

Research Article

Experimental Investigation On 3-D Printed Injectors With Various Orifices

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Abstract

In this study, all the injector plate models are manufactured using the additive manufacturing technique (3D printing). In order to study the spray and liquid sheet characteristics of the liquid, keeping the area constant, we have designed single element injector plates with different shapes of orifices; these are used to experiment. The mass flow rate for all the geometries was measured to determine the coefficient of discharge. The spray and sheet formation of liquid flow at various pressure locations of different orifices, images were observed by DSLR camera, and effects of different injection pressure, orifice shapes, break-up length of the liquid have been studied. The experimental results have shown that the mass flow rate and the discharge coefficient are highest for injector plates with a triangle-shaped orifice at higher pressures. When it comes to break-up length, the square-shaped orifice is found to have the shortest break-up length at maximum and minimum pressure values, whereas the triangle-shaped orifice was found to have a long break-up length at all pressure values. Since break-up length for square is minimal, we can conclude that it will atomize faster and aid in rapid combustion.

Keywords: *Injector, 3D printing, Cold flow test, Breakup point, Orifice effects*

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Introduction

The injector is a rocket engine component that releases the liquid propellant into a thrust chamber with uniform fuel-ratio, mass flow rate and atomizes at its specific design. While designing the injector, atomization plays a key role because its work under potential due to pressure drop. A square root of pressure across the injector decides the flow speed. Modern injectors consist of minor holes which aim at the jets of fuel and oxidizer, so they intersect at a short distance from the space of the injector plate. This helps in faster atomization by breaking the liquid flow into little droplets. Various injectors like Showerhead, self-impinging doublet, unlike impinging doublet, centripetal or swirling, and pintle. Hypergolic propellants are vastly used in liquid rockets due to their short ignition delay when an external ignition source is not present. For liquid hypergolic recants, impinging jet injectors are more suitable due to their simple design and high efficiency [1]. In fluid mechanics, the liquid is a Newtonian-fluids where viscosity is independent, and shear stress is zero like water, and gel is a non-Newtonian where viscosity and shear stress are dependent on each other like blood and ethanol gel [2]. The liquid propellant has high energy, and it is easy to control the engine thrust, but the drawbacks are safety factors and complex structure. The gel propellants have great significance for their stable and high-efficiency operation of thrusters. Due to their yield stress and high viscosity of gel propellants, they are a bit difficult to atomize, decreasing the performance [3]. Research on characteristics of impinging jet atomization dates back 50 years ago, and still, to this date, no comprehensive model was accepted for estimating the liquid sheet break over a wide range of configurations [4]. The instability of high-frequency combustion is when pressure oscillations are expanded through in-phase heat addition/extraction from combustion, which is known as acoustic instability [5]. By studying the flow and deformation properties under applied forces of static and dynamic, we can understand the gel propellants behavior [6]. The self-impinging doublet injectors where two fluids impinge on each other at an angle were studied in [7]. The fluid sheet is formed at an impingement point which is perpendicular to the injector's plane. The lateral directions and downstream stretching are produced by jet kinetic energy and eventually leads to breakup into droplets [7]. In this experimental study we use injector plats having only a single discharging orifice, with different orifice shapes that are 3D printed by using FDM (Fused deposition modeling) process. At different pressures we have calculated the mass flow rate, coefficient of discharge and break-up length.

Injector Design:

We have designed our 3D models using solid works software. All the designed models are converted into STL format and then send to CURA software to analyze time taken for layer processing and modeling of specimen. The single element injector discs with different orifices are presented in Figures 1 through 4. Area of orifice has same for all injector shapes. It has to be mentioned that all the orifices have a constant area to facilitate for comparison of their injection characteristics.

