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Design and Analysis of Rocket Engine Injectors

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Abstract—*The quality and homogeneity of an atomized fluid and therefore the stability and efficiency of hybrid engine are basically determined by the oxidizer injection system. The hybrid rocket engine uses gaseous oxygen as oxidizer. Evaporation and combustion of the atomized gaseous oxygen droplets needs to be completed inside the combustion chamber, which is less than one meter long. The pressure drop over the injector protects the feed and tank system against backflow of hot combustion gas. To respect this amount of requirements the most important equations and design of several injectors are explained. Different types of injectors are designed to use in solid, liquid and hybrid rocket engine. The injectors are experimentally analyzed using special test bench and wind tunnel. The flow over injectors are studied and determined.*

1. INTRODUCTION

The use of rocket engine in day to day life is rapidly developing faster and they are used in various field. Hybrid rocket motor is an engine which is the advantages of both solid and liquid engines. This employs a solid fuel typically a polymeric material and liquid or gaseous oxygen. The concept has been known and tested for many decades. The advantage of hybrid rocket engine compared to solid motor is the controllability. The advantage in comparison to high performance liquid oxygen and hydrogen engine is the easier and safer handling of the propellant. Gaseous oxide is used for hybrid rocket engine as oxidizer, because it liquefies at a pressure of about 50 bars at environmental temperatures. In that condition nitrous oxide has a considerably higher density needs less tank volume for storage as at lower pressures. During the feeding of the oxidizer from the tank to the injection system the nitrous oxide pressure declines and thus a liquid-gas mixture is injected. Fluids are composed of molecules that collide with one another and solid objects. However, the continuum assumption considers fluids to be continuous, rather than discrete. Consequently, properties such as density, pressure, temperature, and flow velocity are taken to be was defined at infinitesimally small points and are assumed to vary continuously from one point to another. The fact that the fluid is made up of discrete molecules is ignored. The flow coefficient C_d for this liquid-gas mixture, which is estimated for new injector design by previous experimental research, is validate by test runs at an injector test bench. Moreover the different gaseous oxygen injector is filmed by a high-speed camera through the acrylic glass of the injector test bench chamber. Finally the most efficient, simple and stable injection system is selected for hybrid rocket engine.

2. ATOMIZATION AND HOMOGENITY

Reynolds number: a velocity profile gives the variation of the velocity in the boundary layer as a function of y. In general, the velocity profiles at different x stations are different.

The slope of the velocity profile at the wall is of particular importance because it governs the wall shear stress. Let $(dv/dt)_{y=0}$ be defined as the velocity gradient at the wall. Then the shear stress at the wall is given by

$$\tau_w = \mu(dv/dy)_{y=0}$$

Where μ is called the absolute viscosity coefficient (or simply the viscosity) of the gas. The viscosity coefficient has dimensions of mass/(length)(time), as can be verified with Newton second law. μ varies with T. For liquids,μ decreases as T increases (we all know that oil gets “thinner” when the temperature is increased). But for gases, μ increases as T increases (air gets “thicker” when temperature is increased). For air at standard sea-level temperature,

$$\mu = 1.7894*10^{-5} \text{ kg/ms} = 3.7373*10^{-7} \text{ slug/ft s}$$

Reynolds number is defined as the ratio of inertia force to the viscous force. The expression of the equation is given by,

$$Re_x = \rho_\infty v_\infty\ x/\mu_\infty$$

This non-dimensional number describes the ratio of the inertia force to the viscous force. The velocity v of the injected fluid can be calculated using the mass flow and the density ρ of the oxidizer. For the typical orifices this number need to be clearly larger than 2300 to archive turbulent flow and therefore to enhance the mixing process of the injected fluid with the hot combustion gas. The limiting factor for the orifice diameter is the attachment of the flow, which is only guaranteed if the depth in comparison to the diameter of the orifices is larger than about 4. The second non dimensional number is the ohnesorge number oh:

$$Oh = \eta/\sqrt{\rho\sigma d}$$

This non dimensional number compares the influence of the viscosity to the forces of the droplet deformation. An adequate ohnesorge –Reynolds number diagram ensure the atomization of the injected fluid directly after the injection. This is guaranteed by the high friction force in comparison to the low inertia and surface forces of the fluid.

