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Computational Simulation of Fuel Nozzle Multi Holes Geometries Effect on Direct Injection Diesel Engine Performance Using GT-POWER

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Abstract: The computational model simulation development is use the commercial computational fluid dynamics of GT-POWER 6.2 software were specially development for internal combustion engines performance simulation. The research concentrated on one dimensional model and focuses on fuel nozzles multi holes geometries variation developed from all of the engine components size measurement of the original selected diesel engine. All of the measurements data input to the window engines component menu for running input data in the model. Results of the diesel engine fuel nozzles multi holes geometries model simulation running is in GT-POST. The model performance shows in engine cylinder and engine crank-train on software window output. The performance analysis effect of the model investigated of fuel in-cylinder engine, indicated specific fuel consumption, indicated torque and indicated power of engine modeled. The simulation result was shows that the seven holes nozzle provided the best burning for fuel in-cylinder burned and the five holes nozzle provided the best for indicted power, indicated torque and indicated specific fuel consumption in any different engine speed in simulation.

Keywords: Computational simulation, diesel engine performance, fuel nozzle multi holes

INTRODUCTION

A four-stroke direct-injection diesel engine typical measured and modeled by Bakar[12] using GT-POWER computational model and explored of single-cylinder diesel engine performance effect based on engine rpm. GT-POWER is the leading engine simulation tool used by engine and vehicle makers and suppliers and is suitable for analysis of a wide range of engine issues[2]. The details of the diesel engine design vary significantly over the engine performance and size range. In particular, different combustion chamber geometries and fuel injection characteristics are required to deal effectively with major diesel engine design problem achieving sufficiently rapid fuel-air mixing rates to complete the fuel-burning process in the time available[15-23]. A wide variety of inlet port geometries, cylinder head and piston shapes, and fuel-injection patterns used to accomplish this over the diesel size range[1, 10]. The engine ratings usually indicate the highest power at which manufacturer expect their products to give satisfactory of power, economy, reliability and durability under service conditions. The importance of the diesel engine performance parameters are geometrical properties, the term of efficiency and other related engine performance parameters. The engine efficiencies are indicated thermal efficiency, brake thermal efficiency, mechanical efficiency, volumetric efficiency and relative efficiency[10]. The other related engine performance parameters are mean effective pressure, mean piston speed, specific power output, specific fuel consumption, intake valve mach index, fuel-air or air-fuel ratio and calorific value of the fuel[1, 10, 12]. According to Heywood[1], in the diesel engine geometries design written that diesel engine compression ratio is maximum cylinder volume or the displaced volume or swept and clearance volume divided by minimum cylinder volume. The power delivered by the diesel engine and absorbed by the dynamometer is the product of torque and angular speed.

This research investigated the performance effect of fuel nozzle holes material geometries on the engine indicated power, indicated torque, fuel consumption and fuel in-engine cylinder.

Diesel engine compression ratio is maximum cylinder volume or the displaced volume or swept (V_d)

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and clearance volume (V_c) divided by minimum cylinder volume (V_c). The diesel engine compression ratio:

$$r_c = \frac{V_d + V_c}{V_c} \tag{1}$$

The power delivered by the diesel engine and absorbed by the dynamometer is the product of torque and angular speed. Diesel engine power definition as :

$$P = 2\pi NT \tag{2}$$

In the engine efficiencies, every its efficiencies were defined[1, 8, 9, 10]. Indicated thermal efficiency (η_{ith}) is the ratio of energy (E) in the indicated power (ip) to the input fuel energy. Brake thermal efficiency (η_{bth}) is the ratio of energy in the brake power (bp), Mechanical efficiency (η_m) is defined as the ratio of brake power (bp) or delivered power to the indicated power (ip) or power provided to the piston and it can also be defined as the ratio of the brake thermal efficiency to the indicated thermal efficiency. Relative efficiency or efficiency ratio (η_{rel}) is the ratio of thermal efficiency of an actual cycle to that of the ideal cycle, the efficiency ratio is a very useful criteria which indicates the degree of development of the engine. The one of the very important parameters, which decides the performance of four-stroke engine volumetric efficiency (η_v), where four-stroke engines have distinct suction stroke and therefore the volumetric efficiency indicates the breathing ability of the engine. The volumetric efficiency defined as the volume flow rate of air into the intake system divided by the rate at which the volume displaced by the system. The normal range of volumetric efficiency at full throttle for SI engines is 80%-85% and for CI engines is 85%-90%.

