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EXPERIMENTAL INVESTIGATION OF FUEL INJECTION AND FUEL TRANSPORT INTO THE CYLINDER IN A PORT-INJECTED SI ENGINE (XU7JP-L3)

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ABSTRACT: Liquid fuel inflow into the cylinder is considered to be an important source of exhaust hydrocarbon (HC) emissions from automotive spark ignition engines. These liquid-fuel caused emissions are increased significantly during the start up and subsequent warm-up period. The two phase fuel/air flow through an internal combustion engine inlet valve has been studied experimentally in a specially designed rig. The separated flow associated with fuel films on the inlet port and droplets on the valve stem can readily be seen. This study analyzes the influence of several engine and injection design variables, on the fuel entrainment and in cylinder liquid fuel behavior. The effect of the following parameters on the characteristics of the fuel droplets entering the cylinder was studied: spray geometry, spray targeting, flow velocity and intake valve lift. The present study shows substantial dependence of in cylinder liquid fuel characteristics on the above parameters. It is shown that the droplet size distribution, the amount of liquid fuel, and the spatial distribution of droplet characteristics around the intake valve circumference were affected to different degrees. The observed trends in the droplet characteristics are explained in terms of changes in the previously identified mechanisms. The observed differences in in-cylinder liquid fuel behavior are significant enough to be reflected in engine out emissions behavior.
KEYWORDS: Injectors, inlet port, spraying, lift

INTRODUCTION

Today the high volume of fuel consumption in addition of using so much energy and so expensive costs that puts on the shoulder of humans, in regards of air pollution and environmental dangers that exists for the citizens of a community, it has been under attention, so scientists are trying to find a way to reduce fuel consumption and optimize its combustion.

Therefore, many efforts have been done that the great deals of these efforts are about the fueling process in automotive engines and propulsions. Also the use of injector for the disperse of fuel and creation of full combustion was the result of such efforts and it led to the reduction of fuel consumption and lesser pollution and better combustion are the result of this significant change in the engine industry and propulsion.

The formation of a fuel mixture and air reasonably and the procedure of fuel entry into cylinder in the spark ignition engines was one of the important factors in getting ideal efficiency with the level of low pollutants and it can occur when the fuel droplets with diameters less evenly with the lowest concentration in the port enter into the cylinder.

Lefebvre has studied the liquid film thickness on the air jet in 1980and found that the droplet size is dependent on the film thickness and also concluded that the fluid velocity, air velocity and mass flow rate of liquid and air are dominant on the thickness of the liquid fuel [1].

Lawta has measured the rate of transient torque and ratio of air to the transient fuel for an engine in two states of the injector in 1987 and found that by changing the injector's position in the cylinder, the surface of the wetting wall will significantly changed. Also the ratio of air to fuel and momentum will be changed too.

Mayer considered the effects of fuel characteristics and engine design parameters on the analysis of the fuel transfer in 1999; the results measure the amount of pollutants changes of parameters output of the fuel [3]. Ohyama used the process of fuel mixture combination and the level of liquid fuel film for the purpose of assessing the quality of creation and preparation of the mixture in 1996 [4].

Behnia investigated the effect of the location of the fuel injector to the cylinder and the result of study was the formation quality of the mixture in the cylinder and measuring the fuel films and droplet size on entry to the cylinder in 2001 [5]. Curtis observed the phenomenon of film failure by applying the symmetric steady flow with a single cylinder engine. Repeated research work developed by Curtis.

In 2002 concluded that how the valve changes and port geometry affected better than fuel properties on atomization fuel film [6].

In order to develop and optimize the fuel system in injector engine with multi-point dispersion (Chen), a one-dimensional transient model was developed from a multi phase flow in an intake manifold and the formation process of air-fuel was investigated along the input port [7]. Milton and Elerman experimentally investigated two-phase flow of air and fuel in an internal combustion engine in different places of high-dispersion, different nesses of valves and velocity of flow and showed the effects of these parameters on entry and re-fuel atomization [8].

