Characteristic Study of Two phase Unlike Impinging Injectors

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Abstract

The possibility of using two phase impinging injectors as an alternative for coaxial injector used in cryogenic or semi cryogenic engines is studied experimentally. In addition to simplicity of design and fabrication, the flexibity of spray shaping according to the need is possible with gas-liquid impingement. In the present study, water and air in appropriate proportions are used as simulants in place of commonly used liquid oxygen and hydrogen. The SMD values obtained in the case of gas-liquid impingent were found to be lower compared to the shear coaxial atomizer for the same mass ratios of water to air. Gas penetration through the liquid sheet at high gas pressures seems to constrain some of the geometric parameters in such injectors. This can be overcome by using larger gas orifice compared to liquid orifice and employing lower gas pressure drops. For characterizing the spray resulting from gas-liquid impingement, the ratio of normal gas momentum to liquid mass flow rate was identified as a suitable parameter.

Introduction

Impinging jet injectors are the preferred injector geometry for rocket engines that use storable propellants. Compared to shear coaxial atomizer Impinging jet injectors are easy to manifold and simple to design. They permit variations in mass distribution even as they provide reasonably uniform mixing. They may therefore be used as a desirable substitute to coaxial injectors which are commonly used in gas and liquid propellant combinations. But the design analysis for unlike impinging injectors, especially with gas-liquid combinations is not well developed as it is for the coaxial injectors. Some of the basic mechanistic features of sprays from such injectors need to be studied before one looks into their performance as engine components.

The unlike impinging configuration consist of a fuel jet and an oxidizer jet that impinge at a given angle at prescribed distance from the injector face. The schematic of the unlike impinging injector is shown in figure 1. Atomization studies with liquid-liquid jets [1] have shown that both the orifice diameter and the diameter ratio influence drop size; in particular, smaller the jet diameter, smaller the drop size. The angular distribution and mixing uniformity are known to depend on the impingement angle [2]. It was also found that greater the impingement angle, greater the amount of propellant backflow [2]. In fact propellant backflow is proportional to the cosine of the impingement angle. Impingement angle affects drop size and this effect has not been well understood for unlike impinging elements. However most unlike impinging elements have been designed with an impingement angle of 60°. It has been also found that misimpingement of jets affect mixing uniformity and drop size [3]. For the unlike-impinging type it is recommended that the impingement distance should not be greater than 5 to 7 orifice diameter [2]. Since the diameter of fuel and oxidizer generally are different, an average value should be selected. Thus it is seen that several geometric parameters such as diameters of orifices, angle of impingement and inter-orifice distance exert influence on the atomization process.

In two phase unlike impinging configuration under study a gas jet is made to impinge on a liquid jet. Air and the water are used to simulate gaseous hydrogen and liquid oxygen which are used in shear coaxial atomizers. In the shear coaxial injectors, the liquid oxygen is injected through the central orifice while gaseous hydrogen is injected through the annular portion. Though the typical Reynolds number and Weber number used in actual rocket engine conditions are higher, experiments have been done at lower values with the objective of understanding some of the basic features. The Reynolds number used is upto 30,000 and the Weber number about 10,000. The pressure drop used was up to 7 atmosphere. Typical orifice discharge coefficient was above the sharp edge value of 0.61 but rarely above 0.9.

A parametric study of the gas liquid impingement is reported in the present work. As stated earlier, the geometrical and injection parameters that are likely to have an impact on spray characteristics are orifice diameter (D_o), ratio of orifice length to diameter (L_o/D_o), preimpingement length (L_i) of individual jets, inter orifice distance (L_A), im-

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pingement angle (2θ), jet velocity (V_j) and the condition of individual jets prior to impingement(ruffled or unruffled). The orifice diameter determines the jet diameter and the mass flow rate of the liquid for a given pressure drop. Larger D_o is expected to result in coarse atomization. A progressive increase in the L_o/D_o tends to increase the losses by friction and hence to reduce the jet velocity V_j, which in turn will have an effect of increasing drop size. The normal component of momentum of liquid jet increases with an increase in 2θ, which is expected to increase the quality of atomization.Inter-orifice distance and the impingement angle will together decide the preimpingement length (Li) which when increased progressively is likely to introduce disturbance in the velocity profile of the air and liquid jets due to aerodynamic interaction with the surrounding medium.

