COMPENSATION OF VOLUMETRIC EFFICIENCY BY TURBOCHARGING IN AN INSULATED DI DIESEL ENGINE WITH ALCOHOL AS FUEL

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Abstract:

With the stringent emission legislation all over the world an intensive search is going on for diesel fuels which produce more environmental pollution. This simulated interest in alcohol-fueled diesel engines because it is renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce particulate emissions in diesel engines and ethanol diffusion flames produce virtually no soot. But due to alcohols higher latent heat of vaporization, the higher temperatures available in the Insulated engine (IE) are used for vaporizing the alcohols and this decreases the ignition delay and aids combustion. With the higher temperatures in the insulated engines there will be drop in volumetric efficiency and this further increases the frictional horse power due to thinning of lubricant. So the volumetric efficiency drop is to be compensated by turbocharging to improve the thermal efficiency of insulated engine. Hence the present experimental work is planned accordingly.

In the turbocharger the exhaust gases are expended in a turbine which is further coupled to engine. Further the turbine forces more air, proportionately more fuel into the combustion chamber, thereby enhancing the power output without increasing the cylinder capacity. Experiments are carried out in a single cylinder water cooled DI diesel engine with an air gap insulated piston, air-gap insulated liner and ceramic coated cylinder head and valves (Insulated engine) and the reduction in the volumetric efficiency is compensated with turbocharging. The insulated diesel engine with turbocharging gave the better performance and reduced smoke. Further the engine performance is also studied with the raise of intake boost pressure.

Key Words: Alcohols, Insulated engine, Super charging, Turbocharging, Volumetric efficiency

Introduction

In most of the diesel engines maximum amount of heat is lost to the cooling medium. With the lower temperatures in the combustion chambers the alcohols will not burn because of its higher latent heat of vaporization. So, insulated engine was developed with the insulation of the combustion chamber components. With this the heat rejection to the cooling medium is reduced and the same thing can be recovered in the form of useful work by expanding the exhaust gases in lower pressure turbines. Some important advantages of the insulated engines are improved fuel economy, reduced HC and CO emission, reduced noise due to lower rate of pressure rise and higher energy in the exhaust gases [2 & 3]. However, one of the main problems in the insulated engines is the drop in volumetric efficiency. This decrease in the volumetric efficiency is attributed to the decrease in the density of air entering the cylinder because of high wall temperatures of the insulated engine. The degree of degradation of volumetric efficiency depends on the degree of insulation. J.Cheong et al (7) conducted experiments on high speed direct Injection (HSDI) diesel engine and concluded that air mass is increased by 10-20% low speed range. With that smoke was reduced and fuel consumption was improved with the same fuel delivery and injection pressure.

Rakopoulos et al (8) developed a computer analysis for the study of performance of turbocharge diesel engine, operating under transient load conditions and it is validated with experimental results. Naser et al (9) concluded that the reduction was with the reduction of cylinder volume. With the increase of intake pressure the performance gains will be reduced due t decrease in density and this can be compensated with intercooler. He developed a MAT LAB program to find the effect of intercooler on a multi-cylinder engine for operation at constant speed of 1600 rpm. Eyub et al (10) conducted experiments with turbocharger with intercooler and found that the engine power output can be increased by 154% with ideal intercooler while single turbocharger without intercooler can only increase 65%. Also the size of the cylinder can also be reduced to half by means of turbocharging and inter cooling.

Yashvir et. al**., (11)** conducted experiment on LML 125 cc and analyzed parameters like torque, power and specific fuel consumption with turbocharger. It is observed that power and torque of the engine increases from 7 to 11 KW and 9 to 13 NM at 7500 and 9000 RPM respectively. Ghodke et al (12) conducted experiment on turbocharger with intercooler. In the intercooler he reduced the outlet temperature to ambient and also increased the oxygen content in to the engine cylinder which leads to faster burn rates and ability to control exhaust emissions.

