Journal of Cardiovascular Disease Research

ISSN:0975-3583,0976-2833 VOL8,ISSUE04,2017

Experimental investigation and optimization of fuel injector in gas turbine engine in trinary region

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Abstract

Conversion of bulk liquid in to small droplets raging in sub microns to several hundred of microns that process is Atomization it is a complicated process. Fuel injection is a necessary component for all high pressure engine because the air must precisely controlled due to extreme pressure and temperature found in high compression turbine engine on the trinary range This kind of simplex injector finds its use in combustor (Direct injection method

The need to minimize the combustor length usually leads to a spray angle of around more than 60°. The experimental investigations of simplex plain jet injector for spray cone angle and penetrant length at different injection pressure ranging from 0.5bar to 3bar in an increment of 0.5bar is carried out. The results are then compared with different injector dimensions of 2mm, and 2.5mm with water and Keresan as fuel. The discharge coefficient and the spray cone angle were evaluated experimentally and compared with the available data. The investigation and optimization of fuel injection is carried out to identify the different spraying stages so that combustion can be sustained and mixing of air –fuel is time lined. Furthermore the mixing enhances the combustion followed by increase in combustion efficiency and low emission.

Keywords— Injector, penetration length, Spray cone angle, Combustor, Test chamber, Atomization, water, kerosene

I. INTRODUCTION

Injector is the one of the major role playing in numerous engineering application in which the liquid must be broken down in to very small droplets, that broken down droplets are purposefully utilized for combustion process in burners, IC- engines, and

turbo jet engines, rocket engines ,it`s also used for coating purpose, Drying, or spraying process In industries like surface treatment, spray painting the combustion process takes place in the aircraft engines ,automotive engines and industrial furnaces are depends on the atomization process and to increase the specific area of the fuel spray patterns by mixing and evaporation at high rate The fuel spray characteristic are mainly depends on the injection pressure, density of the fuel, velocity of the fuel ambient pressure of gas and temperature of the gas, current Development of next generation gas turbine engine is driven by advancements in performance that are related to fuel Injection, to improve the performance of the engine by improved turn down of the fuel or specific fuel consumption designed for turbine engine with high pressure ratios, and another major challenge to gas turbine engine Nowadays have to reduce the pollution emission, especially NO_X, CO2, emission due to lean burn of hydrocarbon fuels, to reduce the lean burn by improving the atomization process of the air and fuel mixture, for the high atomization process the high pressure required and the velocity of the fuel also to be increase by varying the dimensions of the fuel

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injector nozzle and varying the fuel pipe line dimension, the optimized fuel injector will be placed trinary range and on this range the fuel is replaced with water the constant chamber should be capable of 140 psi pressure(,10 bar) the spray cone angle and penetration length are compared by experimentally ,the paper done experimental and theoretical investigation of the ambient pressure of the spray characteristic of the fuel ,the image of the atomized spray had been analyzed by the acrylic sheet with measurements ,carbon sheet and bluethelights with digital camera fuels used for testing with water and Keresan(Vasanthy and Jeganathan 2007, Vasanthy et.al., 2008, Raajasubramanian et.al., 2011, Jeganathan et.al., 2012, 2014, Sridhar et.al., 2012, Gunaselvi et.al., 2014 , Premalatha et.al., 2015, Seshadri et.al., 2015, Shakila et.al., 2015, Ashok et.al., 2016, Satheesh Kumar et.al., 2016).

Motivation of work

- Evaluate and develop the injector concept of advance gas turbine combustor
- Develop and troubleshoots the characterize of air /fuel mixing for liquid injector
- Diagnosis and apply the mechanism understanding of the candidate injector concept and to optimization of the design
- Develop the thrust by spraying the water in trinary region and also in exhaust nozzle (after burner)

II. *INJECTORS*

Injector is the components which mainly considers to digamous the success or failure of the combustion chamber and to find the performance of the engine too

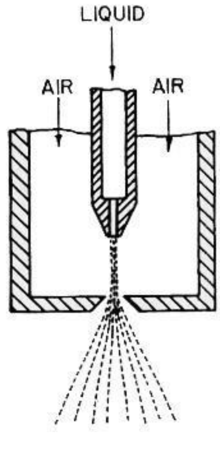

Figure 1 .Physical properties of fuel injector

A. Concept of the injector

When a liquid is pass through the at a small nozzle hole under high applied pressure the high pressure energy is converted in to high kinetic energy n the discharge point which is produce the atomization by converting small droplets into very finite spray nearly gaseous stage .sub microns to several hundreds of microns