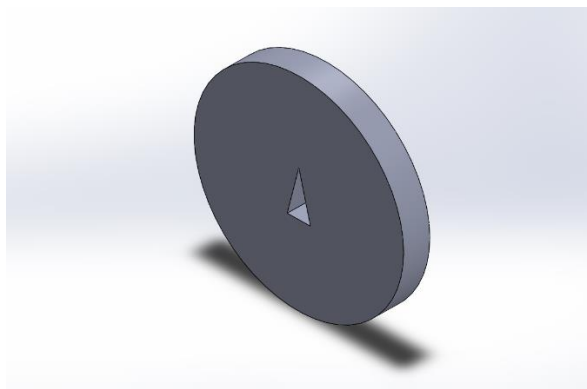


Figure 1 Injector plate with triangle orifice

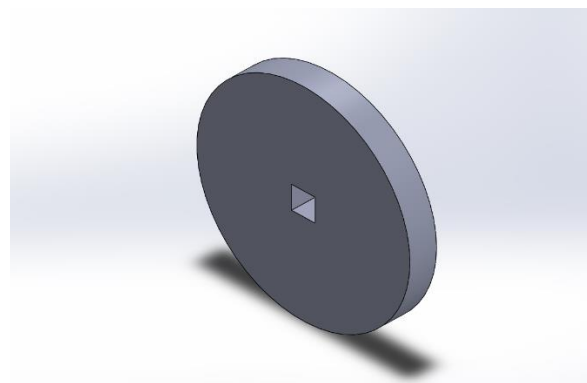


Figure 2 Injector plate with square orifice

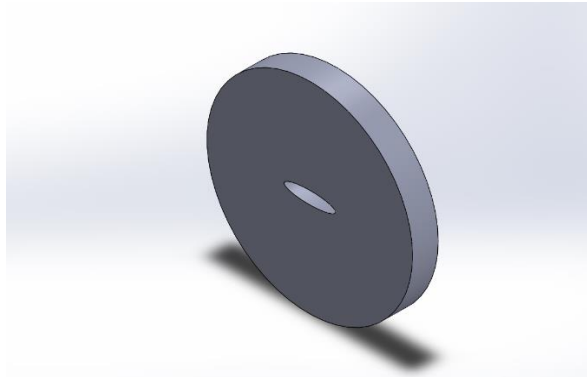


Figure 3 Injector plate with ellipse orifice

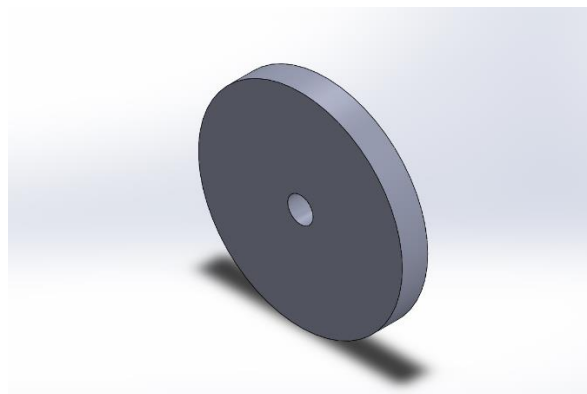


Figure 4 Injector plate with circle orifice

Material Selection

ABS stands for Acrylonitrile Butadiene Styrene. ABS is an impact-resistant engineering thermoplastic & amorphous polymer. ABS is made up of three monomers: acrylonitrile, butadiene and styrene:

Acrylonitrile: It is a synthetic monomer produced from propylene and ammonia. This component contributes to ABS chemical resistance & heat stability

Butadiene: It is produced as a by-product of ethylene production from steam crackers. This component delivers toughness & impact strength to ABS polymer

Styrene: It is manufactured by dehydrogenation of ethyl benzene. It provides rigidity & processability to ABS plastic.

ABS is produced by emulsion or continuous mass technique. The chemical formula of Acrylonitrile Butadiene Styrene is $(C_8H_8.C_4H_6.C_3H_3N)_n$. The natural material is an opaque ivory color and is readily colored with pigments or dyes. ABS is a strong & durable,

chemically resistant resin but gets easily attacked by polar solvents. It offers greater impact properties and slightly higher heat distortion temperature than HIPS.

Acrylonitrile Butadiene Styrene has a broad processing window and can be processed on most standard machinery. It can be injection-molded, blow-molded, or extruded. It has a low melting temperature making it particularly suitable for **processing by 3D printing** on an FDM machine. The fabricated models of single element injectors with different orifice shapes are shown in Figure 5.

