Experimental investigation on NOx and smoke emission from CRDI diesel engine operated with biodiesel blend varying dwell between main and pre injection

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Abstract

Reducing NOx and smoke simultaneously from diesel engine is a big challenge being faced by the researchers in automotive field. Biodiesel produced from non-edible cotton seed oil is found to be a promising eco-friendly renewable alternative fuel to petro-diesel. Cotton seed oil biodiesel is produced using transesterification process and characterized for its properties. The blend B20, which is most accepted and does not need any modifications of the engine, is used as fuel. Formation of NOx is very much dependent on the peak temperature in the combustion chamber. The researchers are trying with different techniques for reducing NOx, like dilution using EGR, injection of water, retardation of injection timing etc. With the development of CRDI systems split and multiple injection strategy attracting the attention of researchers as a promising technique in reducing the NOx emissions. In this work, an attempt is made to study the effect of dwell between pilot and main injection in a multiple injection strategy of Pilot-Main-Post injection while retarding main injection. In this multiple injection strategy of three injection pulses the pilot fuel quantity is fixed as 10% of total fuel injected, post injection fuel quantity is fixed as 0.5 mg. The dwell between pilot and main was varied at different main injection timing. The post injection is closely coupled with main injection with a dwell of 3 CAD. The main injection timing along with pilot and post was retarded from the recommended 23o bTDC in steps of 3 degrees. At all main injection timing the dwell of 10 CAD observed to be the best for smoke reduction, whereas 20 CAD is better for NOx reduction. In overall Dwell 10 CAD is better for tradeoff between NOx and Smoke.

Keywords: *Biodiesel blend, Dwell, Pilot injection, Post injection, Transesterification*

1. Introduction

Depletion of fossil fuels due to heavy usage of fossil fuels like gasoline and diesel to meet ever growing energy demand world over became a prime concern of the world at the moment. In addition the environmental degradation caused by the harmful pollutants emitted.

by burning of petroleum fuels is also haunting the world. With the growth of the population, the usage of Diesel has been increasing in transportation and industrial applications to meet the energy requirements causing the release of tons and tons of dangerous pollutants adding to the atmospheric air. These emissions are the main reasons for the consequences like global warming, acid rains and various ailments of human beings. In an effort to minimize the damage caused to the environment, the global world over imposed a stringent regulations on the emissions from usage of petroleum fuels and other fossil fuels. Complying with stringer environmental regulations became a big challenge for industries, automobile manufactures and the researchers in the field. Different ways and means are being explored to conserve the conventional fuel resources, reduce the dependence on petroleum fuels and reduce the environmental degradation.

One way is to look for biobased alternative fuels like biodiesel, bio-ethanol etc., which are renewable, eco-friendly and home grown. It gives the solution to the problems like depletion of petroleum resources, environmental damage and dependence on oil importation. Another way which is tried with is improvement of combustion process by improving the design of combustion chamber, modifying the fuel injection system etc., which improves the fuel economy, efficiency of combustion process, reduces the greenhouse gases and other harmful emissions.

Vegetable oils, having features of renewability, biodegradability, eco-friendly etc., are promising replacement for conventional petroleum diesel. Higher viscosity is the major drawback of straight vegetable oils which hinder its usage directly in unmodified diesel engines. Direct usage of straight vegetable oils may cause deposits in combustion chamber and damages the engine. Transesterification process is the well-established procedure which can be used to produce biodiesel by bringing down the viscosity. Tri-glycerids present in vegetable oil get converted into mono alkyl esters of long chain fatty acids (Biodiesel) when vegetable oil reacts with alcohol in the presence of catalyst. Glycerine comes out as a byproduct (Pankaj et al., 2016).

Therefore, explorations to find Biodiesel are one of the most promising alternative fuels to replace or to reduce dependency on the conventional petroleum-based fuels with multiple environmental advantages and application in compression ignition (CI) engines with no modification. Biodiesel is nonexclusive, biodegradable, non flammable, renewable, nontoxic, environment friendly, and similar to diesel fuel (Yanuandri et al., 2013). The main advantages of biodiesel include the following: it can be blended with diesel fuel at any proportion; it can be used in a CI engine with no modification; it does not contain any harmful substances; and it produces less harmful emissions to the environment than diesel fuel. Biodiesel, popularized as the mono alkyl esters are derived from triglycerides (vegetable oils or animal fats). Transesterification is the most convenient process to convert triglycerides to biodiesel. Transesterification process involves a reaction of the triglyceride feedstock with light alcohol in the presence of a catalyst to yield a mixture of mono alkyl esters currently, using hydroxides of sodium or potassium, is the common route for industrial production of biodiesel **(**Atabani et al., 2013).

