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Experimental investigations of air assisted pressure swirl atomizer

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Abstract

In pressure-swirl atomizer, a swirling motion is imparted to the fuel, leading it under the action of the centrifugal force to spread out in the form of a hollow cone as soon as it leaves the exit orifice. This kind of atomizer finds its use in gas turbines and liquid propellant rockets. The combustion usually starts at the periphery of spray and the flame front travels towards the center of the spray. The availability of air for combustion therefore decreases as the flame travels towards the center of the spray from pressure swirl atomizer. The newer approach is to develop a swirling air core in the center of the spray. This approach led to the development of air assisted pressure swirl atomizer. This paper presents the experimental investigations of air assisted pressure swirl atomizer for spray cone angle and penetration length at different injection pressure differential ranging from 3 bar to 18 bar in an increment of 3 bar. The results are then compared with conventional pressure swirl atomizer; with same nozzle dimensions, same inlet pressure and temperature, same mass flow rate and same injection pressure differential.

Keywords: Air assisted pressure swirl atomizer, spray cone angle, penetration length, injection pressure.

Introduction

The environmental and energy challenges for gas turbines require new combustion concepts. The fuel is injected into the combustion chamber without premixing and pre-vaporization and hence the atomization of liquid fuel plays a critical role in determining the combustion efficiency and reduction in emissions. In micro gas turbines, the chemical energy should be converted into thermal energy with efficiency of 90% or above and the combustor pressure drop should be less than 5% to complete the thermodynamic cycle with higher exhaust gas temperature (Peck, 2003). These requirements are difficult to meet as the residence time inside the gas turbine is inevitably small, while the residence time in conventional combustion chamber is of the order of magnitude greater than that of chemical reaction time. The micro gas turbine has large surface area to volume ratio and hence the micro gas turbine losses more heat through surface. The large surface area to volume ratio leads to quenching of reactions at wall and hence compromises the combustion efficiency (Epstein, 1997). Therefore, good atomization with smaller cone angles and penetration length are necessary for good combustion efficiency of micro gas turbine engines (Waitz, 1998). The conventional pressure swirl atomizer usually gives higher cone angle and high penetration length. Therefore, conventional pressure swirl atomizer may not serve the purpose of atomization in micro gas turbine engine.

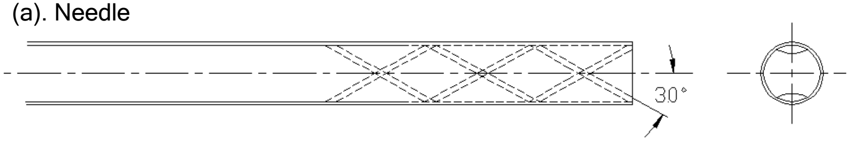
In this investigation a simple modification is proposed in the conventional pressure swirl atomizer. Air is injected in the pressure swirl atomizer after the swirl chamber near the nozzle exit. Experimental comparison of spray cone angle and penetration length is studied. The nozzle dimensions and inlet conditions are kept same for conventional as well as air assisted pressure swirl atomizer.

Air assisted pressure swirl atomizer

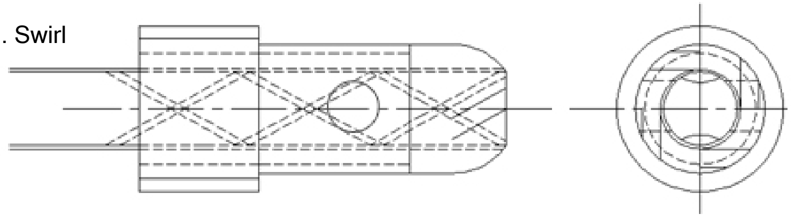
In conventional design, the combustion start from periphery and moves towards the center of spray which may lead to less availability of air for combustion near the

Fig. 1. Detailed dimensional drawing of air assisted pressure swirl atomizer (All dimensions are in mm).

