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The Strategy of using porous material in liquid fuel space propulsion injectors

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In the course of all-round advancement of engineering science, space research can be considered as the drivers of this forward movement. In the field of space propulsion, this trend can be seen as a backward trend, not in the sense of regression, but in the sense of optimizing the original designs used for space systems, which not only lead to the re-invention of these systems based on the acquisition of specific modern manufacturing technologies, but also strengthened the link between sciences such as Materials science and Mechanics science. In this research, according to the space propulsion system roadmap and also the review of old and reference designs, an attempt has been made to study some of the optimizations made in recent years and to express the weaknesses and challenges ahead. One of the ideas that optimizes, minimizes and increases the reliability of the space propulsion system is the injection of fuel through the porous media. The study of a type of showerhead injector expresses the formation path of the idea of using porous materials in the injection system and then the efficiency of these two types of injections is compared in a design that connects the porous material with the coaxial injector design.

Keywords: *Injector, Injector face plate, Porous material, Space propulsions*

Introduction

Space is called an empty atmosphere. Lack of air has not reduced the complexity of physical laws of object motions in this environment. Rather, it has complicated the equipment of space carriers, especially the heart of these systems. Every creature that has movement also has a heart that causes this movement. In the space carrier system, the engine also acts as the heart of the complex. Since there is no fluid in space that can produce propulsive force with the help of aerodynamic force (hydrodynamic), in order to produce force in this environment, objects must be ejected from the engine quickly. Power generation in liquid fuel space propulsion is also based on the rapid release of combustion gases. Many different engines are designed and built to generate propulsion force in space. But there are still many challenges to miniaturization, upgrading, and light weighting, which are the three main strategies of space propulsion systems. Any progress in this regard will increase the payload mass in space or increase the operating time of the space propulsion system. Increasing the combustion efficiency by using porous materials in the injector face plate (fuel

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injector face plate) of space engines is one of the designs that leads to miniaturization and light weighting the engine of space propulsion systems. Also, the use of injector face plate made of porous materials improves the atomization quality of fuel in the combustion chamber and prevents the formation of fluid lumps with different proportions of compounds in the combustion chamber. In high-propulsion engines such as RD-170 (its fuel consumption is about 2250 kg/s) which have high fuel consumption, any improvement in combustion efficiency will lead to a significant increase in specific thrust [1]. Also, more uniform combustion in low-propulsion engines (micro engines) will increase controllability. The above items express the importance and position of the leading subject in accessing more distant orbits and increasing the durability of satellites in orbit.

Porous injectors have been studied since 2003 at the German Space Propulsion Institute [2]. At this time, the emphasis was on investigating the flame behavior near the injection face plate in an injector consisting of liquid oxygen stations and a surface of porous or semi-porous face plate through which fuel was injected. Numerous experiments have also been performed to evaluate the performance of injectors made of porous materials at the European High Pressure Research Group.

In this research, with the help of articles, new designs and hardware used in modern systems that have been used in recent years to optimize injectors and injector face plate and move towards complete combustion, we have tried to provide sufficient reasons for the use of porous materials in liquid fuel space injectors.

Search method to collect articles used in this study was searching conducted in databases, such as Web of Science, Scopus, Google Scholar, with emphasis on keywords such as porous materials, space propulsion injector, porous injector face plate, etc. . during this search, about 80 articles related to the mentioned titles were found. Then, with a closer look at these articles, the search continued based on research conducted at aerospace institutes of Germany, Korea and Europe. Among these, the work records of people such as Dmitry suslov, Jan Deeken, Oskar Haidn, Dohun kim and Ulrich Gotzig were considered in the articles that will be reviewed in the continuation of this study.

In the following, the general path of forming the idea of using a porous injector (injector face plate) is drawn. Then, by examining the main design of some porous injectors, the strengths and weaknesses and the challenges related to each design are expressed. Finally, by analyzing the results of experimental experiments or simulations performed, a suitable solution has been proposed to remove the obstacles ahead.