Objective

The main objective of this investigation is to experimentally determine effect of turbocharger on volumetric efficiency in an Insulated engine with alcohol as fuel at a reduced fuel injection pressure of 165 bar. The total experiment consists of

(i) Insulated engine components preparation
(ii) Experimental details
(iii) Results
  (a) Investigations with different piston materials – selecting the best piston material
  (b) Investigations with turbocharger on the above best piston material

Insulated Engine Components Preparation

For the development of the Insulated engine (IE) in the present investigations the coating material selected must withstand for higher temperature and should also have sufficient strength. Among all the coating materials searched the partially stabilized Zirconium (PSZ) is found to be quite useful for adiabatic engine application because of its excellent insulating characteristics, adequate strength and thermal expansion characteristics [1, 3]. The insulated engine developed is having an air gap piston and liner, PSZ coated cylinder head and valves. The coating thickness on the components was based on the theoretical analysis and recommendations made by Wong et al [13]. The insulation methodology is explained in detail as follows.

Insulated Air Gap Piston

In this a 2 mm air-gap (whose thermal conductivity is low) is provided between a metallic crown and the standard piston made of Aluminum alloy. This air gap is optimized based on the literature available [1]. The metallic crown and standard piston were separated by copper and steel gaskets. Figure.1 shows the air gap insulated piston with brass insert.

Figure1: An air-gap insulated piston with brass insert

Insulated Cylinder Head and valves

The combustion chamber area of the cylinder head and the bottom surfaces of the valves are machined to a depth of 0.5 mm and are coated with PSZ material for the same depth [3].The details of cylinder head and valves are as shown in the Figure 2.

Figure 2: PSZ coated cylinder head and valves

Insulated Cylinder Liner

A thin mild steel sleeve is circumscribed over the cast iron liner maintaining a 2mm layer of air in the annular space between the liner and the sleeve [2]. The joints of the sleeve are sealed to prevent seepage of cooling water into the air-gap region.

Experimental Details

A stationary, four stroke, 3.68 Kw direct injection Kirloskar water cooled single cylinder diesel engine is used to conduct experiments. If the engine is operated at normal injection pressures the amount of alcohol injected (due to low viscosity) in to the engine will be more and further it may cool the engine due to its higher latent heat of vaporization. So the fuel injection pressure is reduced to 165 bar for the experiment (12). With the high self ignition temperature of alcohol it takes more time for the vaporization. So the injection timing is made advanced to 27^0 bTDC. All the tests are conducted at the rated speed of 1500 rpm. The concentrations of smoke are measured with Bosch smoke meter; Air suction rate and exhaust air flow rates are with an air box method. Temperatures at the inlet and exhaust valves are monitored using Nickel-Nickel Chromium thermocouples. Time taken to consume 20 cc of fuel was noted using a digital stop watch. Engine RPM is measured using an electro-magnetic pick up in conjunction with a digital Indicator of AQUTAH make. The experimental set up used is as shown the following Figure.3.

Figure3. Experimental set up of Insulated Engine Test Rig

From the past literature it is observed that among various losses of heat in the combustion chamber, maximum heat transfer occurs through the piston. So in order to reduce the heat transfer, a piston is designed (similar to that of original piston) which is capable of absorbing heat from the hot combustion gases during the peak cycle temperature conditions and gives out the same to the incoming fresh charge during the suction and compression strokes of the next cycle. This improves the combustion efficiency and further thermal efficiency. So in order to retain the heat in the combustion chamber, to reduce the heat losses from the piston crown to the piston skirt and further to the exhaust a thermal barrier piston crown is designed with brass (BP) due to its lower thermal conductivity.

Further the combustion efficiency can be increased with good turbulence in the combustion chamber. So an attempt is made in this work with nine number of grooves on the brass crown piston in an insulated engine. The size of the groove on the piston crown is selected in such a way that maximum number of grooves can be generated. This brass crown is further knurled to increase its surface area thus facilitating better heat transfer rate from the hot gases to the crown. The photographic views of the following two pistons are as shown in the figures (Fig 4 & 5).

Figure: 4 Photo Graphic of Brass crown piston (BP)

Figure: 5 Photo Graphic View of Brass Crown Piston with 9 grooves (BP9)

These crowns are same in the size of the original piston and can be adapted without any major modifications to the original design. In the present work investigations are carried out on brass crown piston (BP) and brass crown piston with nine grooves (BP9) in order to find the best one at which the insulated engine gives maximum performance and the same is compared with aluminum piston.