The minimization of fuel consumption and the reduction of emissions have been two driving forces for engine development throughout the last decades. The first objective is in the financial interest of the vehicle owners. The second is imposed by legislation, sometimes also supported by excise reductions or customers' demands for clean engines.

The ongoing emission of NOx is a serious persistent environmental problem due to; it plays an important role in the atmospheric ozone destruction and global warming (Pushparaj et al., 2013). NOx is one of the most important precursors to the photochemical smog. Component of smog irritate eyes and throat, stir up asthmatic attacks, decrease visibility and damages plants and materials as well. By dissolving with water vapor NOx form acid rain which has direct and indirect effects both on human and plants. An SCR (Selective Catalytic Reduction) exhaust gas after treatment system which uses urea solution as a reducing agent has a high NOx reduction potential and is a well-known technique for stationary applications (Busca et al., 1998). The idea of using urea SCR systems for the reduction of NOx emissions in diesel engines is two decades old. Since then, many applications have been developed, some of which have reached commercialization (Bosch et al., 1988). But, it is still a challenge for researchers.

With the recent development of common rail direct injection system, it became possible to reduce NOx and other emissions by adopting multiple injection strategy (Imarisio et al., 2000; Badami et al., 2002).

Split fuel injection involves reducing splitting the injection as two or more events which can lead to a reduction in the ignition delay in the initial fuel pulse. This leads greater fraction of combustion to occur later in the expansion stroke. As majority of NOx occurs during premixed stage, the net amount of NOx formed during the split fuel injection is lowered (Gao et al., 2001). Multiple injections method is found to be very effective at reducing particulate emissions at high load, and combined technique of multiple injections with EGR is effective at intermediate and light loads. However, increased particulate emissions due to EGR causes increased engine wear due to degradation of lubricant. Increased Brake Specific Fuel Consumption (BSFC) is another concern. Split injection up to 5 splits, are experimented (Wang et al., 2007) in combination with EGR. In this work B20 was used as fuel, since B20 is mostly accepted and does not need modifications of the engine.

2. Methodology

This work is done with the main objective of investigating the effect of multiple injection strategy with varying injection timing and dwell period on harmful emissions from CRDI diesel engine fueled with biodiesel blend. The dwell is varied from 10 CAD to 20 CAD in three steps. Cotton seed oil is used for the preparation of biodiesel. Biodiesel is prepared using transesterification process.

A novel scheme of experiments is adopted in the work to understand the influence of multiple injections by varying different parameters on the emissions from the engine.

The used injection strategy is pilot (pre)-main-post. The pilot is fixed at 10% and post fuel quantity is fixed as 0.5 mg/cycle.

The following were the steps followed in this work:

- Extraction of oil from cotton seeds using mechanical press
- Preparation of biodiesel using tranesterification process.
- Characterisation of biodiesel
- Preparation of B20 blend
- Testing the performance of CRDI diesel engine with B20 with multiple injection strategy varying injection timing
- Comparing the emissions from multiple injection and single injection

Figure1. Cotton seed oil, Biodiesel, B20, Diesel

Engine setup

The setup consists of single cylinder, four stroke, CRDI VCR (Variable Compression Ratio) engine connected to eddy current dynamometer. Specification of the CRDI Engine is given in Table 1. It is provided with necessary instruments for combustion pressure, crankangle, airflow, fuel flow, temperatures and load measurements. These signals are interfaced to computer through high speed data acquisition device.

The setup has stand-alone panel box consisting of air box, twin fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and piezo powering unit.

Rotameter are provided for engine cooling water flow measurement. CRDI VCR engine works with programmable Open ECU for Diesel injection, fuel injector, common rail with rail pressure sensor and pressure regulating valve, crank position sensor, fuel pump and wiring harness.