Review of liquid fuel propulsion injection system strategy

According to a report released by NASA in 2015 under the title of Technology Roadmaps, the chemical space propulsion system has a set of goals, which include increasing efficiency, increasing reliability and improving the level of security in these systems [3]. Some measures can increase the efficiency and increase the engine safety factor of the space propulsion system. Correction of injectors to prevent local accumulation of unburned fuel in the engine is one of these measures that reduces the possibility of engine explosion of space propulsion systems in the first moments of fuel injection. Also, the improvement of the atomization quality of fuel components has always included the evolution of combustion and consequently the increase of combustion efficiency [4] - [6]. The stated cases can be achieved only if a special design of the injector is used. In the continuation of the present study, the concept of injection through porous surface with different purposes and applications and in the form of various designs has been investigated.

Direct flow injector system

The design of the injector in modern liquid propulsion rocket engines has the greatest impact on the overall efficiency of the engine as well as the combustion stability. Competing injector designs must achieve a uniform mass distribution and good mixing performance while providing stable combustion. In addition, the combustion efficiency must be close to 100% to ensure maximum overall performance.

Direct flow injector face plate that is one of the simplest fuel injection systems and one of the most widely used systems in liquid fuel propulsion engines, has been used in the present research as a reference for comparing the data obtained from testing new injection designs and examining efficiency changes in reviewed articles. The most common injector design widely used for cryogenic liquid oxygen-hydrogen (LOX/H_2) propulsion is

the direct current injector. This injector is used in many high-efficiency engines, such as the SSME, Vulcain II, and the Vinci high-end engine that is currently under development. In the direct coaxial flow injector element, the liquid component is injected through an inner tube at an average speed of 20 to 30 m/s. The spray is surrounded by fuel, which is injected through an annular gap at a speed of 200 to 400 m/s. The shear forces between the two components lead to the decomposition and atomization of the liquid jet. The injector heads of engines such as; SSME and Vulcain II have a maximum of 500-600 single coaxial injector elements. Direct-axis injectors have good overall performance and good combustion stability compared to collision injectors. However, the limited gas consumption, as well as the high cost of applying high quality to have a small gap dimensions, indicate that this injector design is not ideal. Especially when it comes to performance-enhancing properties, such as collapse or reducing the risk of combustion instability, which leads to hydrodynamic mechanisms [7]. Also, in this type of injectors, the type of fluid movement inside the porous medium is also important that the turbulent flow model created inside this medium can be investigated using different methods [8].

Ulrich Gotzig et al. [9] presented a new design based on direct flow injectors and by correcting the arrangement of the classical coaxial injector face plate and the way fuel components are introduced, for bipropellants engines in the 500 N class in a private complex in Germany under the supervision of the European Aeronautic Defense and Space Company. Also, John Deeken et al. [2] used a direct flow injector head with 42 coaxial injectors and a direct flow injector head with 13-elements coaxial injection with the same combustion chamber to compare hot tests data in various studies, with the aim of investigating the operating conditions of porous injectors and also the study of transpiration cooling design in the German Space Research Center (DLR). Dohun Kim et al. [10], compared the data obtained from the hot and cold test of the new injector with the classical injector by changing the structure of the shear coaxial injector and using porous material in the new structure at the Korean Aerospace University.

Micro shower head injector system

To study the potential of a new injector system for liquid fuel bipropellants, the European Aviation and Space Administration launched an Internal Research and Development program in 1998 to validate a shower injector face plate in 400N class. The results of these experiments were promising, so the shower head injector design was selected as the main basis for the development of 220 N mid-class thrusters and also for high efficiency 500 N engines [11]. In 2005, Ulrich Gotzig et al., In a paper entitled "The New Generation of EADS bipropellant Engines with a Shower microinjector System", presented a new design of injection system for 220 N engines which the main basis of its design was based on the old design of classical coaxial injectors, but it was made with the help of modern methods. [9]. Meanwhile, an important turning point was achieved during the development of the 220 N class propulsion with a successful vacuum flight simulation test with similar propellants, which ultimately confirmed the good performance of the new injector system. The schematic of the main design of the shower head injector is shown in Figure (1).