Materials and Methods

Figure 2 shows the experimental setup used for studying the characteristics of unlike two phase impinging injectors. It consists of a two stage reciprocating compressor with an intercooler and an automatic shutoff facility and is driven by a three phase 10hp motor. The air from the compressor is stored in an air storage tank which is capable of delivering air at pressure up to about 15 atm. From the air storage tank two air lines are taken, one of which is connected to a water storage tank of about 40 liter capacity and the other end which is the airline is connected to the control board for the impinging injectors. The air line is then connected to the air injector on the left side of the injector plate through a valve and a pressure gauge. A water tapping is taken from the bottom of the water storage tank and is connected to a water filter fitted on the control board. The line from the water filter bifurcates into two parallel water connections and one of the water connections is connected to the injector on the left side of the injector plate through a pressure regulating valve and pressure gauge.

The inset in Figure 2 shows the details of the injector used for studying the unlike impingement atomization. It consists of an injector body and an injector element. The injector is modular in design so that injector elements of different diameters can be inserted in to the injector body. The tip of the injector is grooved to attach a line to enable gas flow measurement when required. The internal passage is smoothly converged to avoid pressure loss.

The droplet distributions are measured using Malvern Matersizer X particle analyzer that works on the principle of laser diffraction due to the presence of droplets in a spray. The instrument provides the line of sight averaged diffraction data [7].

Results and Discussion

The liquid orifice was calibrated by collecting water in a measuring flask. It was found that for L/D ratio of 5, a sudden jump in Cd was found. This was in accordance with the observation of Kling and Leboeuf[4] who reported a jump in the value of Cd at a pressure drop value of about 0.3MPa resulting from the separation of liquid from the wall. This effect persists until L/D of 10 albeit weakly. So an L/D ratio of 15 was selected for the study. The gas orifices are calibrated by using a volume flow meter.

Figure 3 shows the development of the spray with increasing gas pressure for a given liquid pressure. It was found that as the gas pressure increases the liquid jet bends from its path and assumes a fan like shape normal to the plane of liquid and gas jet. When the liquid fan becomes normal to the plane of the jets a liquid sheet is seen just below the point of impingement. As the gas pressure is further increased a spray cone is formed which tends to retain its position despite an increased gas momentum. At high gas pressure penetration of the liquid jet by the gas jet occurs. Figure 4 shows the deviation of the spray with gas pressure. The deviation angle is defined as the angle between the initial jet direction and spray centre (see inset in Fig 4). It was observed that the deviation angle increases sharply at the initial stage and then the slope decreases which may be due to the onset of gas penetration through the liquid fan.

The spray angle shown in the inset of Fig 5 is defined as the angle of expansion of the spray as viewed parallel to the plane of the jets. Figure 5 shows the deviation of spray angle with gas to liquid ratio. It was found the spray angle increases sharply and suddenly drops after reaching a certain pressure. This may be due to the gas penetrating the liquid jet.

It was observed that SMD (sauter mean diameter) decreases along the axis and reaches a constant value. Based on the axial measurements axial location of 6.5 cm is chosen as the measurement location beyond which there would be no further breaking of the drops. As a pilot comparative study the gas liquid impingement is compared with liquid-liquid impingement under identical pressure drop conditions. It was found that the SMD values in the gas-liquid impingement are very small compared with the liquid-liquid impingement. The smaller SMD may be due to the less mass of liquid at the point of impingement for a given normal momentum.