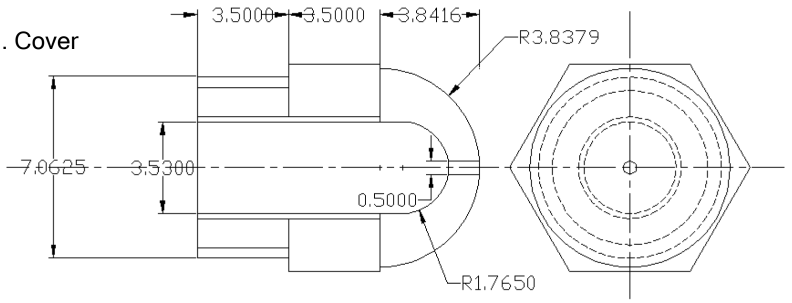
(a). Needle



(b). Swirl



(c). Cover



centre of the spray. This leads to lower combustion efficiency as complete combustion may not occur near spray centre due to less availability of air for combustion. Therefore, modifications are made by providing air inlet in the basic design of the pressure swirl to convert it into air assisted pressure swirl atomizer. Basic construction of air assisted pressure swirl atomizer is shown in Fig. 1. The swirling motion of the air is provided by using a needle. To swirl the air using needle, the helical grooves are provided. The helical grooves are made such that the included angle is obtained as per the requirement at the exit of the nozzle. By changing the helix angle of the groove the range of included angle can be achieved. The dimensions of the needle may not be derived by distinct calculation; it should only meet the requirement of air pressure. The schematic diagram of needle is shown in Fig. 1a. The design of swirl is same as the pressure swirl atomizer and arrangement is made to pass the needle by drilling the swirl through its length. The hole is drilled according to the needle dimensions. The swirl thus developed is shown in Fig. 1b.

Plate 1. Swirl Chamber of conventional

Plate 2. Swirl chamber of air assisted pressure swirl atomizer.

The plate 1&2 shows the conventional swirl chamber of pressure swirl atomizer and air assisted pressure swirl atomizer. Plate 3 shows the needle used to supply swirling air to air assisted pressure swirl atomizer. The complete assembly of air assisted pressure swirl atomizer is shown in Plate 4.

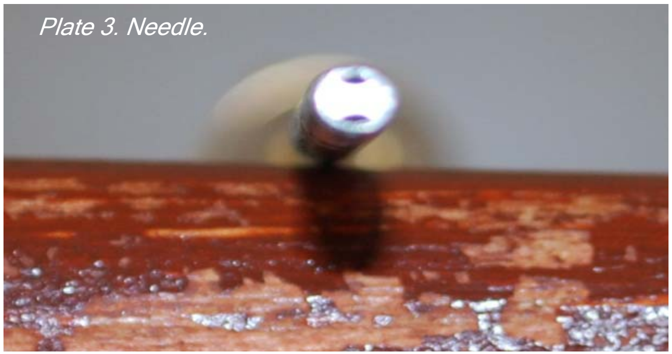


Plate 3. Needle.

Plate 4. Complete assembly of air assisted atomizer.

Experimental setup

The experimental setup for the measurement of spray penetration length and cone angle is shown in Fig. 2. Kerosene is sprayed in the test chamber from air assisted pressure swirl nozzle having half spray cone angle of 30°, 45° and 60° at pressure differential of 3 bar, 6 bar, 9, bar, 12 bar, 15 bar and 18 bar, with constant air pressure 9 bar. The photographs are taken with high speed camera. The photographs are analyzed and penetration length and spray cone angle are measured using software adobe photoshop CS4 extended.

