DESIGN, DEVELOPMENT & EXPERIMENT ON AIR ASSISTED ATOMIZER

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ABSTRACT

The transformation of bulk liquid sprays and other physical dispersions of small particles in a gaseous atmosphere are of importance in several industrial processes and have many other applications in agriculture, meteorology, and medicine. Numerous spray devices have been developed, and they are generally designated as atomizers. The process of atomization is one in which a liquid jet or sheet is disintegrated by the kinetic energy of the liquid itself, or by exposure to high-velocity air or gas, or as a result of mechanical energy applied externally through a rotating or vibrating device. Combustion of liquid fuels in diesel engines, spark ignition engines, gas turbines, rocket engines, and industrial furnaces is dependent on effective atomization to increase the specific surface area of the fuel and thereby achieve high rates of mixing and evaporation. The process of generating drops is called atomization. The process of atomization begins by forcing liquid through a nozzle. The process of atomization is a process where a liquid jet or sheet is broken up by the kinetic energy of the liquid itself or by exposure to high velocity air or gas. These ligaments then break up further into very small "pieces" which are usually called drops, droplets, or liquid particles.

Keyword: - *Atomizers, Sprayers, Swirler, Nozzles etc.*

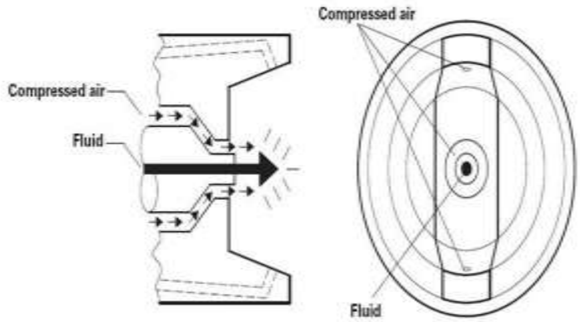
1. INTRODUCTION

The conversion of bulk liquid into a dispersion of small droplets ranging in size from submicron to several hundred micrometer in diameter is of importance in many industrial processes such as spray combustion, spray drying, evaporative cooling, spray coating, and drop spraying and has many other applications in medicine, meteorology, and printing. Numerous spray devices have been developed which are generally designated as atomizers, applicators, sprayers, or nozzles.

A spray is generally considered as a system of droplets immersed in a gaseous continuous phase. Sprays may be produced in various ways. Most practical devices achieve atomization by creating a high velocity between the liquid and the surrounding gas. All forms of pressure nozzles accomplish this by discharging the liquid at high velocity into quiescent or relatively slow-moving air. Rotary atomizers employ a similar principle, the liquid being ejected at high velocity from the rim of a rotating cup or disc. An alternative method of achieving a high relative velocity between liquid and air is to expose slow-moving liquid into a high-velocity stream of air. Devices based on this approach are usually termed air-assist, air blast or, more generally, twin-fluid atomizers.

Most practical atomizers are of the pressure, rotary, or twin-fluid type. However, many other forms of atomizers have been developed that are useful in special applications. These include "electrostatic" devices in which the driving force for atomization is intense electrical pressure, and 'ultrasonic' types in which the liquid to be atomized is fed through or over a transducer which vibrates at ultrasonic frequencies to produce the short wavelengths required for the production of small droplets. Both electrical and ultrasonic atomizers are capable of achieving fine atomization, but the low liquid flow rates normally associated with these devices have tended to curtail their range of practical application.

The atomizer is a key part of the liquid fuel combustion. Many experimental and theoretical studies about the atomization method have been carried out since the atomizer was used on the diesel engine in 1892 and many atomizers were created and developed. At present, there are four typical types of atomizers used universally. They are the pressure atomizer, air-assist atomizer, air-blast atomizer and rotary atomizer. The air spray atomization with high velocity and coaxial atomization is shown in figure 1 and 2.