The SMD variation with gas pressure was measured for 1mm liquid and gas nozzle with the laser beam aligned parallel to the jets (normal to the spray shown in Fig 5). As could be expected the SMD decreases with increasing gas pressure asymptotically reaching a constant value. Conventionally, the variations in SMD are described in terms of mass and momentum ratios and the same are shown in Figures 6 and 7 respectively. Though both figures show high correlation coefficient, the plot against the mass ratio shows a slightly better correlation coefficient. It was found that only the ratio counts on deciding the SMD rather than the actual liquid and gaseous mass flow rates. In order to find the effect of impingement angle on SMD the angle of impingement between the two jets was varied. The impingement angles selected were in the range 40-80. Backflow towards the injector plate was observed at higher impingement angles and since it results in burn out of injector plate in practical systems, the range of impingement angles was limited. Figure 8 shows the variation of SMD with impingement angle. It was found that as the impingement angle increases SMD decreases. This may be because of the increased normal momentum which is available for atomization.

The inter-orifice distance is defined as the distance between two orifices. The interorifice distance in the present case was limited to 3.5 mm to minimize the expansion of the gaseous jet before impingement. The effect of increasing interorifice distance is that it effectively increases the impingement distance. The effect of interorifice distance is plotted in the figure 9. The figure shows that at low gas pressures the effect of interorifice distance is dominant. As the interorifice distance increases the drops become coarse. This may be due to the expansion of gaseous jet and an increased probability of misalignment of jets. At high pressures, due to the fact that the gas may have already penetrated the liquid jet, the drop size becomes insensitive to inter-orifice distance.

The orifice diameter of the liquid and gas nozzles are varied to study its effects on atomization. This is shown in figure 10. It was found that when we simultaneously lower the gas and liquid nozzles diameter the SMD obtained is smaller for smaller diameters than for higher diameters at corresponding pressure drops.

Since the spray formed by the impingement of gas and liquid jet is extremely nonuniform a measurement of SMD perpendicular to the plane of jets was made (Fig 11). It was found that at low gas pressure compared to liquid pressure the spray is coarse in the center and it becomes fine towards the edge. When the gas pressure is very high compared to the liquid pressure the trend is reversed, i.e. the liquid drops becomes finer at the centre and become coarse towards the edge of the spray. As shown in the figure 11 at some intermediate gas pressure, SMD remains constant throughout the spray.

Although mass ratio and momentum ratios show good correlation with SMD they not take into account other parameters like change in impingement angle and orifice diameter. Since the normal gas momentum is the main factor responsible for bending and breakup of the liquid jet and this momentum has to atomize the given liquid mass, the ratio of normal gas momentum to the liquid mass [5] can be used to describe the SMD value of the spray regardless of the geometric and operational condition. The plot of the normalized SMD value against this parameter is shown in the figure 12. The fit shows a very good correlation coefficient.

The main problem encountered with the gas liquid impingement is that for a liquid pressure, a very high Gas pressure is required to obtain a mass flow ratio of around 6 which is the mass flow ratio commonly used in cryogenic applications. This high gas pressure results in penetration of the liquid jet and results in a nonuniform spray. To avoid this penetration higher gas orifice diameters are used with a liquid nozzle diameter of around 1mm. This result is shown in Fig 13. Though higher gas orifice diameter results in increased SMD at high mass flow ratio, it gives low SMD at the required mass flow ratio of around 6. The figure 13 shows the effect of using different gas orifice diameters. The effect of increasing gas orifice diameters on SMD in a plane perpendicular to the jets is that as the orifice diameter increases the SMD decreases.

Conclusion

The characteristics of gas-liquid impingement were mapped taking into consideration several geometric and flow parameters which influence the impingement process. The normal gas momentum to liquid mass ratio was found as a suitable parameter to describe the SMD of the spray. It was found that the spray pattern resulting from the gas liquid impingement can be varied at will by changing the gas pressure. The flexibility in spray shaping was found as the major advantage of the gas liquid impingement .A problem found with the gas-liquid impingement is the spray penetration found at higher gas pressure. This can be avoided by using large gas orifice so that the required pressure drop is less for a given mass flow rate.