The setup enables study of CRDI VCR engine performance with programmable ECU at different compression ratios and with different EGR. Engine performance study includes brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, Air fuel ratio, heat balance and combustion analysis.

Table 1. Specification of the CRDI Engine

Engine	**Kirloskar, single cylinder, four stroke water cooled, VCR**
Stroke	110 mm
Bore	87.5 mm
Capacity	661 cc
Power	3.5 kW
Speed	1500 RPM
Compression Ratio	12-18
Injection system	Common rail direct injection with open ECU
Injection pressure	300 bar
Dynamometer	Eddy current dynamometer
Dynamometer arm length	185 mm

A novel scheme of experiments is adopted in the work to understand the influence of multiple injections by varying different parameters on the emissions from the engine.

The injection is split into pilot (pre)-main-post. After different trials the quantity of Pilot injection is fixed as 10% and post fuel quantity is fixed as 0.5 mg/cycle. The dwell between main and pilot is maintained as 10 degrees. Closely coupled post injection is used with 3 degrees after main injection. Main injection timing is retarded from recommended injection timing of 23^{o} to 11^{o} bTDC. The influence of this retardation on NOx emission and smoke is measured. B20P10M20P3 stands for Biodiesel blend 20, pilot injection with dwell of 10^{o}, main injection at

20° and post injection with dwell of 3°.

3. Result and Discussion

3.1. Biodiesel characteristics

The properties of prepared cotton seed oil biodiesel is given in Table 2.

3.2. NOx Emission

It is observed from the below figures (Figure 2 – 5) that with multiple injection the NOx emission reduced considerably. From Figure 2, it is noted that at M11 the NOx emission is reducing as the dwell between pilot and main increasing from 10 CAD to 20 CAD. There is a maximum reduction of 56.91% with dwell of 20 CAD compared to single injection M23.

At M14 also similar trend of reducing NOx emission with increase in the dwell period. Maximum reduction of 49.75% is noted with a dwell of 20CAD compared to single injection with a load of 6kg.

At M17, Figure 4 dwell 10 CAD found to be better than others. The maximum reduction in NOx emission is 36.20% with a load of 12 kg. It is observed that the effect is equally influential at the load of 9 kg. As the main injection timing is retarded the NOx emission observed to be reducing due to reduction in the peak temperatures developed in the combustion chamber. Multiple injection strategy is observed to be more effective in reducing NOx at part load condition. There is a increment in NOx with P10 M23 P3. In overall the dwell of 20 CAD is observed to be better for NOx reduction. At M17 With single injection it is observed that the peak NOx emission is at 50% load. When the injection is split the peak NOx point shifted towards higher loads. The dwell of 10 CAD is better.

Table 2. Properties of biodiesel (Eta Laboratories).

Properties	B100
Density@15 °C,(gm/cm^3	0.8865
Kinematics viscosity@40 °C	4.85
Flash point, °C	149
Fire Point, °C	160
Cloud point, °C	+1
Gross Calorific Value, kJ/kg	40,695
Cetane number	50.8
Copper strip corrosion @ 50oC for 3 hrs	Not worse than no 1
Acid value as mg of KOH/gm	0.063
Carbon Residue	0.041%
Sulphur	0.0043%