In this paper, a model of a glass from a series of entry port and the cylinder head of an engine (engine of Samand) is made and an auxiliary facility for modeling the performance of engine is fitted in the suction cycle. Using the made sets, different behavior of air and fuel engine performance is studied and analyzed; all models has been achieved for sucking cycle in steady state. Finally, the test conditions are consistent with the predicted function of air flow rate corresponding period RPM 2600 and 6000 and in every cases mentioned, movement quality of the film and droplets of fuel is investigated into the inlet port and its entry to the cylinder. In addition, the influence of injection parameters such as target location, flow rate and valve opening is determined.

ASSUMPTIONS

The study hypothesis is as follows:

A - The behavior of water and mixing with air is very similar to the behavior of fuel in actual condition.

B - The made model is geometrically similar to the true model.

C - The conditions of the experimental model are close to the actual model.

PREPARING THE TEST SET

The built motor is based on Motor XU7JP-L3 (Peugeot 405 and Samand engine) and the engine's information is used for its preparation. A cylinder from the mentioned four-cylinder engine includes the port – the cylinder head, cylinder and ... which is made of transparent glass compromises of glass and Plexy Glass. Meanwhile, the fuel rails and its accessories are made of aluminum.

Figure 1. Spray Tester in the combustion chamber

Figure 1 shows the spray test components as follow:

A - A set of a single-cylinder glass engine of the type MPFI includes: Cylinder head, cylinder, port

B - A set of fuel rails: To supply fuel and necessary pressure for fuel into injector includes: aluminum fuel rails, injector, regulator, injector pump of the feeding source, interface pipes.

C - Collect water: used to gather fluid sprayed into the cylinder and prevent fluid contact with internal components of the machine table.

Cylinder Head

The cylinder head used in the research motor is made of Plexy Glass. First, the cylinder head should be provided as map and all parts are made of the entire lathe and milling operations. The actual dimensions of the cylinder head are presented in Figure 2.

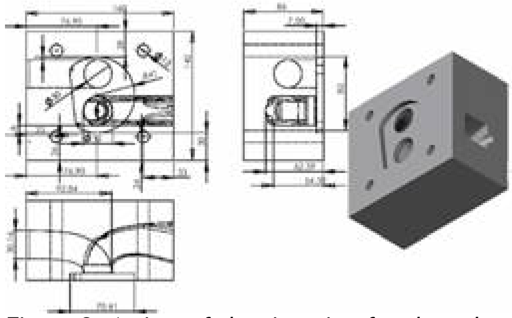

Figure 2. A view of the situation for the valves and ports in cylinder head

Injector

The sprayed injector has multiple flows; as Figure 4 showed opening the ball-valve caused the mainstream fuel flow passed from the primary nozzle and contacted to the center of a plate with three holes around itself and then is divided into three distinct jets.

Cross-section of a sprayed cone yield by jets away from the nozzle has the conical shape.

A view of spray with three non-uniform jets is shown in Figure 4.

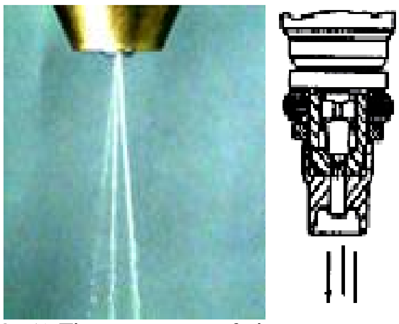

Figure 3. A) The geometry of the spray nozzle (left) B) A view of the spray pattern of spray [9]

Injector is capable of moving in three directions into front, back, up and down and moves around, with 3 degrees of freedom; How to get the pump and the fuel rail and engine power are shown in Figure 1.

The Flow bench is used in order to simulate the air flow into the cylinder during the suction cycle (Figure 4). Using this device, air flow with a distinct and adjusted flow is sucked by the fan from the end of the cylinder. Because the flow of water is not penetrating into the fan and the flow table elements, collector water is used for that as Figure 5 shown. In the collector that put on the flow bench and cylinder, the aluminum sheets of 0.5 mm is used and when suction, the dye-water and material mixture is collected in the bowl and does not achieved the sucking air.