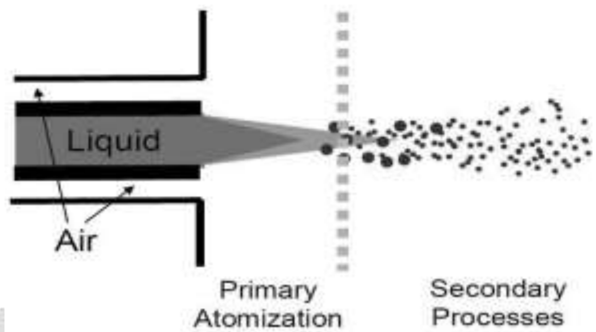


Figure 1: Air Spray Atomization with High Velocity Air Figure 1: Schematic of Coaxial Atomization Processes

1.1 Factors Influencing Atomization

The performance of any given type of atomizer depends on its size and geometry and on the physical properties of the dispersed phase (i.e. liquid being atomized) and continuous phase (i.e. the gaseous medium into which the droplets are discharged).

For plain orifice pressure nozzles and plain jet air-blast atomizers, the dimension most important for atomization is the diameter of the final discharge orifice. For pressure swirl, rotary and pre-filming air-blast atomizers, the critical dimension is the thickness of the liquid sheet as it leaves the atomizer. Theory predicts, and experiment confirms, that mean drop size is roughly proportional to the square root of the liquid jet diameter or sheet thickness. Thus, provided the other key parameters that affect atomization are maintained constant, an increase in atomization scale will impair atomization.

1.2 Fluid Properties Affecting the Spray:

A variety of factors affect droplet size and stream of liquid atomizes. Among these factors are fluid properties of surface tension, viscosity, and density as shown in figure 3.

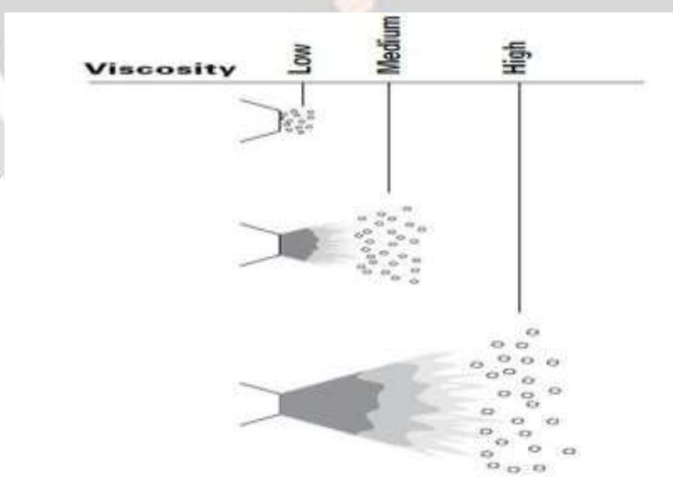


Figure 3: Viscosity and Droplet Size When Atomization Occurs

2. DESIGN CALCULATION:-

2.1 Design of Air Assisted Atomizer

The 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. Air assisted atomizers are widely used for fuel injector in gas turbine engines and have a number of advantages including fine atomization, relatively little change in performance over a wide range of fuel flow rate and low pressure losses.

$\dot{m}_f$ = ρf*A_f*V_f …………………………………………………… (1)

The significant progress has been made in the design of air assisted atomizer. There are two main approaches to this calculation. The first approach uses the principle of the maximum mass flow and the second uses the equation of conservation of momentum. $V_f = c_d\sqrt{\frac{2\Delta P_f}{\rho_f}}$…………………………………………………… (2)

Both the approaches differ with respect to the methodology used, but they consider the establishment of relationships between the same characteristic dimensions of an atomizer, geometric constant K, as well as spray parameters i.e. coefficient of discharge Cd, nozzle angle α.
A calculation method based on the principle of maximum flow with the modified free vortex equation is presented in Ranganadha Babu. Co-efficient of discharge is given by C_d = 0.64.