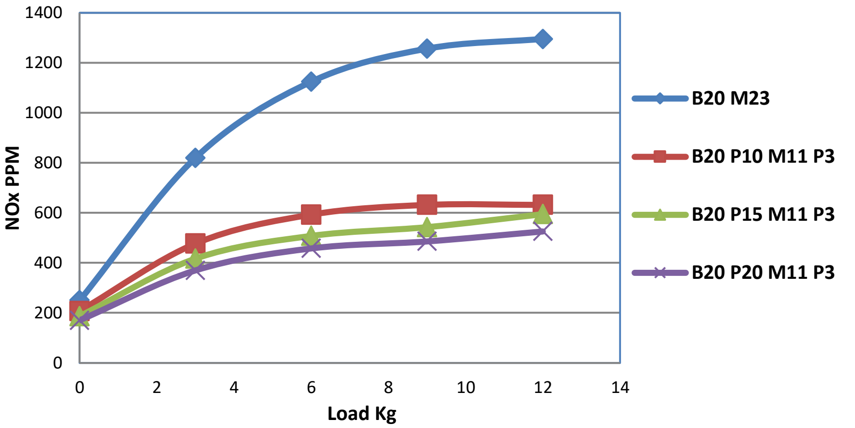

Figure 2. NOx emission at M11

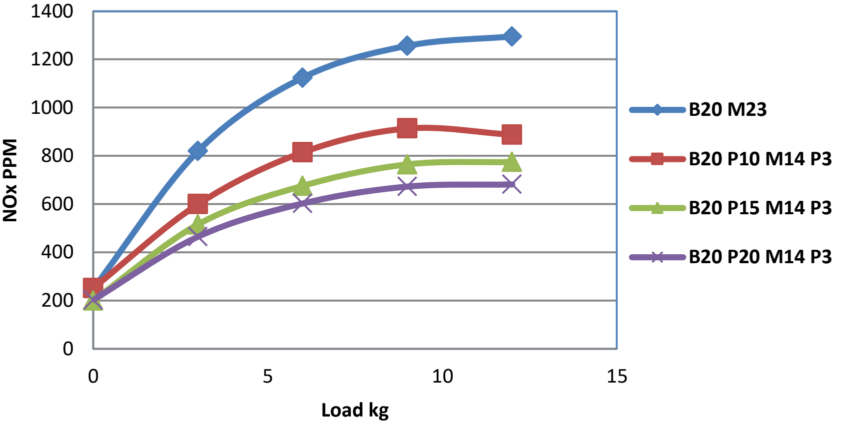

Figure 3. NOx emission at M14

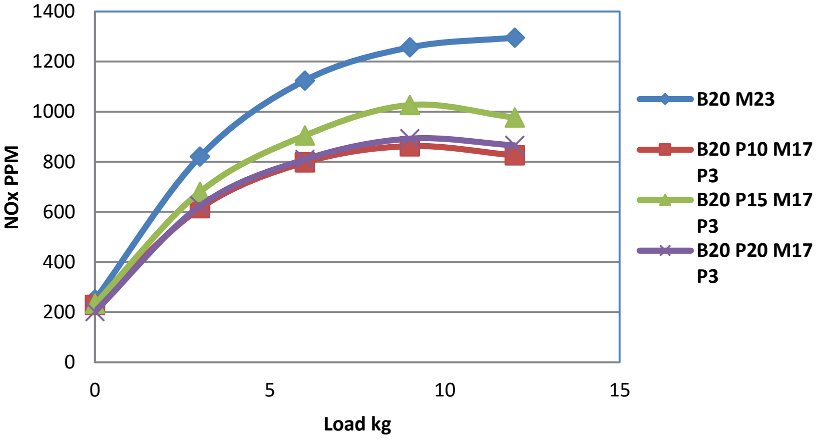

Figure 4. NOx emission at M17

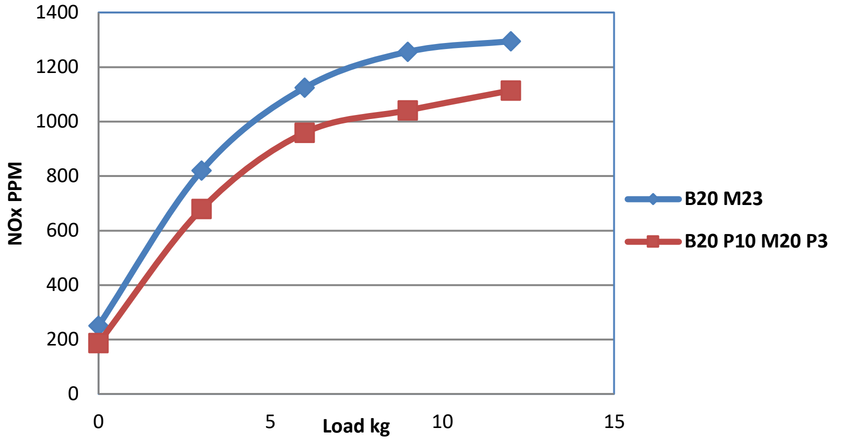

Figure 5. NOx emission at M20

3.3. Opacity

From the below figures (Figure 6 – 10), it is observed that splitting the fuel injection has considerable effect on smoke emission. Maximum reduction of smoke is noted at M14 with dwell of 10 CAD with 6 kg load. At this condition the reduction in smoke is 58.93%. The reduction of smoke at M11 with a dwell of 10 CAD is 55.32% with load of 6 kg.