The Weber number is a dimensionless number in fluid mechanics that is often useful in analyzing fluid flows where there is an interface between two different fluids, especially for multiphase flows with strongly curved surface. It can be thought of as a measure of the relative importance of the fluid’s inertia compared to its surface tension. The quality is useful in analyzing thin flow and the formation of droplets and bubbles.

$$W_e = \rho v^2 l/\sigma$$

It compares the inertia force to the surface forces between the liquid and gaseous phases in the chamber. Therefore the value of the surface tension σ of the injected fluid is needed. Because of the inter between the fast liquid needs to be greater than 50 [3[to create small droplets.

3. INJECTOR DESIGN

The function of an injector, which is located in general, at the forward end of the combustion chamber, is similar to that of the carburetor of an internal combustion engine. The injector introduces and meters the propellant flow to the combustion chamber, and atomizes and mixes the propellants for satisfactory combustion.

3.1 Design Objective

A number of injectors have been developed and many details of successful injector design are now available. However, there still are no hard-and-fast rules to assure a successful design. A more rational approach toward the design of injectors is through understanding and prediction of the chemical and physical processes that are encountered within the combustion chamber, and using this information as a basis for initial injector design. There are numerous requirements to qualify a given injector for operational use. The following are the most important objectives for injector design:

Combustion stability – In combination with a given combustion-chamber configuration and for a given propellant combination, an injector should give smooth combustion, during engine start and stop transients as well as during steady-state operation.

Performance – Combustion performance of as injector is influenced by: propellant mass distribution, local mixture ratios, degree of mixing of injected propellants, in either the liquid or the gaseous phase, or both droplet atomization and vaporization, rate of heat input and chemical reaction rates. These are predominantly a function of suitable manifolding and proper selection of injector-hole patterns.

Structural integrity – An injector should be able to withstand the maximum loads incurred during all phases of engine operation. Sufficient cooling must be provided to prevent the injector face or any other portion from overheating.

Hydraulic qualities – The holes or orifices of the injector must be designed to effect predetermined pressure drops at specific flow rates, and to atomize the propellants properly. A low injector pressure drops is desirable from the standpoint of overall engine-system performance. However, minimum pressure drop is determines from combustion-stability considerations.

Combustion chamber heat production – An injector should be designed to avoid formation of hot spots or streaks on the propellants will prevent oxidizer-rich peak temperature zones from forming, although this may not prevent streaks of high mixture ratio (O/F) from occasionally reaching the chamber wall.

Special requirements – Certain engine systems are required to operate at off-nominal conditions, such as at lower thrust levels during throttling, or other than nominal mixture ratios as a result of propellant-utilization control. In these cases, injectors must be capable of operating reliably under modified as well as rated conditions.

The different types of injector are designed using the CATIA V5 software. The inner diameter of the injector is 30mm, the diameter of the injector hole is 1mm and the injector plate is 50mm in diameter. A set of six injector plates are designed for the testing of flow in hybrid rocket engine. The designs are done using the reference of three axis namely x, y and z axis. The gaseous oxide is being set to a pressure of 50 bar and it is allowed to flow in the wind tunnel, in which the injector is placed. The flow from the injector is visualized by using the camera and the process is carried out for different type of injectors at a contact pressure and time interval. The linear gas flow has been converted to fine droplets after it reaches the injector plate. The flow in the wind tunnel will be as similar as that of the hybrid rocket motor. The injector is designed with the stainless steel of grade 304 to withstand high pressure and temperature. The injector is designed for a typical hybrid rocket engine, so the injector is designed in a way to withstand the high pressure air entering the engine and high temperature build in the chamber. The injector is placed before the combustion chamber section.

3.2 Study of Injector

Shower head injector: This patter employs non impinging oxidizer and fuel steams which emerges normal to the injector face. It relies entirely on combustion chamber turbulence for mixing. While being simplest to fabricate, the shower head injector exhibits poor performance in most application with the exception of certain cryogenic propellant combinations.