The first phase of calculations refers to an ideal liquid. From the equation of equivalence ratio, mass flow rate of air can be calculated. Now, equivalent ratio for kerosene Ø = 2

This thickness was related to spray cone angle and to the velocity coefficient. Knowledge of this coefficient and its changes caused by the atomizer dimensions, liquid properties and atomization condition is the basic condition that allows the design of air assist atomizer.
The aim of the design is to determine the dimensions of an air assist atomizer for the given flow rate of fuel ($\dot{m}_f$), injection pressure of fuel (ΔP_f), nozzle angle (α), mass flow rate of air ($\dot{m}_a$) air injection pressure (Δ Pa) and fuel properties (fuel density ρ_f and kinematic viscosity υ). The basic dimensions of air assist atomizer are given in Figure 4.

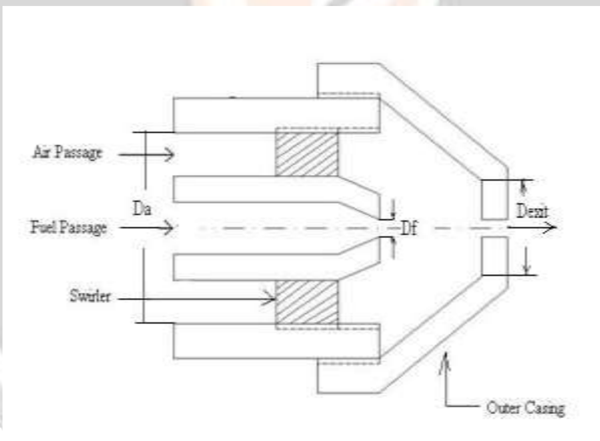


Figure 4: Air Assisted Atomizer

$$Ø = \frac{(\frac{\dot{m}_f}{\dot{m}_a})act}{(\frac{\dot{m}_f}{\dot{m}_a})stochiometric} \qquad (\frac{\dot{m}_f}{\dot{m}_a})act = Ø(\frac{\dot{m}_f}{\dot{m}_a})sto$$

For kerosene $(\frac{\dot{m}_f}{\dot{m}_a})stochiometric = 0.06797$

Now the mass flow rate of air is given by the continuity equation $\dot{m}_a$ = ρ_a A_a V_a……………………………… (3)
Where V_a = $\sqrt{\frac{2\Delta P_a}{\rho_a}}$

As per the ideal gas equation the density of air is given by equation $\rho_a = \frac{P_a}{R\,T_a}$ …………………………………… (4)

The air is injected in annular space between atomizer casing and liquid injector. The annular area required for the air passage can be calculated by equating equation 5.

Area for air passage from equation. $A_a = \frac{\dot{m}_a}{\rho_a V_a}$ …………………………………………………………… (5)

Air passage is annular, therefore it can obtain by equation. $A_a = \frac{\pi}{4}(D_a^2 - D_f^2)$ ……………………………………… (6)

2.2 Swirler Dimension:-

In air assist atomizer swirling air is introduced to the liquid which is to be atomized. The swirler may have axial vane or radial vane. The axial swirlers are widely used in current combustors. Swirler effective area number of vanes, angle and thickness are the main parameters for design. Typical ranges of values for these variables are shown in table 3.1. Figure 3.2 shows the basic dimensions of swirler vane.