B. *Injector Assembly*

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The performance of the combustor is depend on the major performance impact of the fuel injector, In most of the gas turbine engine the simplex nozzle is used to discharge the fuel through a single orifice that the development of the simplex nozzle design is Air Blast Fuel Nozzle .This type of nozzle produces very fine droplets of fuel, The atomization degree depends on the primary air pressure for mixing and vaporization process. When the high velocity of air passed the core vortexes forms and its make the fluid in to hallow cone shape when it`s comes out from the injector The spray cone angle is developed up to 60º

The experimental finding of spray cone angle by using plain jet air blast injector nozzle. The injector nozzle material is made up of mild steel and ,stainless steel (SS316), brass The other material used for the construction of the injector are able to with stand up to 140.5 psi (10 bar)

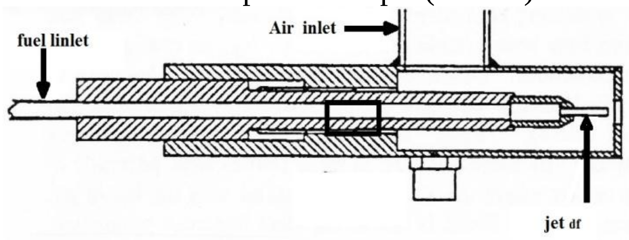
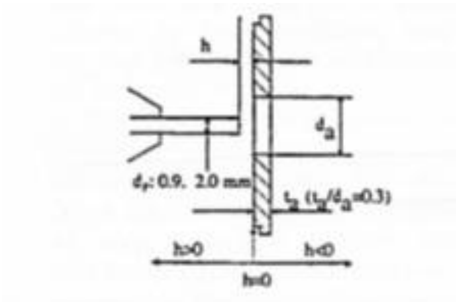


Figure 2.new air blast injector setup



III. FUNDAMENTALS OF ATOMIZATION

Atomization is the process in which the conversation of bulk liquids or set volume of fuel is dissipated disintegration of the jet in to many small finer droplets .That the small droplets are evaporated by applied high pressure air and make that in to gaseous or combustible form .These process determine the structure and shape of the injector .The penetration length of the spray resulting by the characteristic of droplet size distribution and droplet velocity distribution atomization process is controlled by the factor of fuel ,oxidizer ,and injector properties

In the swirl injector the atomization spray stages where differ depends on the velocity of the fuel and pressure of the air. The stages are shown in the picture as follows

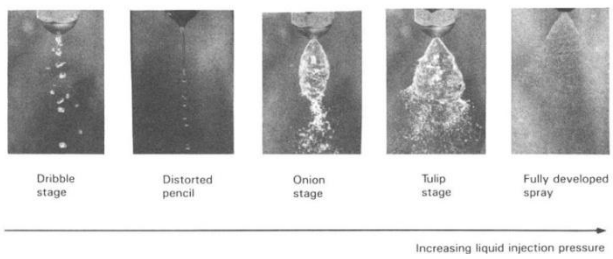


Fig 3. Various stages of atomization

Theoretical method consideration for design and spray predictions for the injector

The flow number which is the key parameter of the injector to represents the effective a

$$FN = \frac{\dot{m}}{\sqrt{\Delta P \rho}} \quad -(1)$$

Whenever studying the atomization process the parameter of droplet size is too important the ultimate aim to design the injector to make combustion process easy and quick. For that the proper and non-disturbed, uniform flow of droplets is required the time required to evaporate and to combustion is depends on the size of the droplet too

Find the drop let size Shown by the D^2 law

$$D^2(t) = D0^2 - KT \quad - \ (2)$$

To find the saturated mean diameter of the droplet is calculated by the equation SMD

The fuel injector discharge coefficient is calculated by the Equation C_d

$$Cd = \frac{\dot{m}_L}{A_o\sqrt{2 \times \rho_L \times \Delta P_L}} \quad -(3)$$