Investigative results with Brass piston in an Insulated engine

Initially the tests are performed at a constant speed of 1500 rpm in a normal engine at a constant injection timing (29^0 bTDC), the fuel flow rate and the load is varied. For all the operating conditions, the cooling water and lubricating oil temperatures are maintained constant throughout the experiment. For the insulated engine, due to higher operating temperatures and further lower ignition delays with insulation in the combustion chamber, the injection timing of 27 ^{0}bTDC is found to give the optimum performance. The above tests are repeated in the insulated engine with alcohol as fuel.

In the first stage the engine is run with aluminum piston. Then the same is run with brass piston and brass piston with nine grooves. This is for finding the best one at which the volumetric efficiency drop is more due to higher temperatures in the combustion chambers. The results obtained are presented in the following graph.

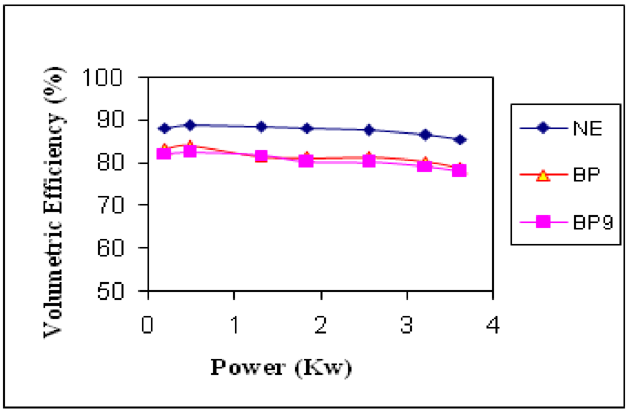

Exhibit 1: Comparison of Volumetric Efficiency with Power output

The effect of brass piston with different configurations on the volumetric efficiency in the insulated engine depicts in Exhibit 1. Due to higher operating temperatures, with insulated components, the intake air is heated to a higher temperature and consequently the mass of air drawn in each cycle is lower, resulting in a decrease in volumetric efficiency. For BP9 of the insulated engine the drop in volumetric efficiency is more and is about 1.2% as compared to BP and about 9.5% compared to normal engine at rated load.

So the drop in power output of an insulated engine can be compensated by turbocharging. Further the investigations are carried out with brass piston with nine grooves at which the volumetric efficiency is low due to higher operating temperatures with turbocharging equipment.

Investigative results of Brass piston with nine grooves (BP9) in an Insulated engine with turbocharging equipment

Generally the Turbochargers used are of forced induction type. They compress the air flowing into the engine so that the engine squeeze more air into the cylinder, and further more fuel can be added. Therefore, we get more power from the engine than the same engine without the charging. This improves the power to-weight ratio for the engine. In order to achieve this boost, the turbocharger uses the exhaust flow from the engine to spin a turbine, which in turn spins an air pump. Since it will be connected to the exhaust, the temperatures in the turbines are also very high. For the present investigations to pressurize the inlet air, internally powered turbocharging equipment with closed loop lubrication is fabricated. The schematic diagram of the turbocharging equipment is shown in Fig: 6. In the turbocharging the high temperature exhaust gases are expanded in a low pressure turbine for the power generation and this is further coupled to motor of the compressor [4, 5]. This compressor compresses the inlet air and supplies to the engine at slightly higher pressure. By controlling the inlet air, the engine is turbocharged at different inlet pressures.

In the present investigations the turbocharging equipment is connected to the insulated engine exhaust. The insulated engine is further run with brass piston with nine number of grooves (BP9) at various boost pressures. The results are summarized below.