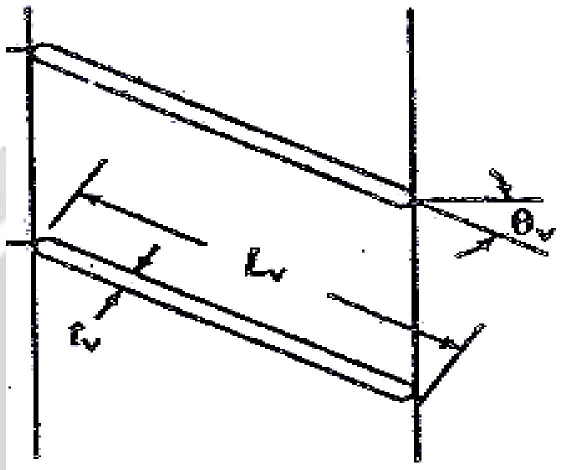


Figure 5: Swirler Vane Dimensions

Vane angle	$30^o - 60^o$
Vane thickness	0.75 – 1.5 mm
Number of vanes	8 – 16

Table-1: Swirler Dimension

The design of a swirler typically starts with a desired airflow, at a given design point inlet temperature, pressure and pressure drop across the swirler. Additional design requirements will include an inner radius needed to provide space for a centrally mounted fuel injector, a minimum vane material thickness based on manufacturing considerations, and a vane angle based on previous successful designs and basic swirler studies.

In the present study axial swirler is selected for the air swirling. The swirler physical flow area is simply. The annuls area corrected for swirl and flow blockage. $A_s = \pi\,(r_a^{\,2} - r_f^{\,2})\cos\theta_v - n\,(r_a - r_f)t_v$ ……………………………… (7)

The overall exit dimensions can be found out from the equation of continuity and velocity as

$A_a V_a = A_s V_s$, where $V_s = \frac{A_a V_a}{A_s}$ ………………………………… (8)

$v_{exit} = \sqrt{\frac{2 \times \Delta p}{\rho_{exit}}}$

Densities of mixture of air and fuel can be calculated on the bases of volume fraction of the individual components.

$\therefore \rho_{exit} = \alpha_{air} \times \rho_{air} + \alpha_{fuel} \times \rho_{fuel}$ ……………………………………………… (9)

Now, Exit area can be calculated from the equation of mass flow rate. $m_{mix} = \rho_{exit} A_{exit} V_{exit}$ ………………………… (10)

An important design feature of this atomizer is that the bulk fuel is first spread into a thin, continuous sheet, and then exposed to high-velocity, swirling air streams on the liquid sheet. The air assisted atomizer is designed for tubular type combustion chamber developed. The design input data is given in table 2.

Mass flow rate of fuel $\dot{m}_f$	7.2×10^{-3} kg/s
Pressure at which fuel is supplied ΔP_f	18 bar
Density of fuel (kerosene) ρ_f	780 kg/m^3
Differential air pressure ΔP_a	4 bar

Table-2: Design Data

The Design is carried out using the above methodology and the desired Atomizer is as shown in figure 6.

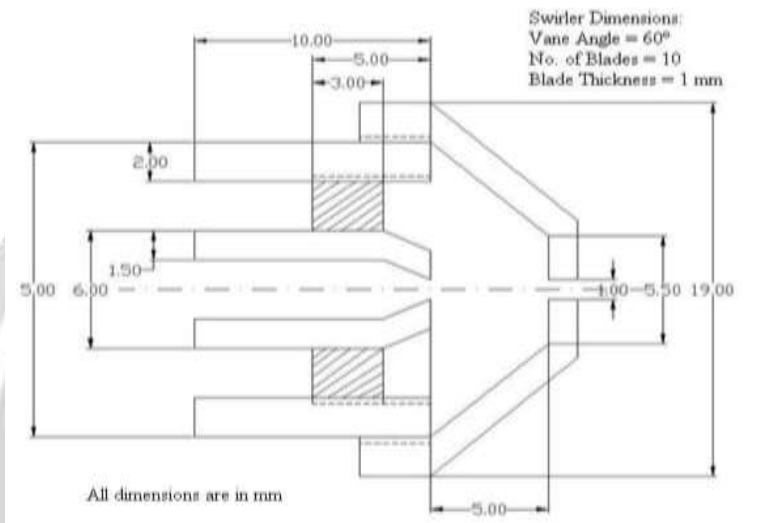


Figure 6: Dimensional Drawing of Designed Air Assisted Atomizer

Physical Parameter	Calculated Values
V_f (Velocity of fuel)	43.5 m/s
$\dot{m}_a$ (Mass flow rate of air)	0.1059 kg/s
V_a (Velocity of air)	338 m/s
ρ_a (Density of air)	5.822 kg/m^3
A_a(Passage air of supplied air)	$2.246 \times 10^{-5}\ m^2$
D_a (Diameter of supplied air)	7×10^{-3} m
A_s (Area of Swirler)	$6.708 \times 10^{-3}\ m^2$
V_s (Velocity at swirler)	1131.70 m/s
V_{exit} (Velocity at exit)	311.435 m/s
A_{exit} (Area of exit)	24.36 mm^2
d_{exit} (Diameter of exit)	5.57 mm