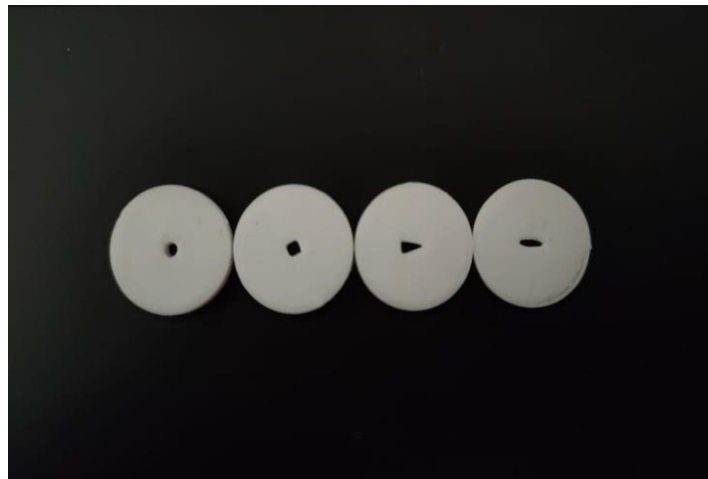


Figure 5: 3D printed single element injector with different orifice shapes.

Experimental Setup:

In this experiment, clod flow tests are carried out to study the configuration of 3D printed injector. We have used a pesticides can sprayer to generate the required pressure. This device has thick walls that it can withstand a pressure of up to 6 bars. This pressure can was altered according to our experimental needs. We have included pressure gauge, it will continuously monitor the pressure value inside the can and then a check valve is used to prevent the back flow of the liquid. We have also used a gate valve whose function is to ON and OFF the liquid flow. There is a provision for mounting the injector plates that were 3D printed in the Injector head that is provided with the can. Collecting tank is been placed down to collect the used water and then DSLR camera is used to capture the flow of the liquid. Backlight was used to generate the required lighting to get the proper flow images. The required connection for the needed setup is done in such a manner as shown in the figure 6.

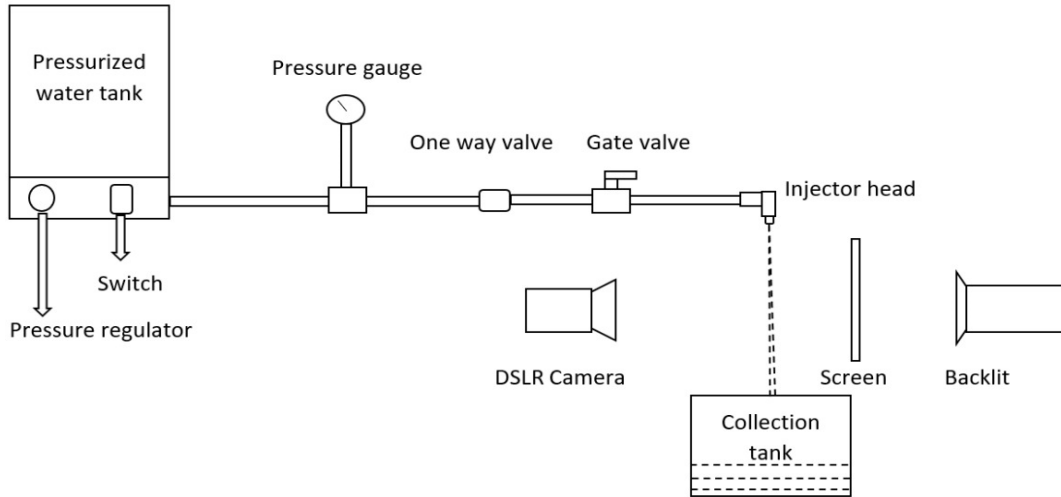


Figure 6: Schematic diagram of experimental setup

Results And Discussion

In this study we have performed cold flow test to study the performance characteristics of each injector. Every Single injector was tested at four different pressures. We have then calculated the mass flow rate, coefficient of discharge and breakup length for all these injectors. The mass flow rate increased as pressure increases for all injectors. As pressure increases, the C_d values for single element injectors decreases. In single element injector the triangle shape orifice has highest C_d value at 1.5 bar pressure. The liquid sheet image that was captured during the experimental process for the various orifice shapes is shown in figure 7.