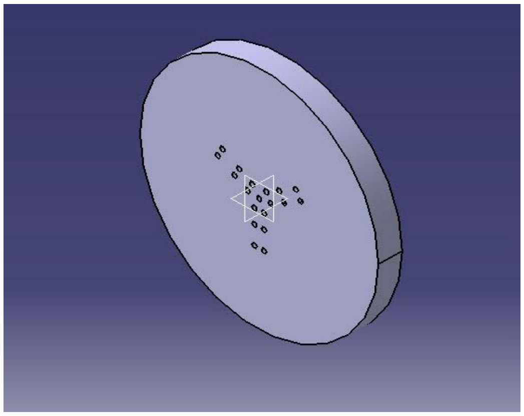


Fig. 3.1: Double row injector design

Doublet head injector: In this design, oxidizer and the fuel jets are made impinge in pairs thus good liquid phase mixing and atomization is obtained. One of the disadvantages of this doublet arrangement is that even if the injector holes have been accurately drilled, the resultant angle of momentum vector or beta angle will vary with mixture ratio, particularly if large impinging angle is used. This variation can adversely affect combustion performance and chamber-wall heat transfer. The doublet head design frequently used in system using liquid oxygen.

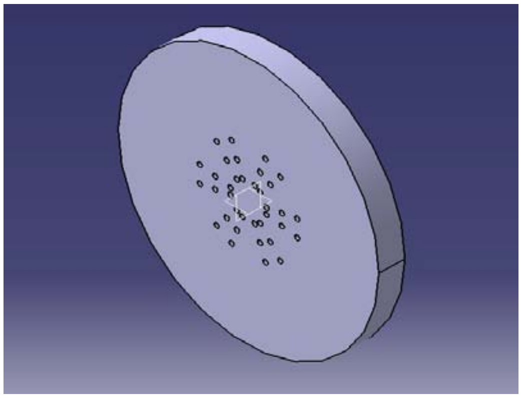


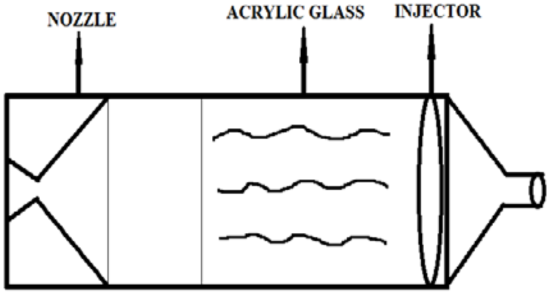
Fig. 3.2: Shower head injector

Self-impinging: This pattern also known as a like-on-like a impingement generally employs self-impinging pairs of fuel and oxidizer. Mixing is accomplished in the combustion chamber by volatilization of the propellants and by turbulence. This design usually provides good inherent combustion stability, at a moderate performance level. Applications have been successful for both cryogenic and storable hypergolic propellant combinations. A modification of this design provides for secondary impingement

4. GLASS WIND TUNNEL

For the experimental determination of the flow coefficient and for the atomization process glass wind tunnel with acrylic glass is constructed. This wind tunnel generates the chamber pressure of the hybrid rocket engine and therefore uses a nozzle at the end of the chamber. The following material properties of gaseous oxide at environmental temperature of the prospective rocket range are used. The injection angles and a raw impression of the atomization process are filmed by a high speed camera. The camera is placed 1m away from the injector with a view angle of 60 degree. The acrylic glass of this wind tunnel is similar to the geometry in comparison to the injector and the nozzle between aluminum flange and threaded rods for the easy working process. The radius of the glass tunnel is 50 mm, the thickness is 5 mm and the length is 450 mm. The gas supply system consists of a gaseous oxide tank and gaseous oxide gas bottle. Then the tank is set to a pressure of 50 bar and the gaseous oxide is allowed to flow in the testing equipment. Using the pressure regulator the various pressure readings are set for the testing. The high speed gaseous oxide is passed in the tunnel and the separation of the flow over the injector is noted using the camera. The flow separation over the injector is visualized and the flow is determined by using the Reynolds's number.

The glass wind tunnel consists of acrylic glass tube in which injector is placed and a injector and nozzle flange is designed for the linear flow over` injector and test section. Nozzle is connected at the end of the test section; these are connected with threaded rods.



5. CONCLUSION

The flow over the injector section made to understand the flow in the rocket engine. The study of separating the linear flow of liquid flow into fine droplets. The flow in the combustion chamber is known by the Reynolds's number calculation and the type of flow is found using the formula. Turbulence is flow characterized by recirculation, eddied and apparent randomness. Flow in which turbulence is not exhibited is called laminar. It noted however the presence of eddies or recirculation alone does not necessarily, indicate flow-these phenomena may be present in laminar flow as well Mathematically, turbulent flow is often represented via a Reynolds decomposition, in which the flow is broken down into the sum of an average component and a perturbation component.

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