Figure 4. A view of flow bench [10]

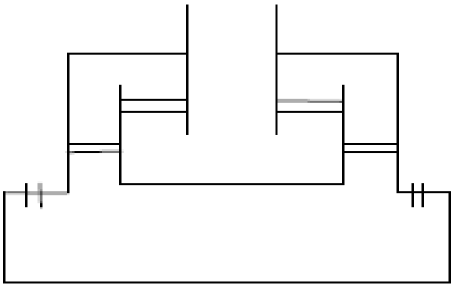

Figure 5. A schematic of absorptive system of water

THE PROCEDURE OF TESTS

The dye-water and material mixture of Proidin Aidin that is used in medicine for disinfecting wounds, is applied for doing test. Proidin Aidin is a colored material that completely dissolved in water and will not leave any sediment that causes clogging the pump and injector; because the used injector is very sensitive and reacted across the smallest sediment and not to show the spraying operations and it become inactive.

MECHANISM OF FUEL ENTRY INTO THE CYLINDER

As pointed out, the made series for the purpose of test of fuel injection is designed during the intake cycle. In this cycle, by moving piston downward, and opening the air valve, the air flows into the cylinder with high-speed. This is the mechanism for transfer of fuel to the cylinder that first the fuel flow is transferred with suitable pressure behind the injector and by opening the injector; the fuel is converted as liquid jet that is a mixture of liquid droplets and fuel film.

After fuel injection into the port, as for their size and speed, some of the fuel particles are divided to the smaller droplets by the effect of drag force or pressure fall that is in port and then evaporated and other fuel particles contacted to the walls of the port and the valve's seat and calf and the film formed the liquid fuel on the wall of the port that its control has an important role in improving atomization and complete combustion.

Flowing the air into the cylinder port, the remained fuel film under the influence of shear stress and gravity began to move towards the regions near the inlet valve, because the higher fuel shall be deposited in the port walls or valves, so it is under study and research and also transferring and fuel atomization have been studied again. In continue, opening the air valve, a percentage of the atomized fuel hovering is evaporated and then entered the cylinder with the flow of air. Despite the presence of air flow through, some of the fuel films that is near the fuel valve is still not atomized and not entered the cylinder through but it moved into the cylinder as the liquid fuel film. After entering the fuel into the cylinder head as the port shape, a vortex of air and fuel mixture is composed in the cylinder head that the shape and thickness and the vortex intensity are varied depending uplifts the valve and the flow rate. Mixture of air and fuel film move on the surface of the upper cylinder clockwise and contact to the bezel area 1 (Figure 6) and form a small vortex of fuel film in area 4. Finally the fuel film shown in Figure 7 entered the cylinder in front port (area 4).

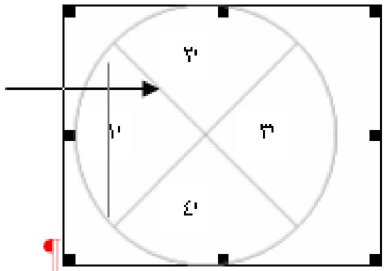

Figure 6. Viewing areas divided by cylinder head

EVALUATING THE EFFECTS OF THE INJECTOR

This case is studied the spray mode in FRONT, CENTER, BACK of the valve and also the valve low uplift and low speed motor. As seen in Figure 7, the fuel goes behind the valve in the spray back of the valve and more fuel goes out of the area and the amount of fuel is collected below the bezel. In the case shown in Figure 8, gathering the fuel film on the bezel is much lesser in spray mode in CENTER & FRONT of the valve.