Other related engine performances defined [1, 8, 9, 10]. Mean effective pressure (mep) where n_R is the number of crank revolutions for each power stroke per cylinder (two for four-stroke, one for two-stroke cycles) as:

$$mep = \frac{Pn_R}{V_d N} \tag{3}$$

The measure of an engine's efficiency which will be called the fuel conversion efficiency is given by[1]:

$$nf = \frac{W_c}{m_f Q_{HV}} = \frac{(Pn_R / N)}{(m_f n_R / N) Q_{HV}} = \frac{P}{m_f Q_{HV}} \tag{4}$$

Specific fuel consumption as :

$$sfc = \frac{m_f}{P} \tag{5}$$

In engine testing, both the air mass flow rate m_a and the fuel mass flow rate m_f are normally measured. The ratio of these flow rates is useful in defining engine operating conditions are air/fuel ratio (A/F) and fuel/air ratio (F/A).

MATERIALS AND METHODS

The development of single cylinder modeling and simulation for four-stroke direct-injection (DI) diesel engine presented in this paper. The specification of the selected diesel engine shows in Table 1.

Table 1: Specification of the selected diesel engine

Engine Parameters	**Value**
Bore (mm)	86.0
Stroke (mm)	70.0
Displacement (cc)	407.0
Number of cylinder	1
Connecting rod length (mm)	118.1
Piston pin offset (mm)	1.00
Intake valve open (^{0}CA)	395
Intake valve close (^{0}CA)	530
Exhaust valve open (^{0}CA)	147
Exhaust valve close (^{0}CA)	282
Maximum intake valve open (mm)	7.095
Maximum exhaust valve open (mm)	7.095
Valve lift periodicity (deg)	360
Fuel nozzle diameter (mm)	0.1
Fuel nozzle hole number (pc)	4

To develop the GT-POWER of single-cylinder four-stroke direct-injection diesel engine modeling is step by step, the first step is open all of the selected diesel engine components to measure the engine components part size. Then, the engine components size data will be input to the GT-POWER library of the all engine components data. To create the GT-POWER model, select Window and then Tile with Template Library from the menu. This will place the GT-POWER template library on the left hand side of the screen. The template library contains all of the available templates in GT-POWER. Some of these templates those that needed in the project need to copied into the project before used to create objects and parts. For the purpose of this model, click on the icons listed and drag them from the template library into the project library. Some of these are templates and some are objects that already been defined and included in the GT-POWER template library[2] . This research focuses on fuel nozzle hole of fuel injector and the engine modeling is according to Bakar[12] shows in Fig. 1.

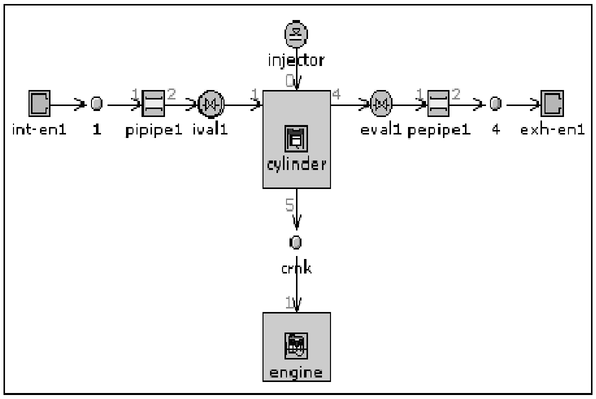

Fig. 1: Single-cylinder diesel engine modeling

All of the parameters in the model listed automatically in the case setup and each one must define for first case of the simulation. The physically of the fuel nozzle hole material detailed were did in the research is shown in Fig. 2. In this figure shows the detail of injection hole or fuel nozzle hole. The fuel nozzle holes changed in wide of diameter hole and in different number.