6.1 Mass flow rate and Coefficient of discharge:

Generally mass flow rate is nothing but mass of the fluid or liquid substance passing per unit time. It is denoted as ' M_o '. We can see typical mass flow rates that we got. Several experiments were performed to get accurate values. Mass flow rate is been calculated to each type of orifice Injector plate. We can see from the Table 1 that for all the orifice shapes, the M_o is found to increase with increasing in pressures. Triangle orifice shape was found to have a higher mass flow rate at high pressures used in our study. Coefficient of discharge is the ratio of the actual discharge to the theoretical discharge. It is denoted as ' C_d '. C_d values were found out for different orifice shapes and are presented in Table 1. We can see that C_d value was found to decrease with increase in pressure. It was observed that triangle shape orifice

has a higher C_d value at higher pressures, whereas circle and square orifices have shown similar value of C_d at each pressure condition.

6.2 Effects of Orifice Geometry and Pressure:

The sequential jet impinging images are shown in Fig. 7. As mentioned in the earlier sections, the minimal pressure was maintained at $P_{inj} = 1.5$ bar. In the low-pressure regimes, from the circular orifice, the liquid jet column emanates from the nozzle possessed the higher breakup length when compared to the other orifices. This is due to the increased hydraulic diameter which resulted in the higher C_d value. Interestingly, at the higher P_{inj} the breakup of the droplets was seen. Contrarily, in the spherical orifice, the peculiar phenomenon of axis switching is happening which resulted in the earlier breakup of the jets. The axis switching rotates the jet in its own axis radially that followed by the sheet formation. This switching is providing the stretching the jet which is ensued as the liquid sheet (See. Inset of square orifice). The triangular orifice, exhibited the more axis switching strength of all the other orifices, hence the sheet formation rapidly coalesced again to form the jet column. During this reconciliation process, the droplets formed from the fringes formed on the sheet. Ellipse orifice acted like an optimum orifice for the present study as the break up occurs in the near vicinity. The higher C_d value is one of the prime reasons for the shorter breakup length. The sheet formation is more predominant as follows $Square > Ellipse > Triangle > Circular$. The finer fragmentation of the droplets from the finger like ligaments which are formed at the sheet periphery was apparently dominant in the elliptical orifice. Hence, the breakup was visible in the low injection pressure. However, the sheet breakup is not happening any of these processes showed the dominance of the surface tension. The predominant breakup happened as the ligament formation eventualized by the droplet atomization. The breakup lengths of the different orifices are shown in Table 2.