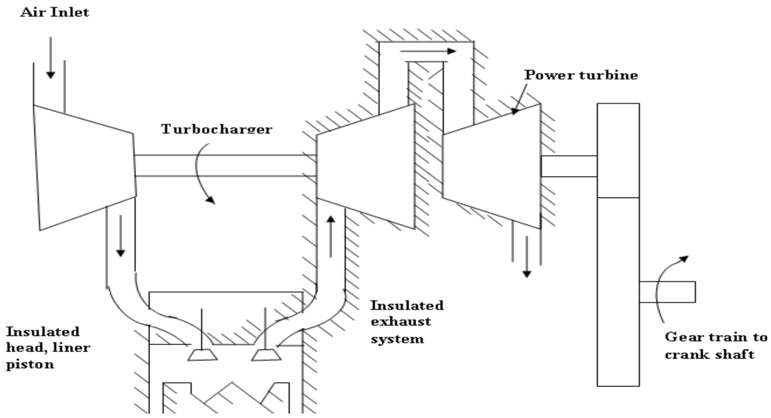

Figure 6. Turbocharged Insulated Diesel Engine

Effect of Turbocharging on the Volumetric Efficiency

The variation of volumetric efficiency with power output with intake boost pressure is shown in exhibit: 2. As the boost pressure is increased, more air is available for the combustion which further increases the combustion efficiency. At higher boost pressures excess air doesn't improve the combustion efficiency [12]. So the optimum boost pressure is 790 mm of Hg at which the drop in volumetric efficiency is compensated with turbocharger. The intersection points of the volumetric efficiency curves of turbocharger and the normal engine gives the inlet pressure of the turbocharger at which the volumetric efficiency drop is compensated. Because of the increase

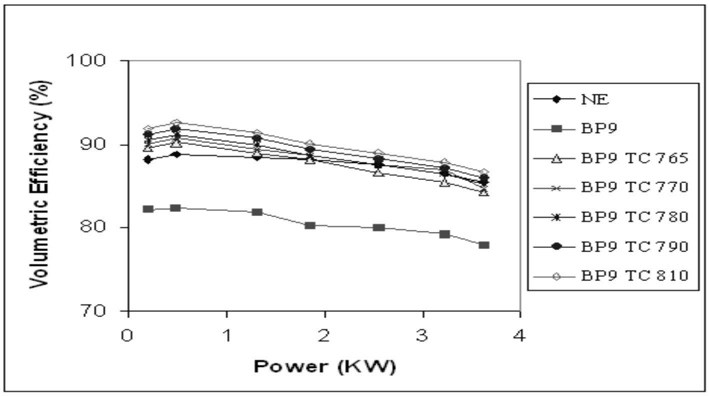

Exhibit 2 Variation of Volumetric Efficiency to power with Turbocharging

back pressure with turbocharging conditions, the inlet boost pressures are higher for compensating the volumetric efficiency drop in normal engine. It requires nearly 4% of intake boost pressure under turbocharging conditions for compensating the maximum efficiency drop of 10% in the normal engine. With the turbocharging the volumetric efficiency is compensated. The percentage of boost pressure required for the volumetric efficiency compensation is shown in the following exhibit.3.

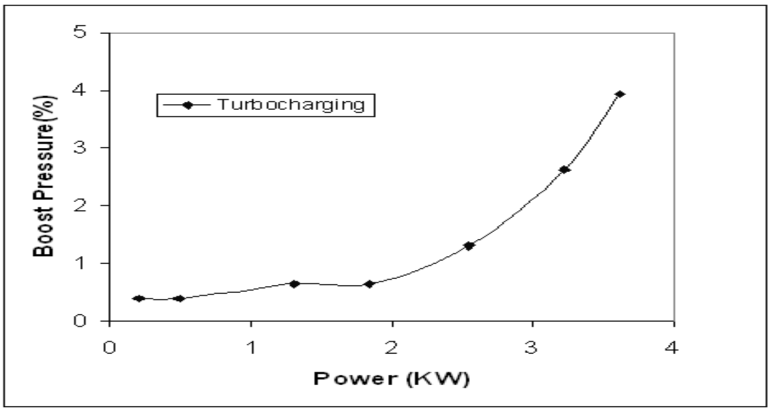

Exhibit 3. Comparison of Percentage of Boost Pressure Required for Volumetric Compensation with Power Output in Turbocharging

Brake Thermal Efficiency

The exhibit 3 shows the variation of brake thermal efficiency with power output for turbocharged condition. When the engine is turbocharged thermal efficiency is improved continuously with load. The maximum improvement is about 4.3% over insulated engine.