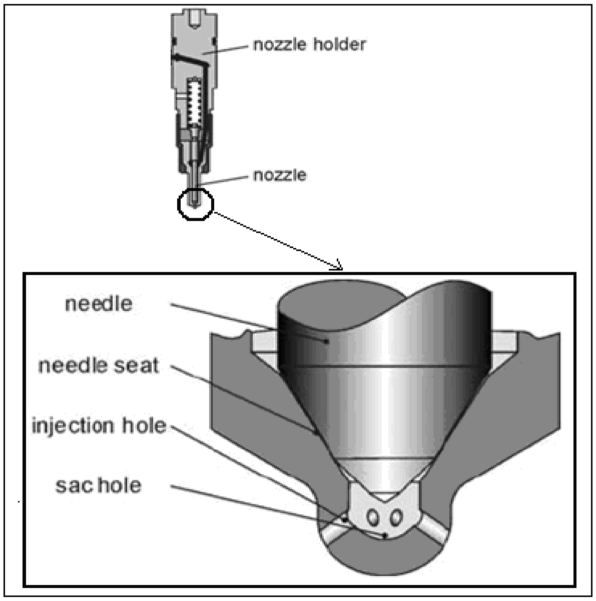

Fig. 2: Detail of fuel nozzle holes

Whenever a simulation run, GT-SUITE produces several output files that contain simulation results in various formats. Most of the output is available in the post-processing application GT-POST. GT-POST is powerful tool that used to view animation and order analysis output[2]. After the simulation was finished, report tables that summarize the simulations produced. These reports contain important information about the simulation and simulation result in a tabular form. The computational simulation of the engine model result is informed the engine performance. The running simulation result in this research is focuses on the engine performance data based on variation of fuel nozzles holes diameter size, diameter number and the different engine speed (rpm). The diesel engine model was running on any different engine speeds in rpm, there are 500, 1000, 1500, 2000, 2500, 3000 and 3500. The variations of fuel nozzle material holes number are multi holes and several number holes, the simulation model there are start from the current fuel nozzle 4 holes as a original holes, 5 holes, 6 holes and 7 holes on the same of total fuel nozzle holes area.

RESULTS AND DISCUSSION

Nozzle Hole Effect in Engine Cylinder Liquid Fuel

The simulation result in every case, case 1 is on 500 rpm until case 8 on 4000 rpm. Numerous studies have suggested that decreasing the injector nozzles orifice diameter is an effective method of increasing fuel air mixing during injection. Smaller nozzle holes found to be the most efficient at fuel/air mixing primarily because the fuel rich core of the jet is smaller. In addition, decreasing the nozzle hole orifice diameter, would reduce the length of the potential core region.