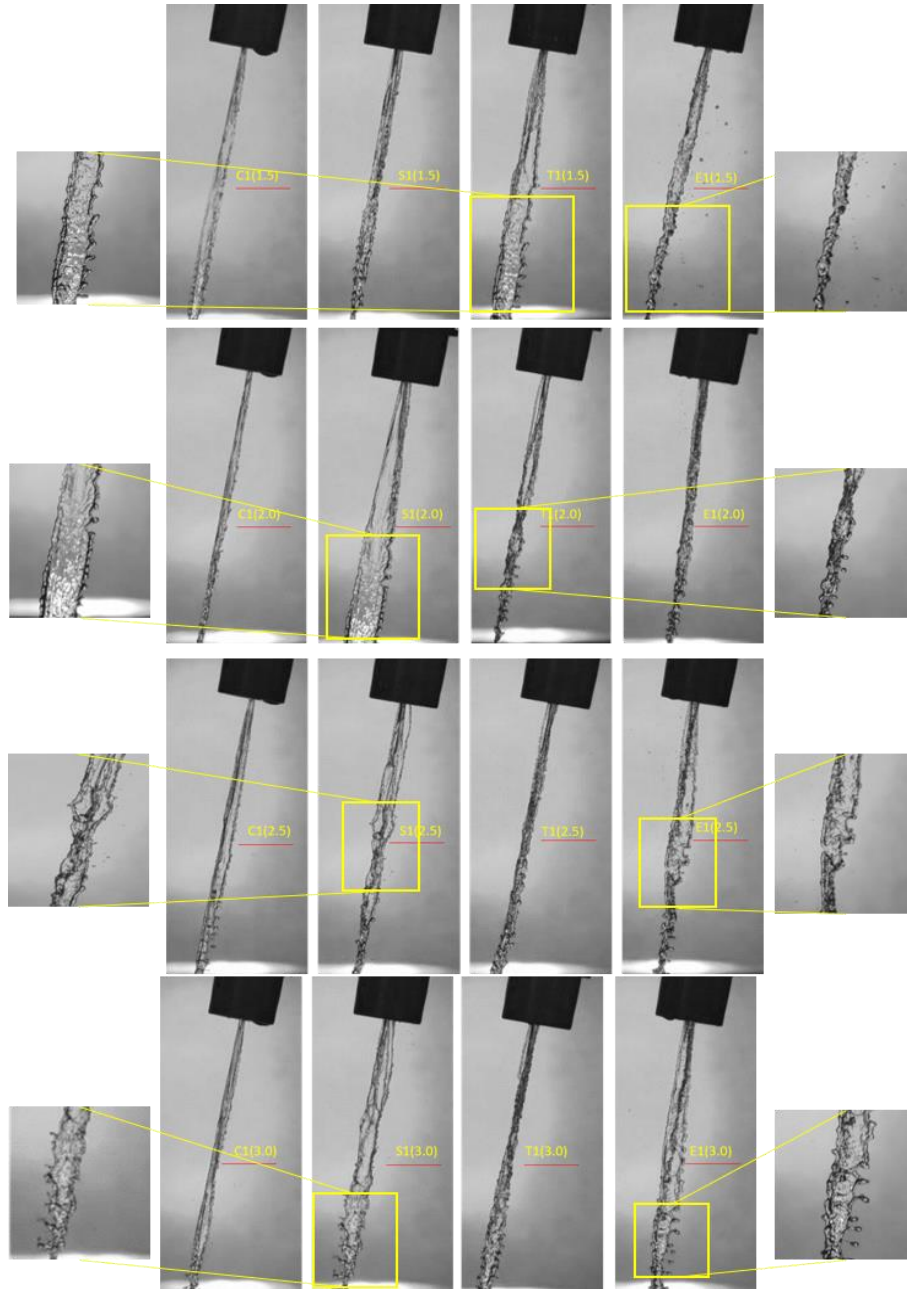


Figure 7: Liquid sheet of Single element injectors with different orifices at various pressures

| Pressure(P) | Mass flow rate | | | | coefficient of discharge | | | |
|---------------------|----------------|---------|---------|----------|--------------------------|---------|---------|---------|
| | 1.5 | 2 | 2.5 | 3 | 1.5 | 2 | 2.5 | 3 |
| Circle(C1) | 0.01783 | 0.01933 | 0.0195 | 0.021833 | 0.7735 | 0.61633 | 0.55825 | 0.5683 |
| Square(S1) | 0.01866 | 0.0185 | 0.0195 | 0.02116 | 0.80979 | 0.58976 | 0.55825 | 0.55095 |
| Triangle(T1) | 0.01833 | 0.02066 | 0.02266 | 0.02433 | 0.81703 | 0.65883 | 0.64891 | 0.63338 |
| Ellipse(E1) | 0.0145 | 0.016 | 0.01866 | 0.0205 | 0.62904 | 0.51006 | 0.53439 | 0.5336 |

Table 1: Mass flow rate and Cd values at various pressure for single element injectors with different orifice shapes.

| | Pressure(bar) | C1(mm) | S1(mm) | T1(mm) | E1(mm) |
|------------------------|---------------|--------|--------|--------|--------|
| Break-up length | 1.5 | 87 | 82 | 87 | 87 |
| | 2 | 84 | 85 | 83 | 83 |
| | 2.5 | 92 | 83 | 88 | 84 |
| | 3 | 89 | 80 | 93 | 90 |