In the past, shower injectors consisted of a drilled face plate that had a limited distance between the oxidizing and reducing holes due to the manufacturing method. But today, advanced drilling technology has led to the re-invention of this type of injectors head. In a modern shower injector, both fuel components are injected coaxially. Radial factors that cause fuel components to mix are jet surface turbulence, jet rupture process, and combustion-induced turbulence.

Because the location of the fluid rupture is highly dependent on the environment in which the jet is injected, two different spray test chambers were constructed by EADS to investigate injection spray under chamber conditions.

* Small combustion chamber for spraying test with ionized water and back pressure up to 12 bar (Figure 2a)
* Larger combustion chamber for real fuel injection test and back pressure up to 10 bar (Figure 2b)

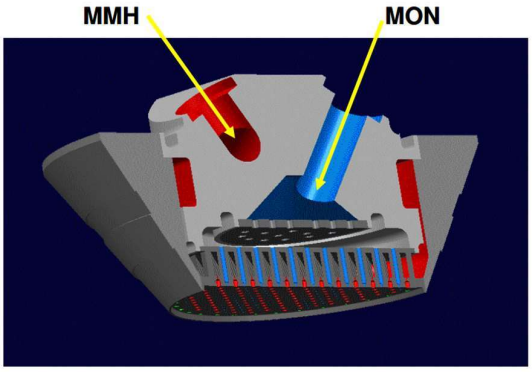

Figure 1 - Modern shower head injector design [9].

Figure 2a - Water test chamber [9]

Figure 2b - Real fuel test chamber [9].

In combustion chambers, the following information was examined for the geometry of a modern shower head injector:

- Pressure drop as a function of fluid mass flow, partial pressure and combustion chamber pressure
- Type of fluid jet rupture and its length
- Ability to test the repeatability and impact of structure parameters

Construction of modern shower head microinjector

Figure (3) shows the general structure of a modern shower injector face plate with welded tube technology in which one fuel component is injected through the tubes and the other component through the drilled face plate. The holes of the face plate, tubes and displacement face plate are drilled with high precision and finally connected to each other with modern welding technology.

The large number of injector elements and their distance ensure a good mixing and therefore high combustion efficiency. It also allows the use of this type of injector heads for different classes of space propulsion. Figure (4) shows the scalability of this type of injector head in a checked arrangement.

According to Figure (4), as the number of injector holes increases, the amount of thrust also increases, which well explains the reason for replacing the porous material in the injection face plate.

The structure of 220 N propulsion made by EADS uses a titanium shower head injector and a combustion chamber with Niobium coating. The results of these tests are as follows:

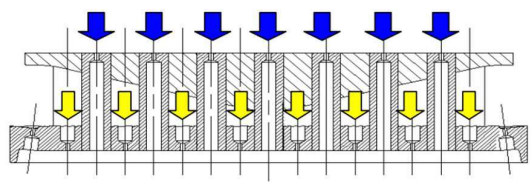

Figure 3 – A view of the internal structure of a modern shower head injector [9]

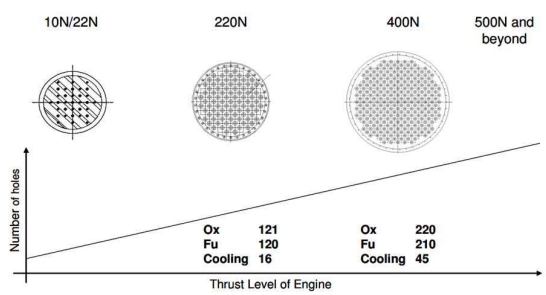

Figure 4 - Scalability of modern shower head injector [9]

Results

A. Temperature distribution under vacuum test conditions

Figure (5) shows the throat temperature for this propellant at about 1027 ° C in the nominal operating mode of the engine, and in the worst case this temperature is measured at 1227 ° C in the throat.

B. Efficiency in vacuum test conditions

Figure (6) shows the very uniform (I_{SP}) efficiency curve in the set of operating conditions. This uniform curve allows to determine the optimal operating point with an accuracy of 0.06 times for the inlet pressure.

C. Sea level test conditions

Under these conditions, the temperature of the combustion chamber was generally below the critical condition and showed a maximum temperature of 1000 ° C for the throat cut. Figure (7) shows the throat temperature in terms of mass flow under sea level operating conditions.

