The CO increases with increasing EGR rates for both the piston. However, CO emissions for biodiesel blends (POME) are comparatively lower at all

EGR rates with internal jet piston. Higher values of CO were observed at full load for diesel with EGR for both the pistons. These higher CO emissions may be due to lower oxygen available for combustion at full load with EGR, resulting incomplete combustion.

F. Nitrogen oxides émission (NO_X)

Figure 9 shows the variations of NOx emissions of diesel and palm oil methyl ester (POME) with and without EGR for base engine piston and internal jet piston respectively. The degree of reduction in NOx at higher at higher loads. The reasons for reduction in NOx emissions using EGR in diesel engines are reduced oxygen concentration and decreased the flame temperatures in the combustion chamber. However, NOx emissions in case of biodiesel blends without EGR are higher than diesel due to higher temperatures prevalent in the combustion chamber. It is also observed from the graph, the biodiesel blends have 15-20 % lower NOx emissions respectively when compared to diesel fuel without EGR.

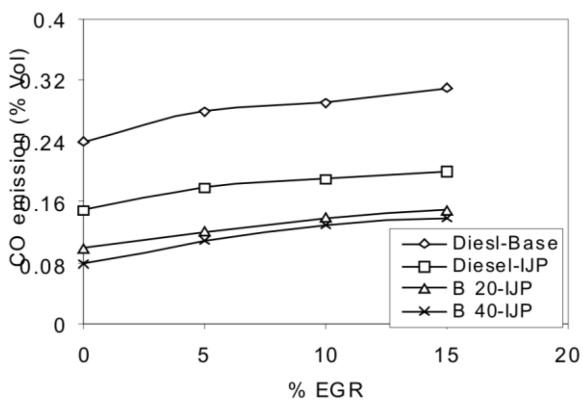

Fig. 8. Carbon monoxide emissions with EGR rate

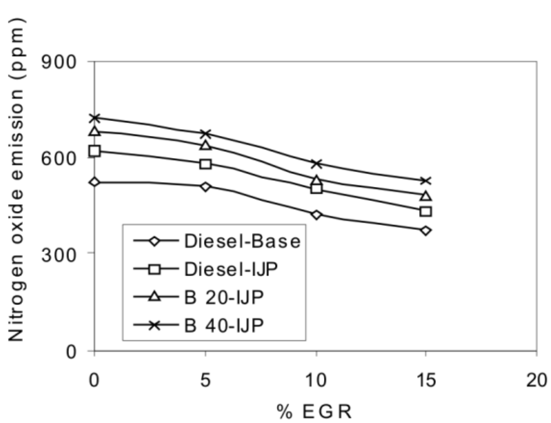

Fig. 9. NOx emissions with EGR rate

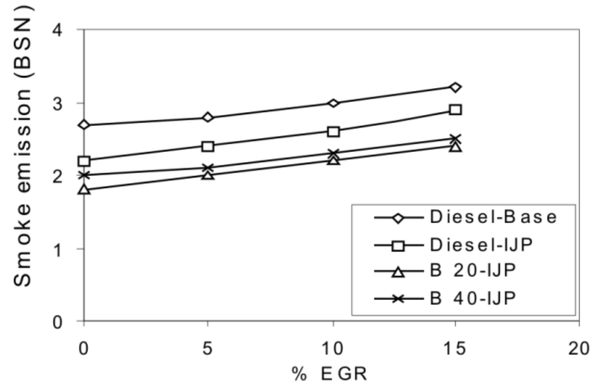

Fig. 10. Smoke emissions with EGR rate

G. Smoke Emissions

Figure 10 shows the variations of smoke emissions of diesel and palm oil methyl ester (POME) blends with and without EGR for base engine piston and internal jet piston respectively. Higher smoke density of the exhaust is observed when the engine is operated with EGR compared to diesel with normal piston without EGR. But the smoke density is about 10 % reduced when the engine is operated with internal jet piston with EGR. This may be due to turbulence inducement results better combustion in the combustion chamber by internal jets in the piston.

IV. CONCLUSION

Transesterification is an effective way to reduce the viscosity of the palm oil. Viscosity, flash point and specific gravity of the oil reduced after transesterification. Based on the exhaust emission tests, it can be concluded that bio diesel and EGR both can be employed together in diesel engines with internal jet piston to obtain simultaneous reduction of NOx and smoke emissions. Other emissions such as HC and CO are also found to be decreased. The results of present work are summarized as follows.

1. Methyl ester of palm oil was prepared with lye catalyst NaOH and methanol.

2. Compared with conventional diesel fuel, the exhaust NOx was reduced about 25% at 20 % biodiesel blends with 10% EGR due to less oxygen available in the recirculated exhaust gases which lowers the flame temperature in the combustion chamber.

3. POME blend with 10% EGR, which improves the 4% of brake thermal efficiency and 10 % increase in BSFC due to lower calorific value of the biodiesel.

4. The total unburnt HC and CO emissions were decreased by 5 % and 10 % for 20 % biodiesel blends respectively compared to diesel fuel with EGR and smoke emissions were observed as increases, due to incomplete combustion.

5. Engine operation with biodiesel while employing EGR were able to reduce 25 % NOx, and reduction

in brake thermal efficiency and increase in smoke, CO and HC were observed compared to diesel.

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