The mass flow rate is calculated by the steady flow energy equation to find the discharge Q .for pressure at 70 psi

$$Q = \dot{m}\{H_2 \times H_1 + P_2V_2 - P_1V_1\} \ -(4)$$

The equation is simplified as

$$Q = \dot{m}\{C_P\Delta T + P_2V_2 - P_1V_1\} \text{ -(5)}$$

Q - Discharge heat energy
$\dot{m}$ - Mass flow rate
v_1&v_2 - Volume

Gas Turbine Ignition System

In the gas turbine engines the ignition systems are primarily for start- up .once the engine is started the ignition system is normally turned off That the system having self-sustained inside of the combustion chamber when the combustion of air &fuel mixture. After the start up the ignition system is no longer required .And also the ignition system is used to precaution against the engine flame out during on the critical operating condition or under the not ideal operating condition
When the turbine engines are in critical suctions like take-off, bad weather and landing or turbulence

Turbine engines which required a high energy, and high –intensity spark for the ignition when engine at high altitude and cold temperature to re-start. The auto –Ignition and auto relight systems are used in the gas turbine engine to provide the ignition to avoid the flame –out condition. The flame out condition is sense by the burner or by the discharge pressure of the compressor. When the air /fuel mixture is not in a

ISSN:0975-3583,0976-2833 VOL8,ISSUE04,2017

proper ratio or that the flow pattern, flow low induced velocity occurs the flame out condition will occur and it cause the failure in the engine

FUEL SYSTEM

In all operating conditions the correct ratio amount of fuel is supplied to the engine by the fuel system. The thrust required for the operation of the engine power increase and decrease by the fuel system. The power is increased or decreased in the combustion chamber by varying the fuel flow. The fuel system delivers the fuel to the combustion chamber not only in a perfect quantity and also perfect condition also. That kind of fuel must be atomized and the atomization process is taken by fuel injector nozzle .The boost pump which is used to pump the fuel from the fuel tank to combustion chamber the velocity given to fuel by the boost pump. The pump is located in the fuel tank. There was two boost pump where attached on the each main tank in the Boeing -747 the main fuel tanks are attaché din the wings. The most commonly centrifugal type of boost pump where used in aircrafts (Manikandan et.al., 2016, Sethuraman et.al., 2016, Senthil Thambi et.al., 2016, Ashok et.al., 2018, Senthilkumar et.al., 2018, Sundar and Jeganathan 2019 & 2020, Anandan et.al., 2019, Murugavel et.al., 2019, Arokiaswamy et.al., 2019 & 2020, Ganesh Babu et.al., 2020, Gomathi et.al., 2019 & 2020, Manju et.al., 2020, Leema Rose et.al., 2020).

Gas Turbine Fuels

There are two category of fuels are used.

Kerosene had more heat energy than the gasoline per gallon and hydro carbon fuels are used for the combustion process. All turbine fuels are dyed in different colors to grade them on order. That the fuels are in light straw color or otherwise colorless,

EXPERIMENTAL SET UP

The experimental setup is made and developed to measurement of spray characteristic and spray cone angle the setup is shown in the following fig (4)

The technique which is used to find the spray cone angle by two methods one is shadow graphic method and another one is using setup of chamber with acrylic sheet and lights. The setup having the compressor with 100psi maximum next to that T-joint which helps to separate the pressure air to the fuel that is secondary and primary air flow the pressure was measured by the pressure gauge which is mounted in the pressure regulator to control the air flow the valves are connected with the tube which

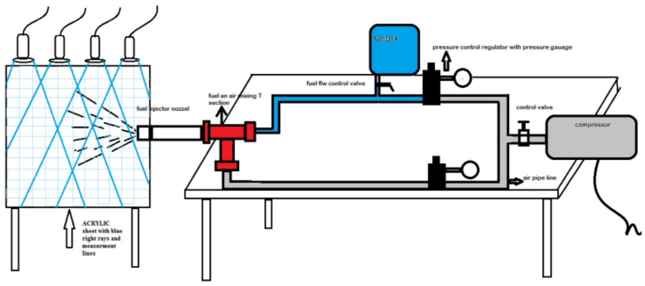


Fig 4. Experimental setup of fuel injector

capable of 10 bar pressure and the fuel tank had a 12 liter fuel capacity the injector design setup is placed in the stand and the test chamber is attached with the stand the test chamber having 2m× 1m×1m three sides of mild steel plates having 3mm thickness and the other side is covered with the acrylic sheet which having