Results and discussion

The experimental results and discussions of spray cone angle and penetration is carried out at different injection pressure varying from 3 bar to 18 bar injection pressure differential for air assisted pressure swirl atomizer designed at half spray cone angle of 30°, 45° and 60°. The results are compared with the conventional pressure swirl atomizer presented in Kulshreshtha *et al.* (2009). Fig.3 shows the spray half cone angle as a function of injection pressure for pressure swirl atomizer and air assisted pressure swirl atomizer designed for micro gas turbine engine. The spray cone angle tends to decrease with increase in injection pressure for pressure swirl atomizer. This is expected as atomization improves with increase in the injection pressure differential. Lefebvre (1989) based upon theoretical and experimental investigations mentioned that the spray angle is an inverse function of the injection pressure keeping the mass flow rate through the atomizer constant and the injector dimensions were adjusted to fit the desired condition, i.e., a completely different case form the one performed here. The influence of injection pressure on spray angle has been

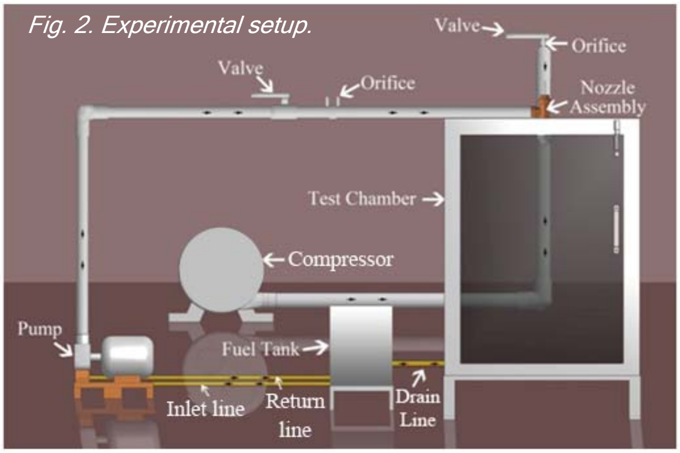


Fig. 2. Experimental setup.

Fig. 3. Variation of spray cone angle at different injection pressure differential for conventional pressure swirl atomizer & air assisted pressure swirl atomizer designed at half spray cone angle of 45°.

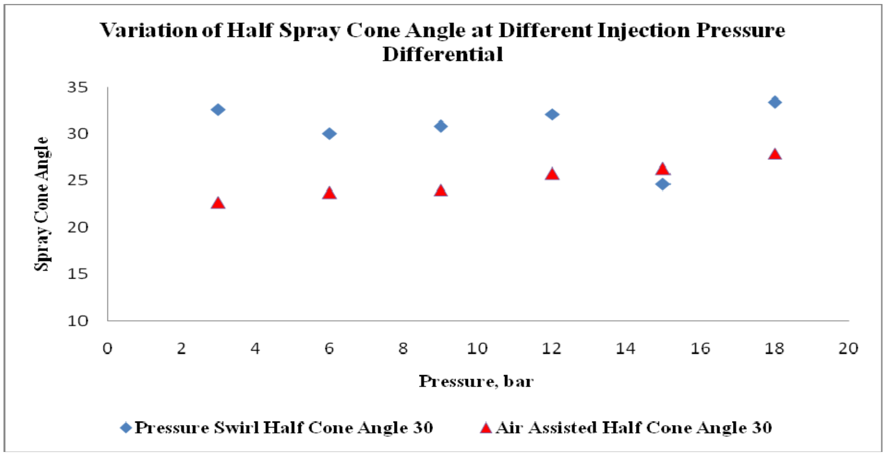


Fig. 4. Variation of spray cone angle at different injection pressure differential for conventional pressure swirl atomizer & air assisted pressure swirl atomizer designed at half spray cone angle of 45°.