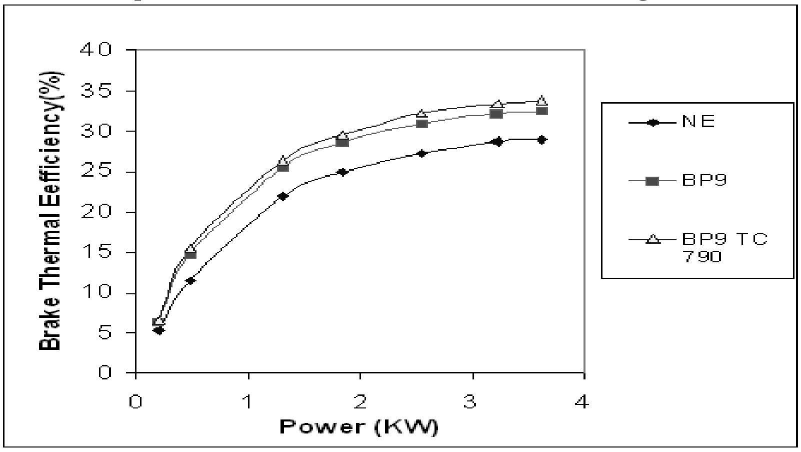

Exhibit 4. Comparison of Brake thermal Efficiency with Power Output for Volumetric Efficiency Compensation with Turbocharging

The improvement in thermal efficiency under turbocharging conditions is marginal due to following reasons:

(a) In the present work inlet boost pressures in turbocharging are moderate, because they were selected on the basis of volumetric efficiency compensation. At higher pressures still higher thermal efficiency could be obtained.
(b) Higher frictional losses due to increase in gas pressures.
(c) The engine had stability problem at higher intake pressures.

Combustion Parameters

In general due to less air availability in the combustion chamber the combustion will not be complete. But with the turbocharging more air will be available for the combustion and this will change the combustion parameters. The variations in the combustion parameters are shown below.

Peak Pressure

The peak pressure variation of turbocharging with power output is shown in exhibit 5. The peak

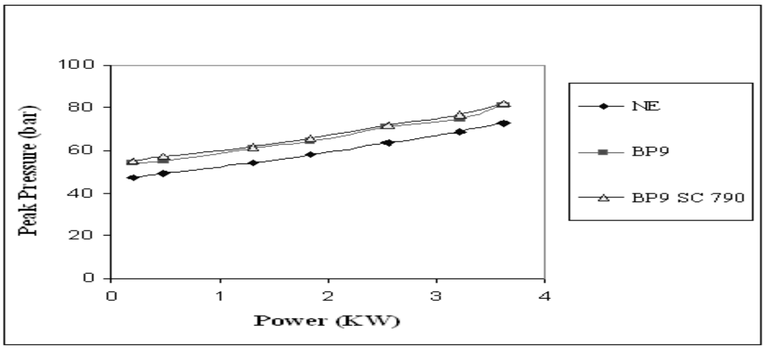

Exhibit 5 Comparison of Peak Pressure with Power Output for Volumetric Efficiency Compensation with Turbocharging

pressures of normal engine, Insulated engine and turbocharged Insulated engines are compared in the same figure. It is observed that the peak pressures are higher with turbocharged engine and is about 82 bar at the rated load. This is due to the complete combustion in the chamber.

Ignition Delay

The variation of ignition delay with power output for turbocharging conditions is shown in exhibit 6. With the turbocharging more amount of air enters into the combustion chamber which increases the combustion process and reduces the ignition delay. But at higher loads due to the high latent heat of alcohol, the ignition delay is slightly increased [6]. It is concluded that there is

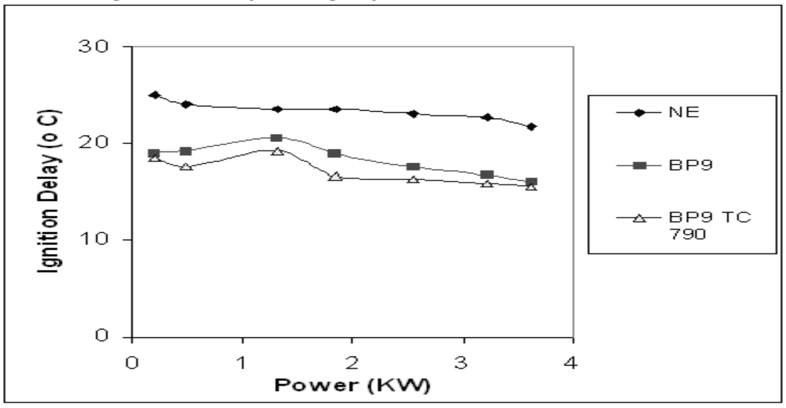

Exhibit 6. Comparison of Ignition Delay with Power Output for Volumetric Efficiency Compensation with Turbocharging

a reduction of 6.2^0 CA for the turbocharged insulated engine compared to normal engine at rated load. So it will be beneficial to increase the turbocharging pressures in order to have a shorter ignition delays.