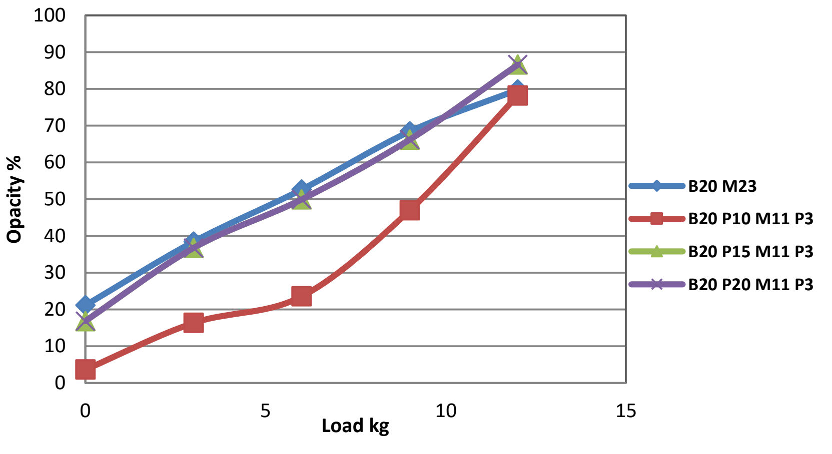

Figure 6. Opacity at M11

It is observed that the engine is hesitating at higher load with higher dwells of 15 and 20 CAD at M23 and M20. At all main injection timing the dwell of 10 CAD observed to be the best.

The retardation of multiple injection with main injection retardation from 23° bTDC to 11° bTDC, smoke emission is considerably effected. Smoke opacity reduced gradually up to main injection 14° and then starts increasing with further retardation. The reduction is 69.1%, 62.23%, 58.93%, 48.68%, 18.29% with load of 0%, 25%, 50%, 75%, 100% respectively at P10 M14 P3.