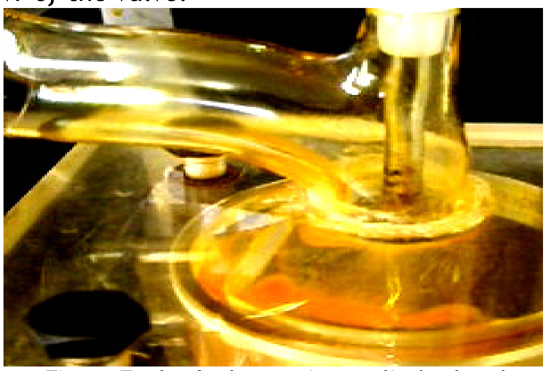

Figure 7. the fuel entry into cylinder head in spray mode behind valve (low lift)

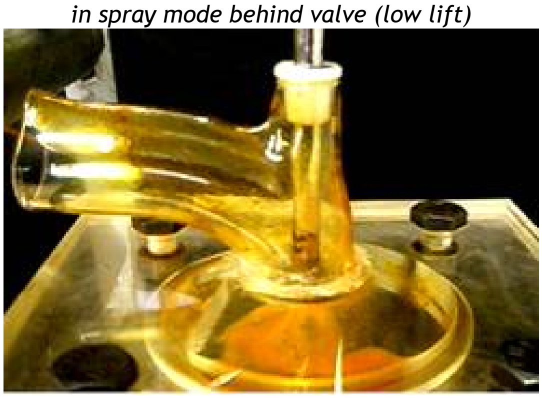

Figure 8. Vortex in the cylinder head in the front and center of the valve in spray mode (low lift)

Since the amount of fuel is collected below the bezel in area 1, the Vortex formation is varied at spray mode behind the valve with the spray mode front the valve. Also in the spray mode center the valve due to air flow, some of the jet fuel is diverted to the front of the valve. In the spray mode in front and center of the valve, a powerful vortex of fuel is formed in the cylinder head.

In spray mode behind the valve, the fuel film hits to the bezel after it leaves the valve (rear area 4 and 1) and some of them is collected below the bezel in area 1 and then returns. But front and center spray valve, the fuel film hits to the bezel in area 1 after removal of the front valve in area 3 and then returns and it flows into the cylinder from there. A few fuel is gather in the bezel, it can to be said that the difference of removal of fuel film in modes 1 and 2 is due to the collision of the jet to the front valve in one case, and back to the valve in another case. Also the thickness of fuel film on the port at the front spray is more than fuel injection in center and back valve.

Also the speed and openness of the valve are the same on the cylinder head in three modes, because the air rotation is also the same. In spray mode back of the valve, due to lack of fuel vortex in the cylinder head, the rate of diffusion of fuel film in the cylinder might be differed with two other modes; As seen in Figure 9, diffusion of fuel film into the cylinder is higher than the other two modes and also we can observe an uniform state in the cylinder than the diffusion of fuel film.

Figure 9. Fuel film diffusion into the cylinder at the back valve in spray mode

But according to Figure 8, as previously mentioned, because the vortex on the cylinder head has more focus in center and front spray valve, the fuel flows into the cylinder as the vortex is formed there and it cannot enter the cylinder evenly. The fuel film thickness in the cylinder is more than the spray mode in back.

Evaluating the uplift of valve

The effect of the inlet valve opening at low engine speed is investigated in this part. First, the excessive uplift of the valve and the spray in front of the valve should be investigated.

As shown in Figure 11, the jet fuel is more deviated due to the excessive uplift of the valve and the air flow passage of the valve, and then the collision of the fuel jet is done in the larger region. This area has been increased due to dispersion of fuel jet; as a result the fuel film thickness is less than the low lift mode. It should be noted that increasing the collision of the jet fuel may be increased the wetted surface portions; however, the evaporation rate is also increased there. In this case, the fuel jet is seen on the port as the fuel film; and there is less fuel film droplets.