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10mm thickness. The spray was viewed by the acrylic sheet. The spray cone angle will not be clearly visualization on the day time for that we are using the blue lights to calculate the spray cone angle and penetration length .that all are recorded and taken picture by digital camera fitted on the chamber

Fig 5.fuel injector nozzle setup

Fig 6. Testing chamber setup

RESULT AND DISCUSSION

Design of the injector nozzle

The various injector nozzle which have 2mm, 2.5mm. Diameter discharge orifice and with different cone angle. The fuel flow tube is 2mm diameter on the end and it will compresses the fuel when decrease the diameter 6mm to 2mm step by step and. The nozzle cone angle also changing to 30^{o},$40^{o}$the nozzle outer diameter is 11mm and inner diameter is 10mm length of the nozzle from the t section is 100mmwater was supplied to injector and sprayed with the help of compressor .Fuel tanks are connected with hose which with pressure regulator the pressure was maintained at 70 psi and the 30 psi, the fuel wassprayed at horizontal axis 4 feet above from the ground there are 180 data points were

ISSN:0975-3583,0976-2833 VOL8,ISSUE04,2017

Fig 7. Injector nozzle with 2mm diameter

Collected on the test system at various injector nozzle diameter, nozzle distance on the chamber, and various velocity of flow rates it is very help to understand the combination of surface tension liquid inertia and aerodynamic forces affected on the liquid break up

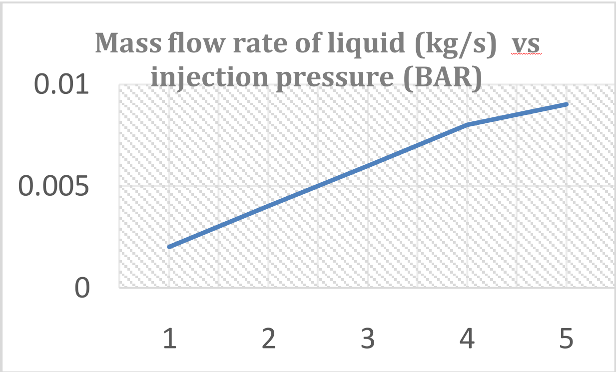

Fig 8.Mass flow rate of liquid (kg/s) vs injection pressure

The design of the plain jet air blast nozzle is carried out the injection pressure at 5bar. Injection pressure is Varied from 0.5 bar to 5 bar the spray cone angle and penetration length are not achieved on the 0.5 to 1 bar the fluid films are not broken in to small droplets from 2bar to 5 bar

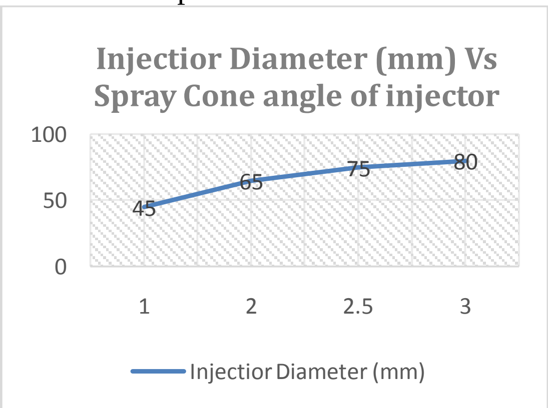

Fig 9.Injector Diameter (mm) Vs Spray Cone angle of injector

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The fluid film started to break and form a fine spray at high pressure the cone angle also increased. The characteristic parameters which is injector diameter ,discharge coefficient ,injection pressure ,fluid density where analyzed by shadow graphic and acrylic sheet method from the result ,when injector pressure increases as the discharge coefficientdecreases .increase the injection pressure increase in spray cone angle the mass flow rate also increase with the diameter of the injector and injector pressure. In this work there are different injection pressure and injector dimensions was investigated and the parameters which collected on the testing are compared. As the part of the future work the same plain jet swirl nozzle injector atomizer experimental investigation carried out for the of injection pressure on flame length with different liquid fuels