References

1. Zodiac, L.J: correlation of injector spray drop size distribution and injection variables. Final Rep.R-8455, Rocketdyne Div., North American Rockwell corp., Dec.15, 1971.
2. Nasa sp-8089,"Liquid Rocket Engine Injectors"

3. Hoehn,F;Rupe,J; and sotter, J:Liquid phase mixing bipropellant doublets Lucien vingert and Pierre GicquelA-tomization in coaxial-jet injectors
4. Kling,R.and Leboeuf,R.,"L'ecoulement dans les orifices d'injection,Application aux moteurs fusees,La Recherché Aeronautique,No.35,Sept-Oct 1953,pp 35-43
5. NASA -72703,"Investigation of Gas augmented Injectors".
6. LucienVingert and Pierre Gicquel,ONERA,palaiseau,France,MichelLedoux and Isabelle Care,CORIA,Universite de Rouen,Rouen,France and Michael Micci and Michael Glogowski,Pennsylvania state university, university park, Pennsylvania ,"Atomization in Coaxial-Jet Injectors".

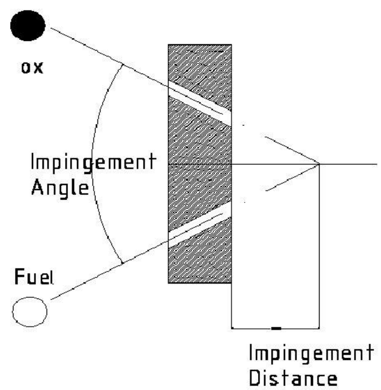

Figure 1. Schematic of unlike impinging injector

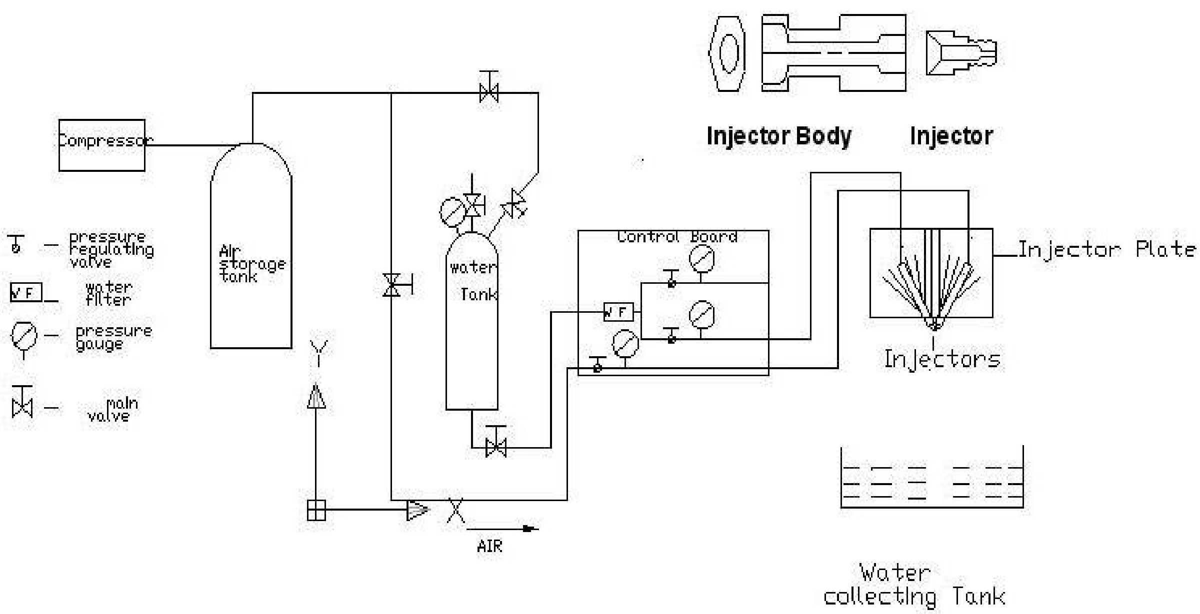

Figure 2. Experimental setup

Figure 3. Development of spray with gas pressure at constant liquid pressure

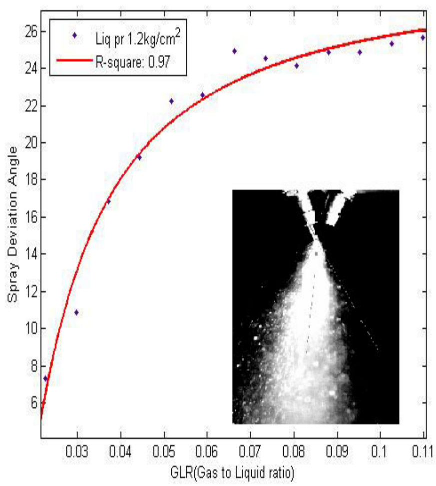

Figure4. Deviation angle variation

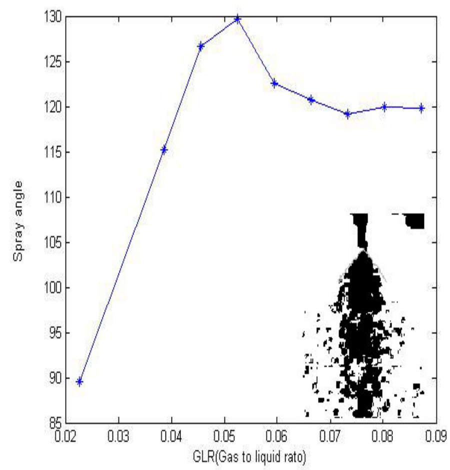

Figure 5. Spray angle (GLR-gas to liquid ratio)