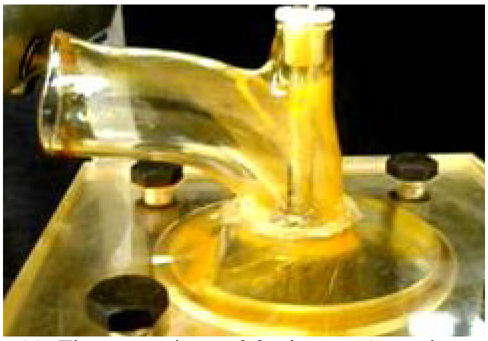

Figure 11. The procedure of fuel entry into the cylinder head at high-lift

According to Figure 11, the fuel exits from the front of the port and it falls in the cylinder head but it cannot gather into the cylinder due to the excessive openness and high speed flow after exiting the valve and the horseshoe vortex do not formed as the low lift mode (Figure 8), and fuel falls speedily into the cylinder (walls, etc.) and due to lack of fuel in the cylinder head, the fuel film thickness is less than the low lift mode in the cylinder head.

After leaving the port on the cylinder head, the fuel hits to the bezel in back of the port as the fuel film and then returns and flows into the cylinder; but returning the fuel from back of the bezel is higher than the low lift is (due to the high velocity air flow). Due to high openness of the valve, the fuel flows into the cylinder more than the low lift mode. Immediately, after leaving the port, the fuel flows directly into the cylinder without any contact with the cylinder head. Also, due to the high speed flow, the diffusion of fuel in the cylinder is more than the low lift mode as it can be seen in Figure 12. Most films in areas 4 and 3 and lowest fuel film below areas 1 and 2 for the cylinder head are visible.

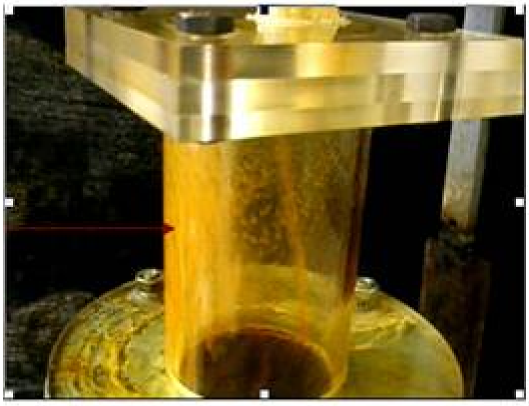

Figure 12. Fuel film diffusion into the cylinder at high-lift

EVALUATING THE EFFECTS OF FLOW RATE - Evaluating the high speed of engine at low uplift valve

The low uplift of the valve (1 mm) and high speed engine (6000 rpm) is investigated in this part.

It is observed that due to the high speed air flow, about 90% fuel film hits into the front of the valve, it means this mode is the same as if we target the *center of the valve so out target will be mistake by increasing the air flow velocity and the fuel jet is deviated from its way and then hits on the front of the valve.*

Meanwhile, the fuel film thickness is low on the surface (front surface) because there is a high flow rate (Figure 13). The fuel film exits from the front of the valve (part 3) and returns to the back by contacting the bezel in area 1 and formed the horseshoe vortex. It should be noted that according to Figure 13, due to the high air flow, the horseshoe vortex is larger and more elongated and high levels of turbulence in the cylinder head is seen more than before and also retuning the bezel is higher than in area 1 (distance of collision to the bezel and return to the fall). Fuel film thickness is high at the cylinder head as mentioned previously, it causes the low valve openness which the fuel film flows to the upper cylinder head before hitting the cylinder's wall; as a result the film thickness can appear high in the cylinder head.

Figure 13. The procedure of fuel entry into the cylinder head at the back valve in spray mode

The fuel falls into the cylinder from area 4 by forming the horseshoe vortex. As shown in figure 14, the fuel film is spread in other parts due to the high speed air flow; and the film's diffusion is observed in regions 2 and 3 and 4 and there is only less fuel film in area 1; and less fuel film is also seen into the cylinder as droplets of different sizes due to the high velocity air flow. There is far too much spin inside the cylinder and generally the spread rate is varied in various parts of the cylinder (Figure 14).