Table-3: calculated value of physical parameter

3. EXPERIMENTAL SETUP

3.1 Basic Setup Model

The experimental setup is developed for the measurement of various characteristic of nozzle. The setup is equipped to measure the spray penetration length and spray cone angle. Fig.4.1 shows the schematic diagram of experimental setup.

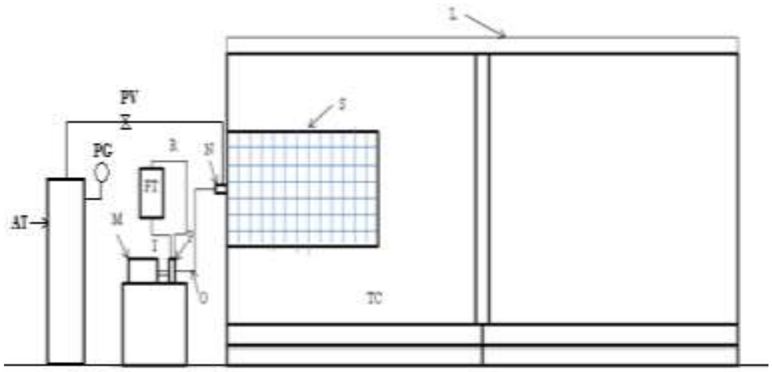


Figure 7: Basic Setup Model

Where, FT = Fuel Tank, N = Nozzle & Nozzle Assembly, O = Outlet Line from Pump,
S = Measuring Scale, M = Motor, PV = Pressure Control valve,
P = Pump, PG = Pressure Gauge, AT = Air Tank
I = Inlet Line to pump, TC = Test Chamber, R = Return Line to Tank,
L = Source of Light,

4. EXPERIMENTATION

The air assisted atomizer is developed and different spray characteristics are measured experimentally like spray cone angle and penetration length.

The experiment performed on designed air assisted atomizer for fuel injection pressure as 8,10,12,15 and 18 bar for different air pressure 1, 1.5 and 2 bar.

The photographs for different conditions are taken by high speed camera. The photographs are analyzed using adobe Photoshop CS5 to measure penetration length and spray cone angle.

Fuel pressure (bar)	**Air pressure** (bar)	**Penetration length** (cm)
8	1	13.12
8	1.5	13.83
8	2	18.1
10	1	13.9
10	1.5	16.91
10	2	19.52
12	1	14.48
12	1.5	17.96
12	2	21.52
15	1	16.51
15	1.5	19.87
15	2	23.95
18	1	21.44
18	1.5	22.39

Table-4: The penetration length measured for different conditions

Fuel pressure (bar)	**Air pressure** (bar)	**Cone angle** (deg.)
8	1	28.4
8	1.5	27.7
8	2	26.6
10	1	26.8
10	1.5	26
10	2	24.6
12	1	26.4
12	1.5	24.2
12	2	23.4
15	1	24
15	1.5	22.4
15	2	19
18	1	21.4

Table-5: The spray cone angle measured for different conditions

5. CONCLUSION

The design and development of air assisted atomizer is done with the help input parameters of the Tabular type Gas Turbine combustion chamber. And the experiment has been performed at different fuel injection pressure varies from 8 to 18 bar at different air pressure 1 to 2 bar. The experimental investigations suggest that spray cone angle tends to decrease with increase in injection pressure for air assisted 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.

7. REFERENCES

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