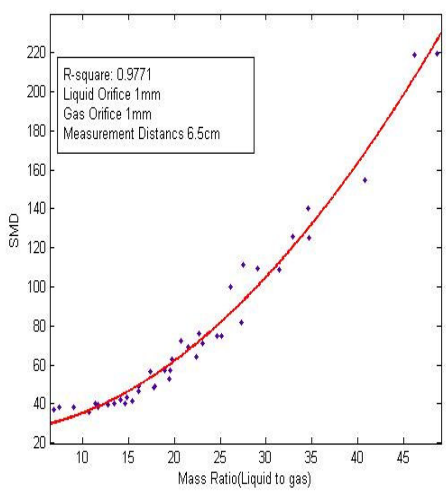

Figure 6. SMD with mass ratio

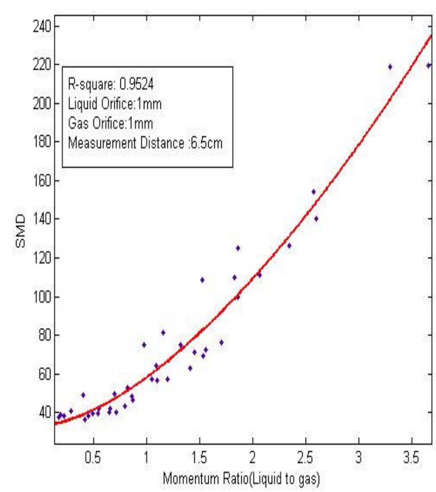

Figure 7. SMD with momentum ratio

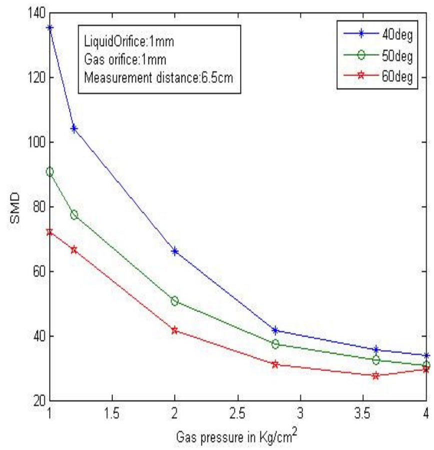

Figure 8. Effect of Impingement angle

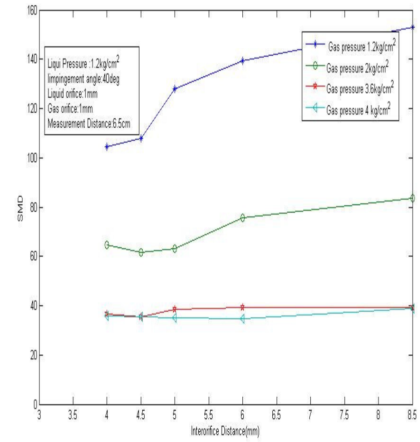

Figure 9. Interorifice distance effect