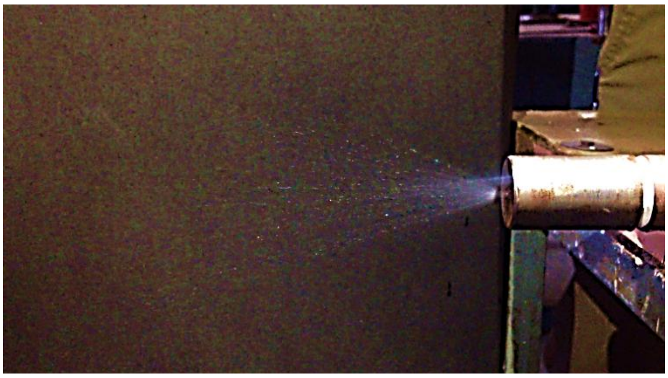

Fig10. Fuel droplets separation

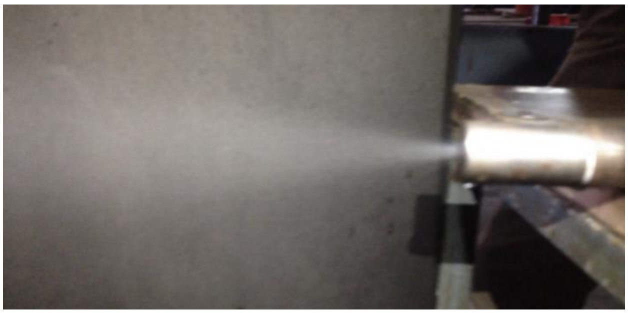

Fig 11. Atomization of fuel at 2 bar pressure

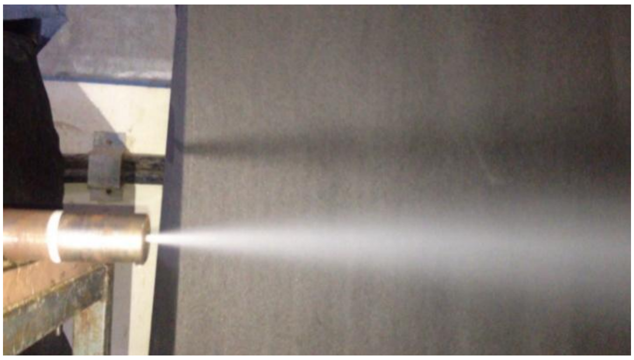

Fig 12.penetration length increased at 4 bar pressure

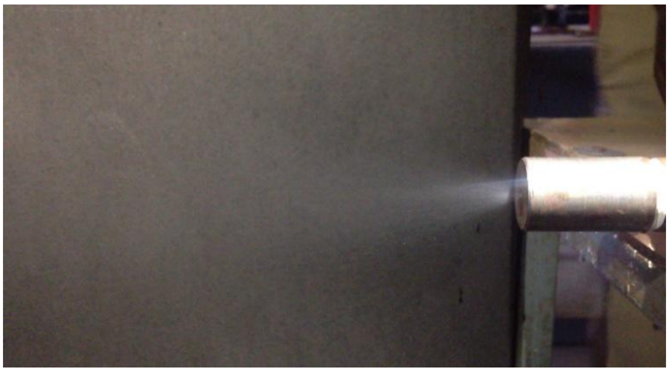

Fig 13. Spray cone angle increased at 3 bar pressure

CONCLUSION

The design of the plain jet nozzle is carried out the injection pressure at 5bar. Injection pressure is Varied from 0.5 bar to 5 bar The spray cone angle and penetration length are not achieved on the 0.5 to 2 bar the fluid films are not broken in to small droplets from 2bar to 5 bar the fluid film started to break and form a fine spray at high pressure the cone angle also increased. The characteristic parameters which is injector diameter ,discharge coefficient ,injection pressure ,fluid density where analyzed by shadow graphic and acrylic sheet method from the result ,when injector pressure increases as the discharge coefficient decreases .increase the injection pressure increase in spray cone angle the mass flow rate also increase with the diameter of the injector and injector pressure. In this work there are different injection pressure and injector dimensions was investigated and the parameters which collected on the testing are compared.*At the primary test with water the mass flow rate is 0.0086 kg/s for 2mm diameter injector at 3 bar pressure the cone angle is 54 degree the penetration length is 15cm -25cmm*As the part of the future work the same plain jet swirl nozzle injector atomizer experimental investigation carried out for the of injection pressure on flame length with different liquid fuels

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