Table 2: Breakup length for single element injector with different orifices

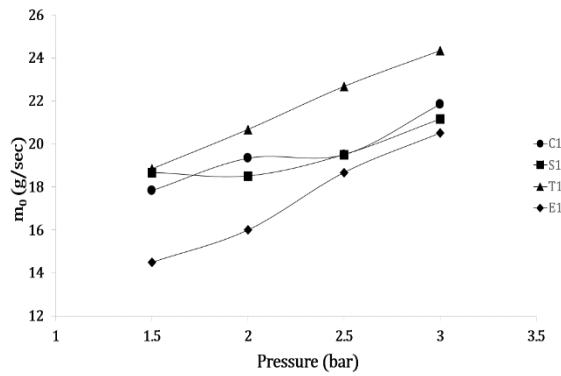


Figure 8: Comparison graph of mass flow rate for different orifice Injector plates at various pressure locations

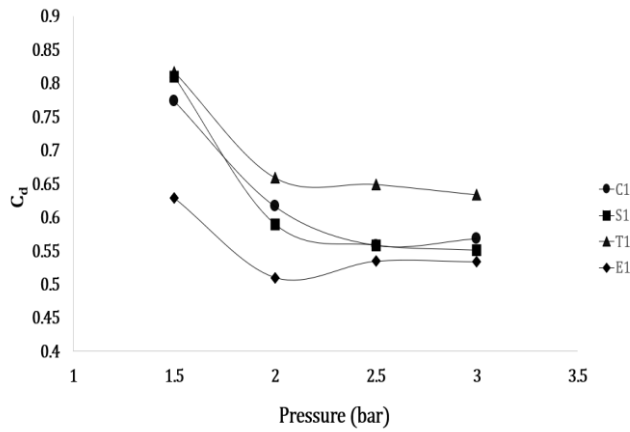


Figure 9: Comparison graph of coefficient of discharge for different orifice Injector plates at various pressure locations.

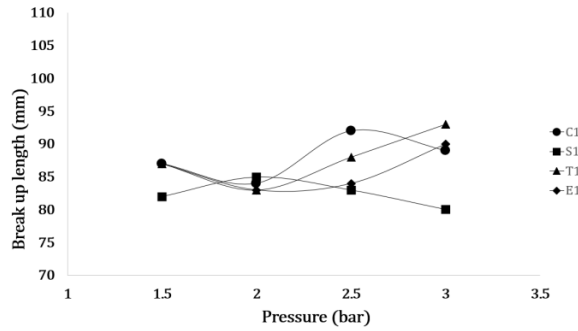


Figure 10: Comparison graph of breakup length for different orifice Injector plates at various pressure locations.

All the images of flow properties were taken by the help of high-definition camera for different orifice shapes. All the needed calculations like break up length, impinging point were found out and mentioned. All needed graphs were drawn and mentioned.

Conclusion

A series of experiments were performed to investigate the jet characteristics using injectors of different configurations of orifices. By looking at the results, we can say that, for single element, mass flow rate passing through each orifice increases with increase in pressure, and that the Coefficient of discharge is decreasing with increase in pressure. Single element injector plate with the triangular orifice was found to have more mass flow rate and coefficient of discharge valve at high pressure. The circular and square shaped orifice injector plates were found to have similar C_d values at the different pressure values. Variation of breakup lengths across the pressure values for different orifices injectors was mentioned. We can see that very quick atomization was happening in single element square shape orifice injector at high pressure. From the images we can see that circle shape orifice was having no sheet formation at low pressures but at 2.5 bar pressure it shows some minimal sheet formation. Square orifice Injector plate was showing sheet formation at 2 bar pressure and triangle orifice injector at 1.5 bar pressure alone. Sheet formation was not observed at remaining pressure conditions for triangular injector. For ellipse shaped orifice no sheet formation is observed but atomization starts from $P_{inj} = 1.5$ bar itself this was observed at high pressure condition as well.

Future Work

The experiments can be continued with two-element, three-elements and four-elements impinging injector plates with different orifices like circle, square, triangle, ellipse and also the injection pressures can be kept at a higher value as well.

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