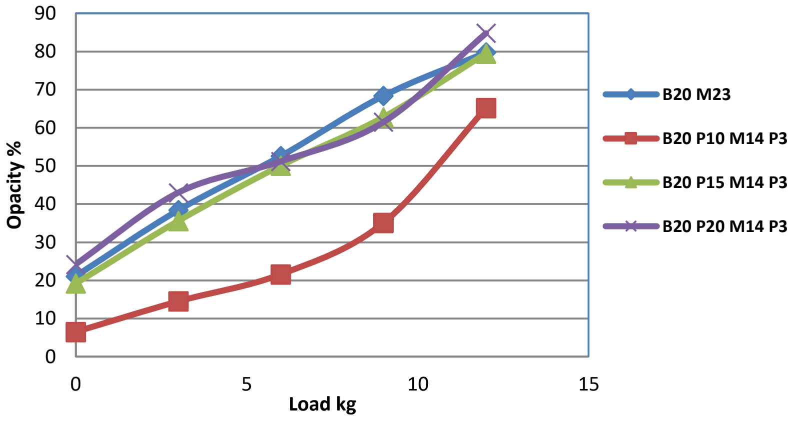

Figure 7. Opacity at M14

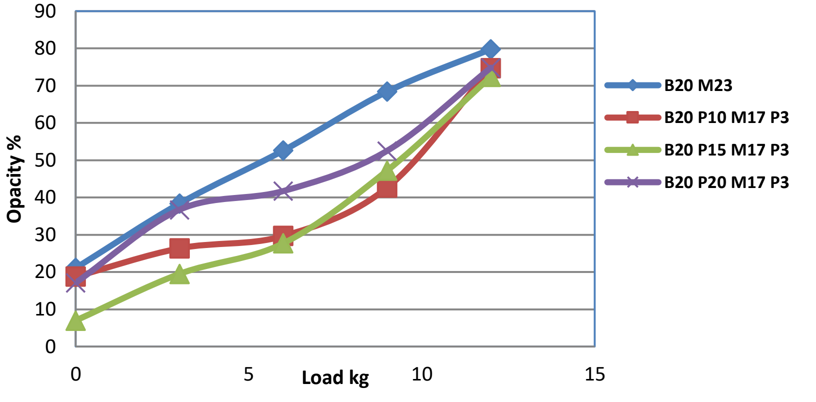

Figure 8. Opacity at M17

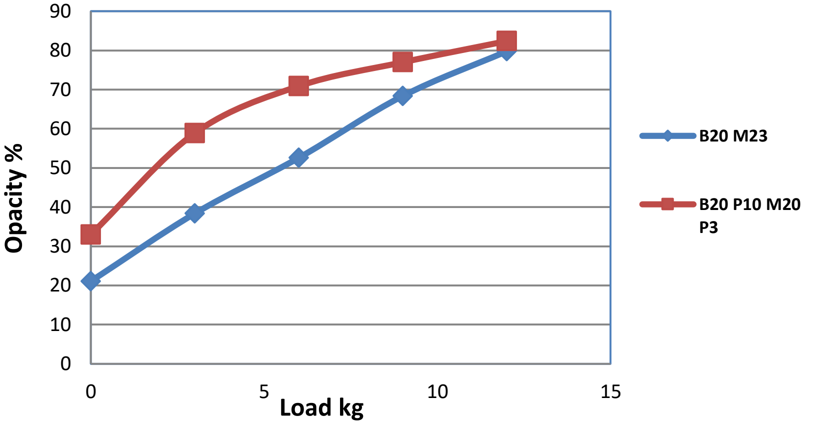

Figure 9. Opacity at M20

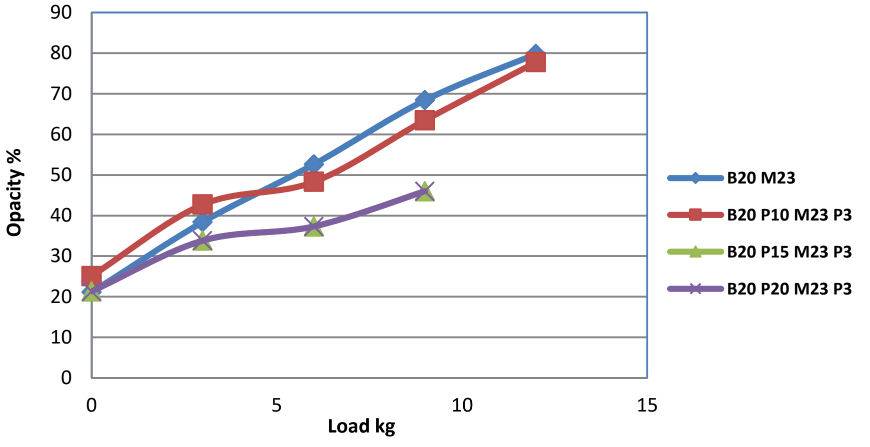

Figure 10. Opacity at M23

4. Conclusion

- Multiple injection is a good means of having tradeoff between smoke and NOx emissions.
- Retardation of multiple injection up to M11 helped in reducing both NOx and smoke.
- P10 M11 P3 is better for smoke and NOx tradeoff. Numerous experiments are required to understand the influence of multiple injection.
- At all main injection timing the dwell of 10 CAD observed to be the best for smoke reduction, whereas 20 CAD is better for NOx reduction. In overall Dwell 10 CAD is better for tradeoff between NOx and Smoke.
- Further combustion related analysis is required to understand completely the influence of multiple injection
- Multiple injection strategy seems to be more efficient than conventional in reducing emission due to their capability in controlling heat release rate and hence peak temperature. Multiple injection is better than single injection in optimizing tradeoff between NOx and smoke due to their efficiency in reducing initial high temperatures and supporting combustion of late injection.
- Reduction in emissions was improved with multiple pre-main-post injection strategy, as pre injection supports main injection combustion and reduced delay while post combustion helps in oxidation of soot particles without impact on NOx.
- Proper dwell between injections was significant as small dwell led to situation of single injection while long reduced the effect of pre-mix combustion. For pilot injection dwell around 10 CAD reduces emission efficiently.
- Around 21 CAD bTDC injection timing of first injection was

observed to be optimum for simultaneous reduction of NOx and soot.

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