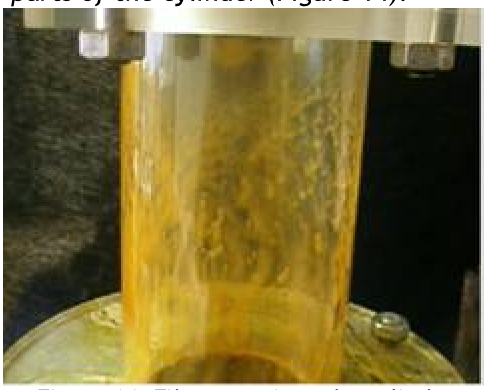

Figure 14: Film entry into the cylinder at high speed

Evaluating the high-speed engine at high uplift valve

The high engine rpm that increases the air flow velocity has a similar effect by increasing the valve opening. In both cases, the inlet air to the cylinder increases by the momentum conditions. In this part, the engine speed increased along with lift (uplift valve) and it investigated the high velocity flow effects associated with the uplift valve.

As seen in Figure 11, increasing the openness of valve causes the fuel jet more deviation and almost the entire surface of the port is covered by the fuel. In this part, the high velocity flow in one hand and high openness of the valve on the other hand may deviated the fuel jet more and also the fuel's diffusion will increase by both mentioned elements and covered the entire surface of the port, so the fuel film thickness seems less likely in the port's surface than the low openness mode by the effect of diffusion and high surface area.

The fuel film returns after collision to the bezel in area 1 and a strong vertex is seen in area 4 where the fuel flows into the cylinder. When more valve lift, the fuel film becomes colorless and pale, because of high velocity flow for the fuel film and low thickness of the film after leaving the valve in the area 3.

In these conditions, the intensity of swirl flow rate will increase the rotating of fuel film on the walls of cylinder as shown in figure 15. (Compare with Figure 14) On the other hand, high air rate will increase the homogeneity of the inlet fuel into the cylinder, so the fuel film thickness is lesser in the cylinder.

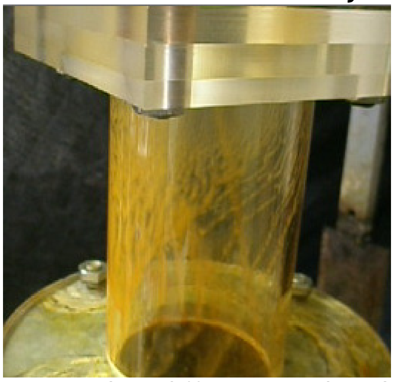

Figure 15. Fuel jet diffusion into the cylinder at high lift and speed

When the engine speed or uplift valve is high in the spray mode back of the valve, the fuel jet is deviated due to high velocity air flow and then hits on the center and back of the valve; and no spray in the back.

CONCLUSIONS

In the engines that the fuel is sprayed on the entry port, the spray features are less important than the air flow and the port geometry and cylinder head, and the advantage and the effect of some parameters such as speed, the level of flow rotation overcomes more than the spray parameters. It is more important at high speed engines, so the spray characteristics are affected by the air flow. The flow rate will be affected by jet's deviation, diffusion of fuel injection and precision targeting, fuel film formation in the port, cylinder head, cylinder, air flow rotation in the port, cylinder head, cylinder, homogeneous fuel into the cylinder. So that the high velocity flow will increase the deviation of jet fuel and diffusion of fuel injection, as a result there is less accurate targeting; and the more fuel film is formed on the port's walls. Also the rotation of air *flow rate and its distortion is more important. On the other hand, the high speed air will increase the homogeneity of the fuel entry into the cylinder, and then the fuel film is less formed in cylinder.*

Changing the spray targeting has not any effect in the deviation of jet, fuel injection's diffusion and the accuracy targeting. But it is effective in forming the fuel film in the port and cylinder and homogeneity of the fuel when entering the cylinder. The high openness of the valve will increase the deviation of fuel jet and therefore the diffusion of fuel injection or fuel film in the port. Also, the intensity of flow rotation and homogeneity of the fuel will increase into the cylinder but reduce the accuracy targeting. No gathering fuel in the port and cylinder head at the high speed flow along with uplift valve because the fuel film thickness is much smaller than in the port and cylinder head.

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