Exhaust Temperature

The increase in the exhaust temperatures are 20^0C to 50^0C with turbocharging compared to without charging. This is due to the increase of mass flow rate of air, reduction in the ignition

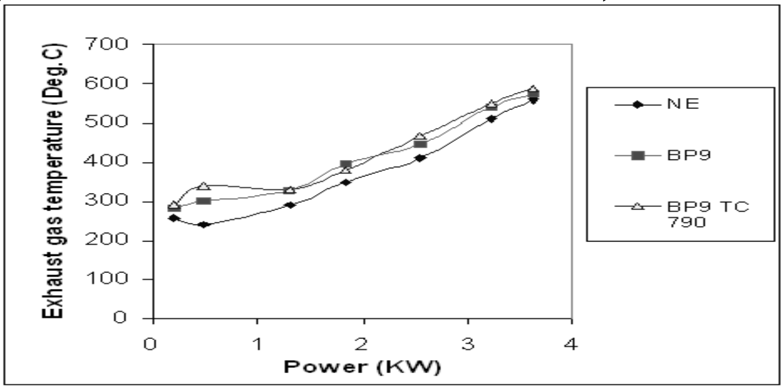

Exhibit 7 Comparison of Exhaust Gas Temperature with Power Output for Volumetric Efficiency Compensation with Turbocharging

delay and hotter combustion chamber which further increases the combustion process. Exhibit 7 shows the variation of exhaust temperatures with power output.

Smoke Number

Exhibit.8 shows the variation of exhaust smoke number with power output for turbocharging condition. It is concluded from the graph that there is a significant reduction in smoke level in turbocharged engine compared to normal engine at rated load condition due to complete combustion. As alcohol is bio based and is having rich in oxygen, literally it produced no soot.

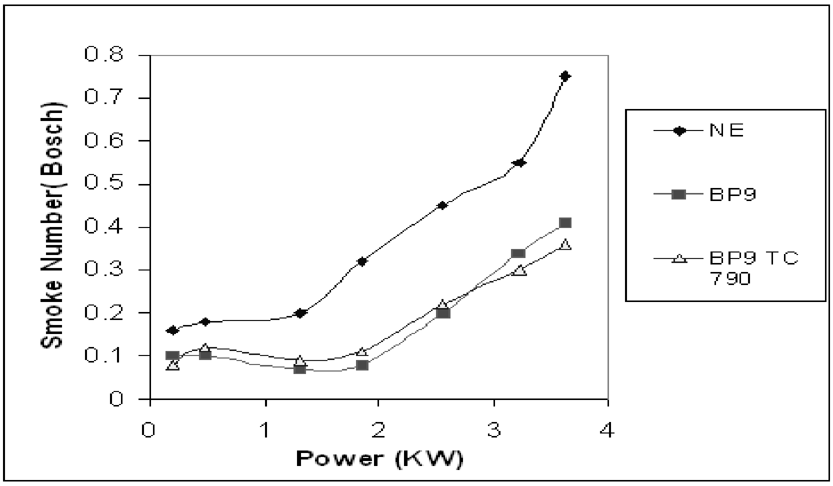

Exhibit 8 Comparison of Smoke Emissions with Power Output for Volumetric Efficiency Compensation with Turbocharging

Conclusions

The following conclusions are drawn based on the experimental investigations on an insulated diesel engine under turbocharging conditions:

1. The increase in the intake boost pressure improves the brake thermal efficiency of the engine.
2. For the compensation of drop in volumetric efficiency of the insulated engine 4% intake boost pressure is required for turbocharging.
3. Though the higher temperatures are available in the combustion chamber due to insulation, the increase in exhaust gas temperature is marginal. This is attributed to the higher latent heat of vaporization of alcohol.
4. As the alcohol contains oxygen and more air is available in the turbocharging for combustion, the ignition delay is reduced.
5. Due to the complete combustion of alcohol at higher temperatures the smoke emissions are also marginal.

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