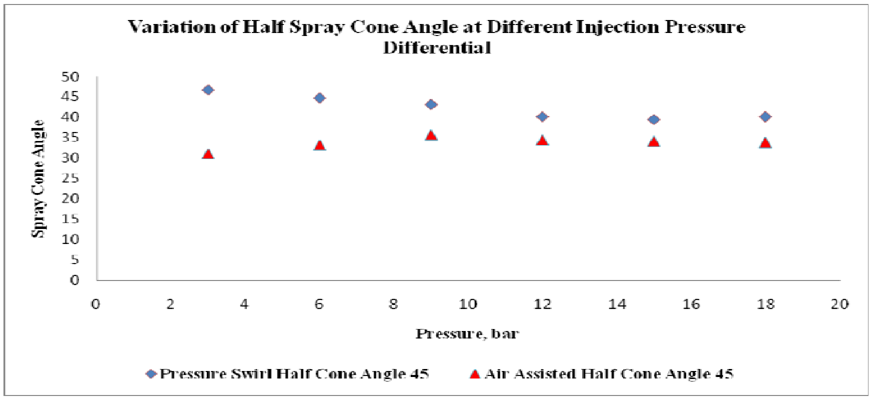
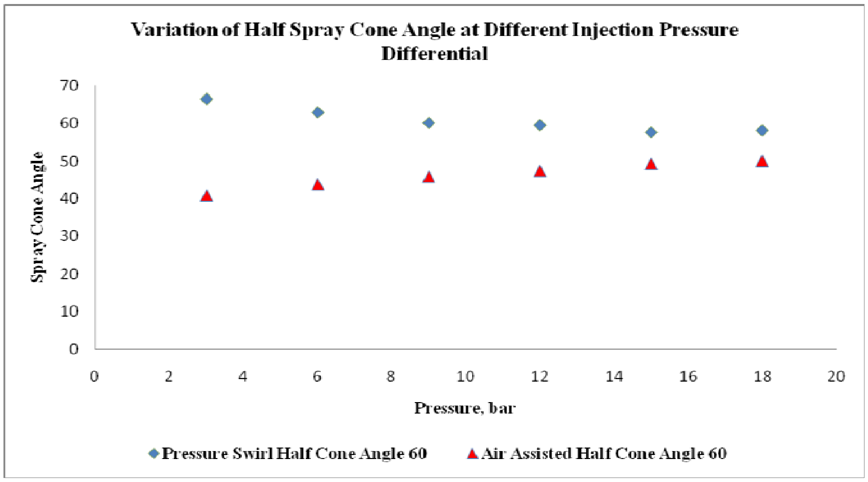


Fig. 5. Variation of spray cone angle at different injection pressure differential for conventional pressure swirl atomizer and air assisted pressure swirl atomizer designed at half spray cone angle of 60°.



investigated by several researchers for pressure swirl atomizer including De Corso & Kemeny (1957), Neya & Sato (1968), Ortman & Lefebvre (1985) and Dodge & Biaglow (1985). The results obtained by De Corso & Kemeny (1957) and Neya & Sato (1968) suggested that the equivalent spray angle is inverse function of injection pressure. Ortman & Lefebvre (1985) suggested that starting from the atmospheric pressure, increase in liquid pressure cause the spray to first widen and then contract. This phenomenon was also observed by Neya & Sato (1968), but not by De Corso & Kemeny (1957), so presumably it is a function of nozzle design.

Slight increase in spray cone angle is obtained for air assisted pressure swirl atomizer. Similar results are obtained by Pedro *et al.* (2004) from the experimental investigations on pressure swirl atomizer has suggested the increase in spray cone angle with increase in injection pressure keeping atomizer dimensions same. Probably this variation of spray cone angle is a function of nozzle design (De Corso & Kemeny, 1957). Similar trends, as obtained in Fig. 3, are obtained for designed pressure swirl and air assisted pressure swirl atomizer designed at half spray cone angle of 45° and 60° as shown in Fig. 4 and 5 respectively.