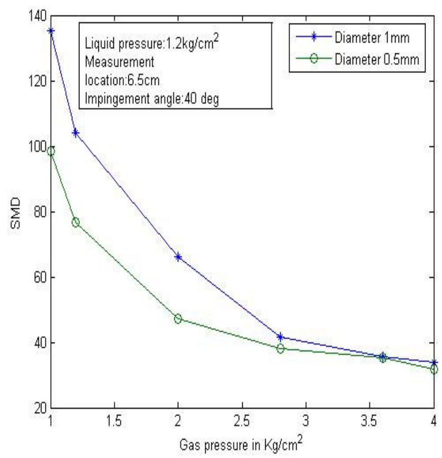

Figure 10. Effect of orifice diameter

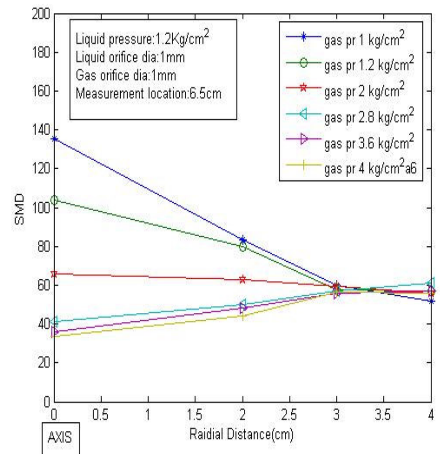

Figure 11. Distribution of SMD perpendicular to plane

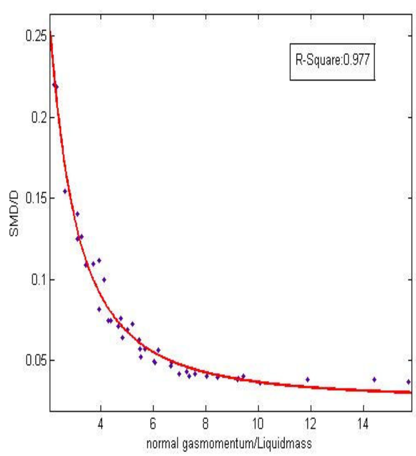

Figure 12. Normal gas momentum to liquid mass as parameter

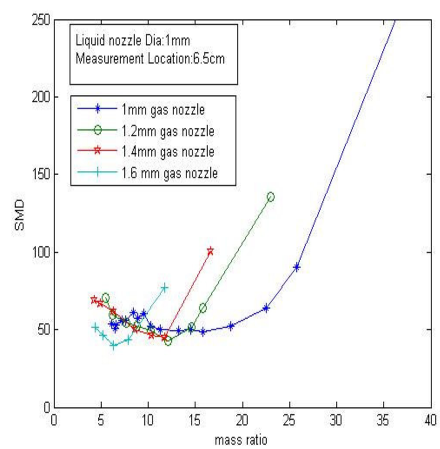

Figure 13. Gas Orifice Variation