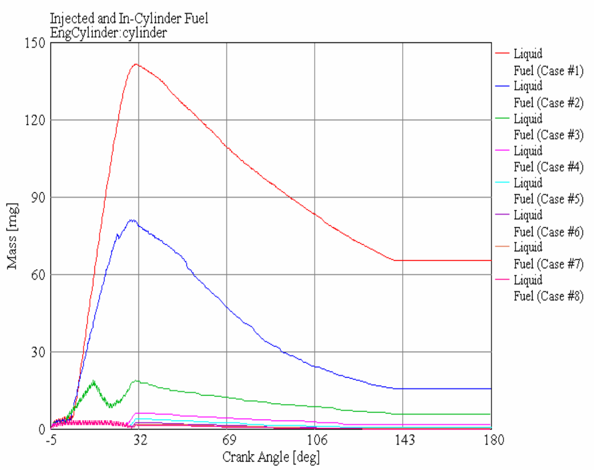

Fig. 3: In-cylinder liquid fuel of nozzle 4 holes

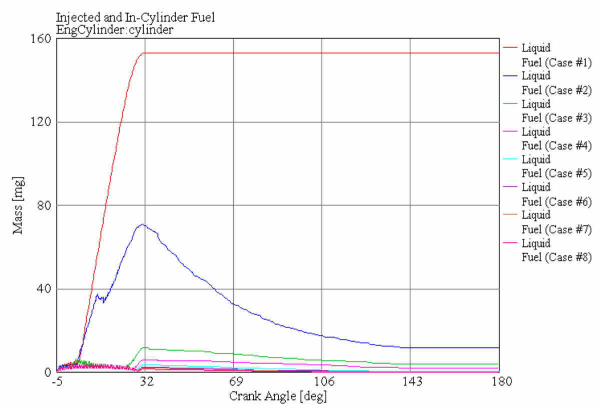

Fig. 4: In-cylinder liquid fuel of nozzle 5 holes

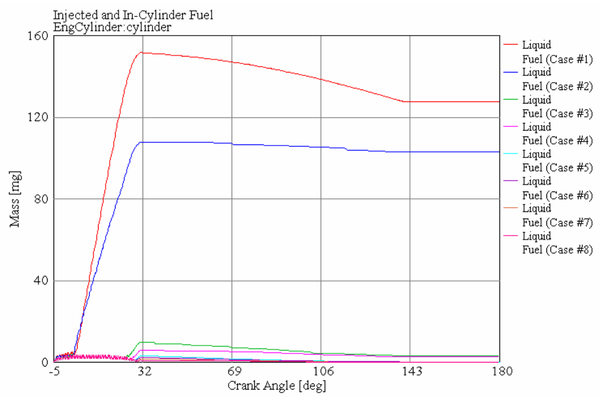

Fig. 5: In-cylinder liquid fuel of nozzle 6 holes

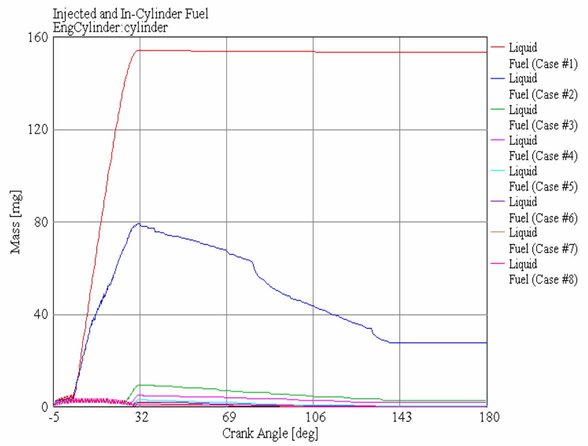

Fig. 6: In-cylinder liquid fuel of nozzle 7 holes

Unfortunately, decreasing nozzle holes size causes a reduction in the turbulent energy generated by the jet. Since fuel air mixing controlled by turbulence generated at the jet boundary layer, this will offset the benefits of the reduced jet core size. Furthermore, jets emerging from smaller nozzle orifices were shows not to penetrate as far as those emerging from larger orifices. This decrease in penetration means that the fuel will not exposed to all of the available air in the chamber. For excessively small nozzle size, the improvements in mixing related to decreased plume size may negated by a reduction in radial penetration. This behavior is undesirable because it restricts penetration to the chamber extremities where a large portion of the air mass resides. Furthermore, it hampers air entrainment from the head side of the plume because the exposed surface area of the plume reduced. It has suggested that a nozzle containing many small holes would provide better mixing than a nozzle consisting of a single large hole. The performance effect of fuel nozzle holes number and geometries of in-cylinder engine liquid fuel shows in Fig. 3 – Fig. 6.

The optimal nozzle design would be one that provided the maximum number of liquid fuel burn in combustion process and minimum number of liquid fuel unburned. Theoretically, the seven holes nozzle satisfies this requirement. Unfortunately, jets emerging from the seven holes nozzle tended to be very susceptible. All of the nozzles examined and the result shown that the seven holes nozzle provided the best results for any different engine speed in simulation and the best performance shows on low speed engine.

Nozzle Hole Effect in Indicated Power, Indicated Torque and ISFC Engine

The simulation result of engine performance effect of fuel nozzle holes number and geometries in indicated power, indicated torque and ISFC of engine shows in Fig. 7 – Fig. 9. The fuel nozzle holes orifice diameter and nozzle holes numbers effect in indicated power, indicated torque and ISFC performance of direct-injection diesel engine shows from the simulation model running output. An aerodynamic interaction and turbulence seem to have competing effects on spray breakup as the fuel nozzle holes orifice diameter decreases. The fuel drop size decreases if the fuel nozzle holes orifice diameter is decreases with a decreasing quantitative effect for a given set of jet conditions. Fuel-air mixing increases as the fuel nozzle holes orifice diameter of fuel nozzle holes decreases. Also soot incandescence is observed to decrease as the amount of fuel-air premixing upstream of the lift-off length increases. This can be a significant advantage for small orifice nozzles hole. However, multiple holes orifices diameter required to meet the desired mass flow rate as orifice diameter decreases. In this case, the orifices diameter need to placed with appropriate spacing and directions in order to avoid interference among adjacent sprays. The empirical correlations generally predict smaller drop size, slower penetrating speed and smaller spray cone angles as the orifice diameter decreases, however the predicted values were different for different relation. All of the nozzles examined and result shows that the five holes nozzle provided the best results for indicted power, indicated torque and indicated specific fuel consumption in any different engine speed in simulation.