The decrease in spray cone angle with injection pressure differential leads to increase in penetration length as depicted in Fig. 6-8 for designed at half spray cone angle of 30°, 45° and 60°. The penetration length for air assisted pressure swirl atomizer is nearly constant till the injection pressure differential is 9 bar, but thereafter there is a sharp increase in penetration length. These results suggest that the penetration length can be kept small only if the fuel injection pressure is either less or equal to air injection pressure. Peters (2007) from the studies of penetration and dispersion of non reacting spray analytically suggested no variations of spray length with injection pressure. At lower fuel injection pressure, i.e., the fuel injection pressure is either equal to or less than air injection pressure; complete atomization is evident from the photograph shown in plate 5. As the fuel injection pressure is increased and reaches beyond the injection pressure of air, in this case the air injection pressure is 9 bar; the onion stage of atomization occurs as shown in plate 6. Probably due to onion stage of atomization for fuel injection pressure above 9 bar, a sharp increase in penetration length is observed (Joyce, 1949).

Fig.6. Variation of penetration length at different injection pressure differential for conventional pressure swirl atomizer & air assisted pressure swirl atomizer designed at half spray cone angle of 30^{o}.

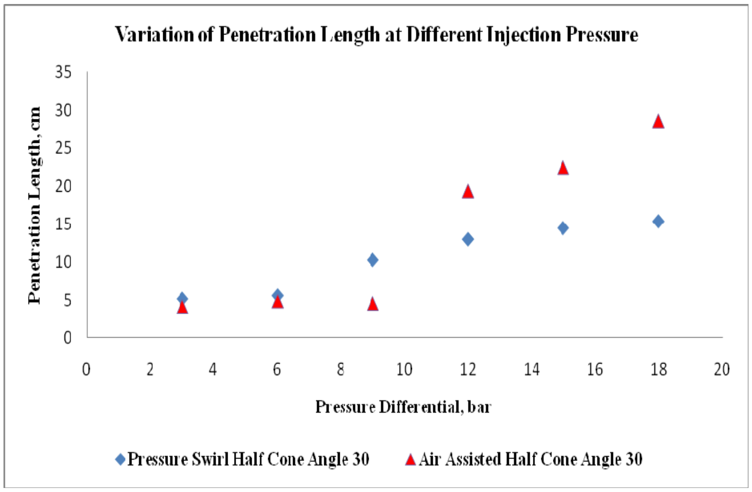


Fig. 7. Variation of penetration length at different injection pressure differential for conventional pressure swirl atomizer & air assisted pressure swirl atomizer designed at half spray cone angle of 45^{o}.

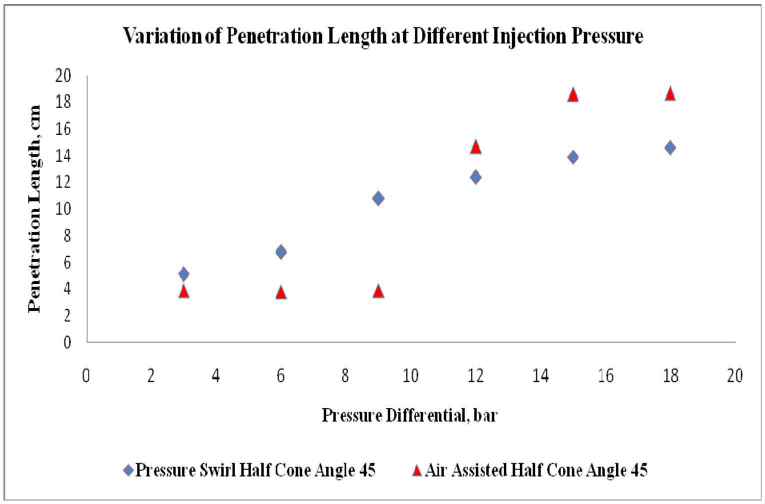


Fig. 8. Variation of penetration length at different injection pressure differential for conventional pressure swirl atomizer & air assisted pressure swirl atomizer designed at half spray cone angle of 60^{o}.

