The process of breaking or atomization of the liquid fuel into tiny droplets plays a vital role in various industrial and propulsion applications. The droplets provide a larger surface area than the liquid itself, thus, reducing the liquid vaporization time resulting in better mixing and increases the time available for complete combustion [1]. There are many issues in spray combustion that are directly related to the characteristics of the spray. For example, non symmetric spray flames and hot streaks can cause serious damage to the combustor liners and have serious impact on the combustion exit temperature distribution [2]. Thus significant improvements in the performance of the liquid fueled combustors can be achieved by understanding the evolution process of the spray and by having the ability to control the spray characteristics.

In the conventional pressure atomizers, the disintegration of liquid jet is promoted by an increase in flow velocity, which enhances both the level of turbulence in the liquid jet and the aerodynamic drag forces exerted by the surrounding medium. Since the flow rates and droplet formation process depends on the pressure drop across the injector, the quality of atomization is very poor at low flow rates. The lower limit of this flow rate depends on the atomizer design [3-5].

In simplex or pressure swirl atomizers, a swirling motion is imparted to the liquid so that, under the action of the centrifugal force, it spreads out in the form of a conical sheet as soon as it leaves the atomizer orifice. This sheet then breaks up into liquid droplets under the influence of external and internal forces [6, 7].

In effervescent atomizers [4, 8, 9], a small amount of air is introduced in the bulk liquid in a mixing chamber upstream of the discharge orifice. The injected gas forms a bubbly two-phase, gas-liquid flow when it mixes with the liquid in the mixing chamber inside the injector. When the gas bubbles emerge from the injector they ‘explode’. This rapid expansion of the gas bubbles shatters the surrounding ligaments, resulting in the formation of fine droplets [4]. The quality of atomization in such an atomizer is good but still they are sensitive to acceleration owing to the sensitivity of air bubbles to acceleration.

In the internally mixed, air assisted atomizers the atomizing air interacts with the liquid inside the injector and assists in the atomization process [10, 11, 12]. It is believed that two effects induce atomization in such an injector. First, as both the liquid and the air share the same flow passage in the injector, the liquid is restricted to a smaller available flow area. The reduction in flow area accelerates the liquid thus increasing its kinetic energy. This increase in kinetic energy of the liquid induces fine atomization. Second, the relative motion between the air and the liquid phases produces shear force at the interface. This force strips liquid droplets from the liquid filaments inducing atomization. The potential advantage of such an injector is choking of the two-phase flow of the liquid and the air as it passes through the injector, due to the low sonic velocity of the two-phase liquid mixture [11]. Therefore, the liquid fuel flow rate is relatively insensitive to variations in combustion chamber pressure and thus the fuel flow rate is not likely to respond to combustor disturbances reducing the chances of coupling of combustor pressure and fuel flow oscillations. The positive aspect of the internally mixed air assisted atomizer is that its atomization characteristics can be controlled [12]. This is possible as the atomization characteristics of the evolving spray can be varied in such a spray device by controlling various parameters like ALR (air-liquid ratio) and liquid supply pressure.
It should be pointed out that some applications of liquid atomization require formation of hollow cone sprays due to their large coverage areas. But, some applications require solid cone sprays with allows for local droplet injection. However, most of the commercial atomizers can provide either a hollow cone spray or a solid cone spray but not both. The novel atomizer studied in this paper, features the combined phenomena of both conventional swirl atomization as well as an internally mixed air assisted atomization. It uses the tangential momentum provided by the swirl as well as the additional axial momentum provided by the assisting air to produce droplets. Therefore, as seen in the presented study, the atomizer was able to provide both a hollow cone spray and a solid cone spray. Due to this feature, this atomizer can find applications in various processes without any design change.

2. EXPERIMENTAL DETAILS

2.1 Injector Design

The cross-sectional view of the atomizer discussed in this paper is shown in Figure 1.

![Fig. 1 Schematic of the Twin-Fluid Internally Mixed Swirl Atomizer](image)

This internally mixed, air assisted, swirl atomizer consist of a liquid inlet port, air inlet holes, air settling chamber, a helical passage, a spin chamber and an atomizer orifice.

The liquid is supplied to the atomizer from the liquid inlet port of 6mm in diameter. A small amount of air is introduced into the liquid stream through six radial holes, each of 0.8 mm in diameter, on the circular wall of the tube in which the liquid flows. Before interacting with the liquid the air is allowed to settle in the settling chamber. This chamber ascertains the uniform distribution of air through the holes in the circular tube. The pressure in this chamber is the total air pressure, which is kept at a slightly higher value compared to static liquid pressure in order to avoid flow of liquid in the air passage. The air coming out of the air inlet holes interacts with the liquid and creates a two-phase air liquid mixture, which flows through the helical passage with a double threaded acme screw element fitting (acme thread of 1.82mm2 cross-section). This passage imparts the tangential component to the flow velocity. The rotary flow then passes through a swirling chamber (of a conical shape of 63 degrees). This swirling two-phase flow finally comes out of the orifice (of 1 mm in diameter) of the atomizer at high velocity and spray characteristics are obtained depending upon the the ALR and the other flow conditions maintained.

2.2 Experimental Set Up

Figure 2 shows the schematic of the experimental setup used for this study. For the purpose of liquid supply to the atomizer, the liquid was first stored in a cast iron vessel. High pressure air was introduced to this vessel to drive the liquid through the pressure regulating valve, a metering valve and a flow meter to the atomizer at the required pressure conditions. The liquid injection pressure was measured using a pressure gage and could be varied using regulating valve. The flow rate of the atomizing air was controlled and measured using the air pressure regulating valve and the calibrated rotameter respectively. For the sake of corrections in density variation, the supply pressure of the atomizing air was closely monitored using a pressure gage.

![Fig. 2 Schematic of the experimental set up](image)

In the present study detailed laser flow visualization was carried out to understand the process of atomization for the atomizer being discussed. The spray produced from the atomizer was illuminated using a 25mw He-Ne laser source of 632nm wave-length. The laser beam was converted into a 1mm thick sheet, by using a cylindrical lens. The laser sheet was passed through the centerline of the spray. A CCD camera was focused perpendicular the laser sheet and the spray images were captured in the computer to which the CCD camera was interfaced. Suitable exposure time (1 ms) was maintained to visualize the cone shape and structure of the spray at varying ALR values (ranging from $10^{-3}$ to $10^{-1}$) for a particular liquid supply pressure of 30 psi (207 kPa). Images obtained using the above mentioned procedure were analyzed for the spray characteristics like cone angle, solidity and breaking distance using a image analysis code in MATLAB.