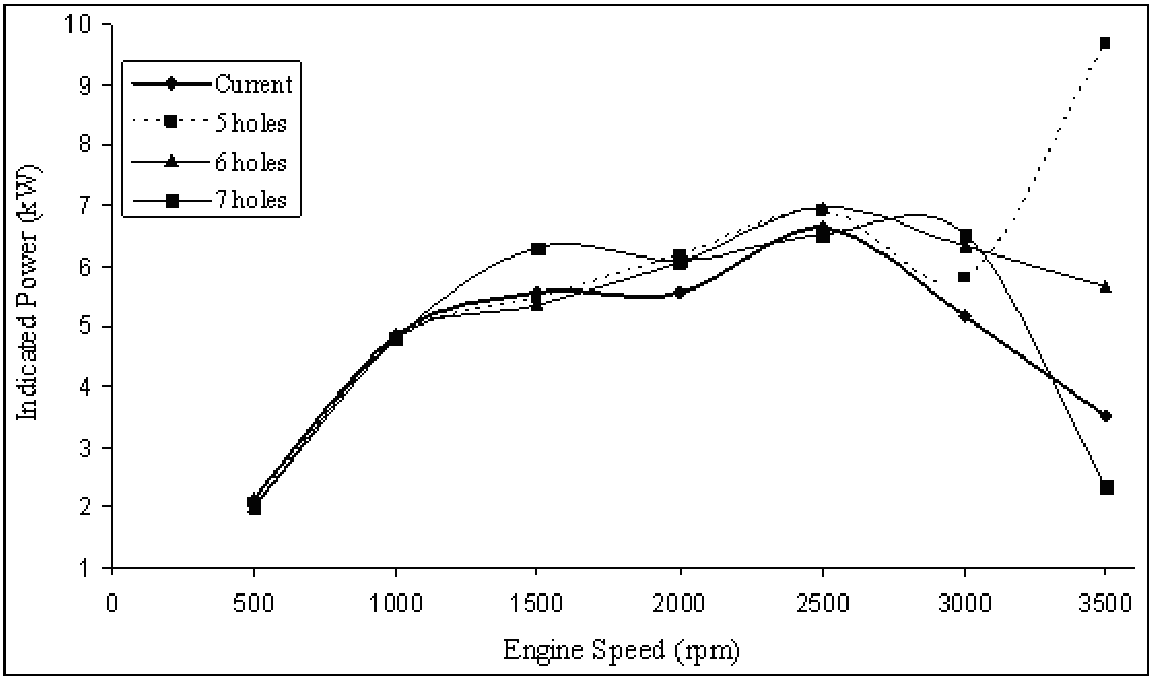

Fig. 7: Indicated power effect of fuel nozzle holes number

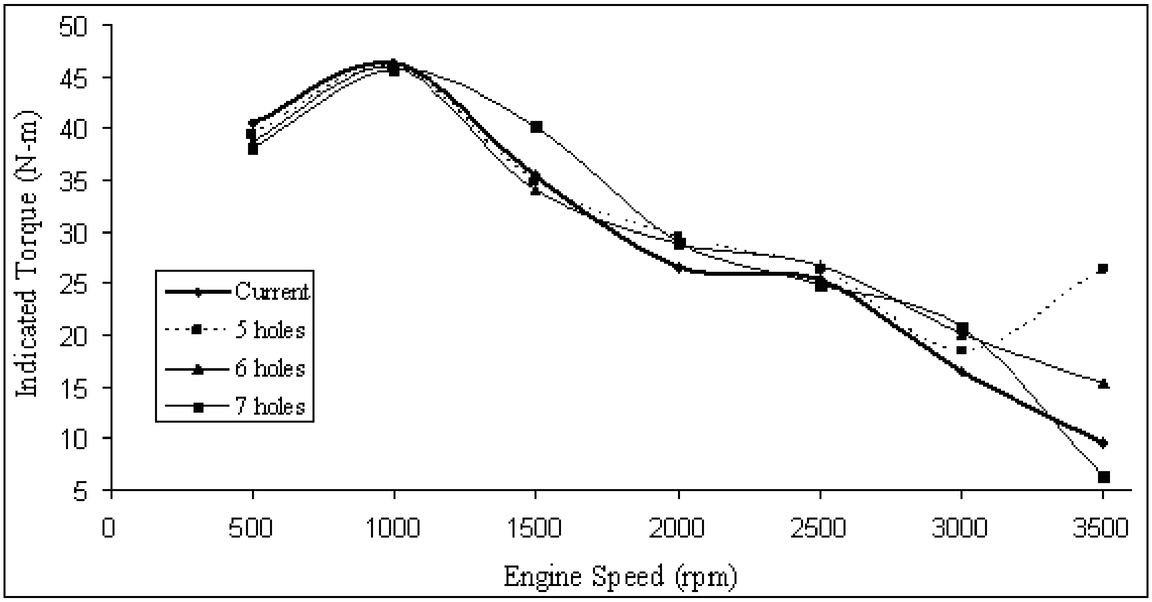

Fig. 8: Indicated torque effect of fuel nozzle holes number

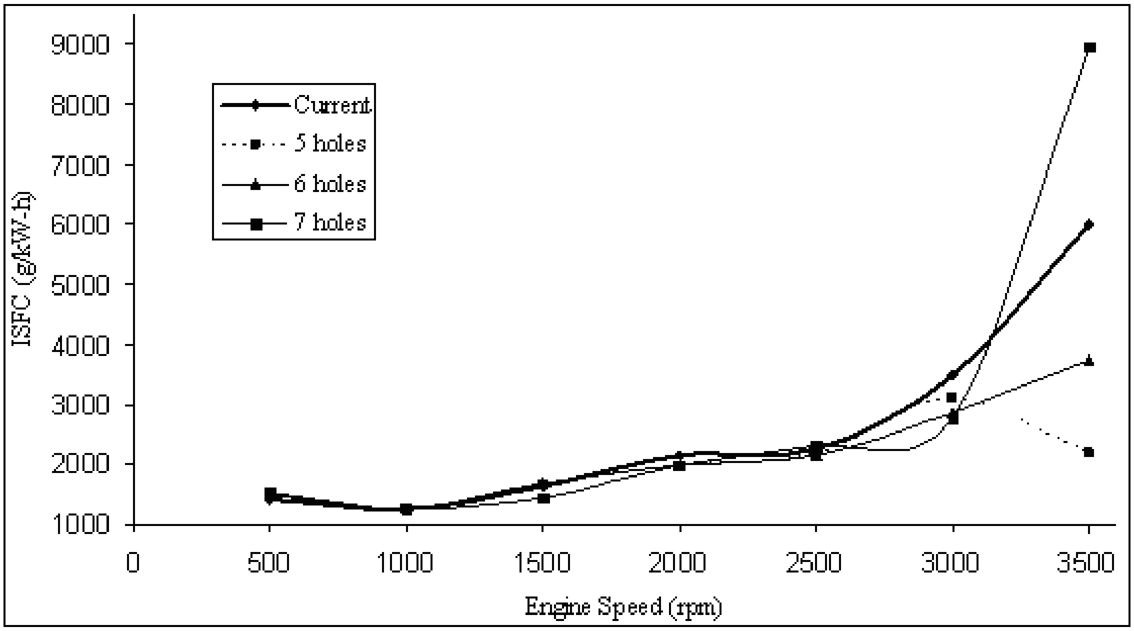

Fig. 9: Indicated specific fuel consumption effect of fuel nozzle holes number

CONCLUSION

All of the nozzles examined and the result shows that the seven holes nozzle provided the best burning results for fuel in-cylinder burned in any different engine speed in simulation and the best burning is in low speed engine. In engine performance effect, all of the nozzles examined and the five holes nozzle provided the best results for indicted power, indicated torque and indicated specific fuel consumption in any different engine speed in simulation.

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