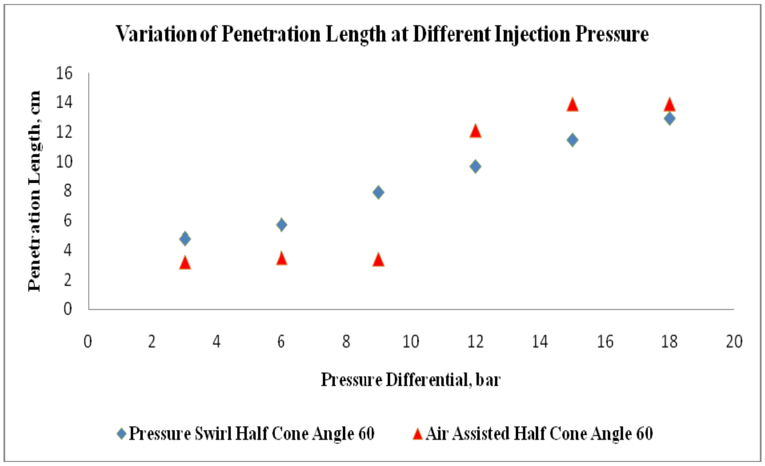


Plate 5. Penetration length for air assisted pressure swirl atomizer at fuel injection pressure of 9 bar.

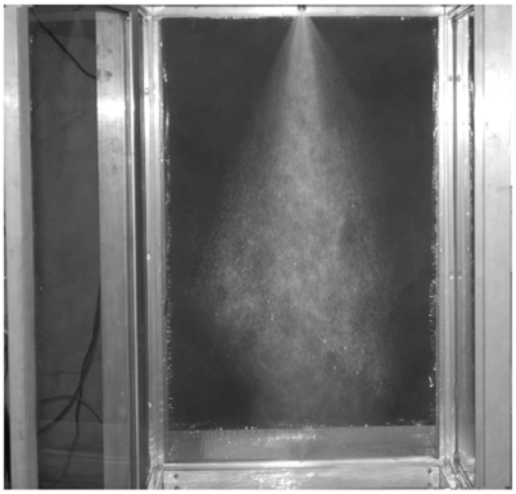
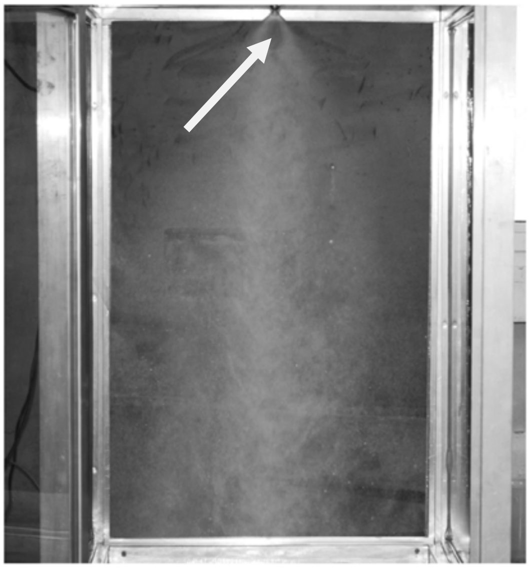


Plate 6. Penetration length for air assisted pressure swirl atomizer at fuel injection pressure of 12 bar.



Conclusion

A simple modification in pressure swirl atomizer is undertaken for the development of air assisted pressure swirl atomizer. The experimental investigations suggest that spray half cone angle tends to decrease with increase in injection pressure for conventional pressure swirl atomizer. This is expected as atomization improves with increase in the injection pressure differential. The decrease in spray cone angle has led to the increase in penetration length with increase in injection pressure. The modified pressure swirl atomizer, called air assisted pressure swirl atomizer, gives lower cone angle and lower penetration length compared to conventional pressure swirl atomizer. The onion stage of atomization occurs when the fuel injection pressure is greater than the air injection pressure.

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