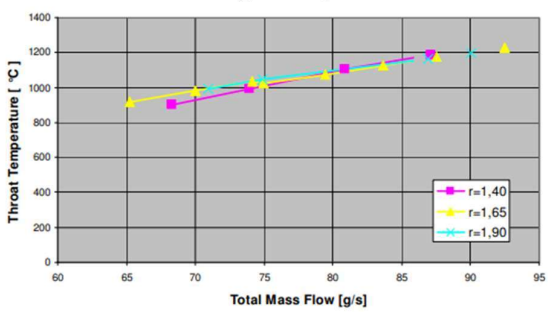

Figure 5 - Diagram of temperature distribution in terms of total mass flow [9]

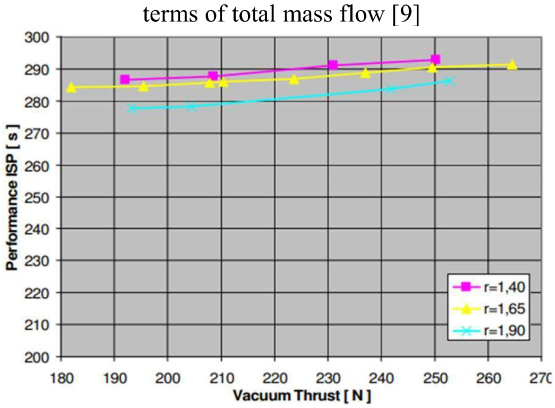

Figure 6 - Efficiency chart in terms of thrust [9]

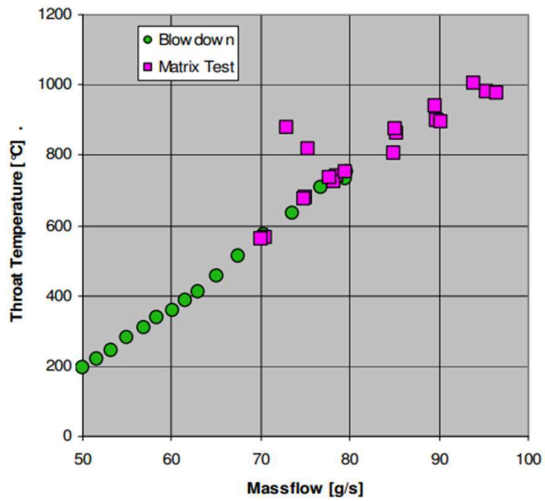

Figure 7 - Diagram of throat temperature in terms of mass flow [9]

Coaxial porous injector

Many closed-cycle liquid rocket engines often use a two-phase gas-liquid injector for the main combustion chamber. The simplest form of injector is the coaxial liquid-gas injector. The main basis of mixing in the shear coaxial injector is the shear force, which is due to the speed difference between the gas and the liquid jet. The simple structure of the shear coaxial injector is a factor to reduce production costs. Density distribution with high gradient in the spray center, limited gas consumption capacity, high dependence of performance and combustion stability on the concentration [12] and [13] and instability phenomenon in the center of the fall or edge of the cone [14].

Average diameter of a liquid droplet injected by a shear coaxial injector is approximately twice the diameter of the droplet injected by a swirl coaxial flow injector, and the atomization efficiency increases with increasing mass flow [15]. In experiments performed by Strakey et al., The mass transfer ratio and mean droplet diameter of a shear coaxial injector and a swirl coaxial flow injector were compared [16]. In this type of injectors, liquid is located in the injector axis. They obtained the mass flow distributions of the two injectors in the same way, but the mean diameter of the swirl coaxial injector droplets was approximately 1.7 times smaller than that of the shear coaxial injector in the center region. Salgues et al. compared the characteristic velocity efficiency of a liquid oxygen and gaseous methane propellant of a shear

coaxial injector with an swirl coaxial injector and found that the swirl flow efficiency was 10% higher than that of a shear coaxial injector with the same injector dimensions and mass flow rate [17]. However, the complex structure of the swirl coaxial flow injector increases its production costs and weight. Delay in filling the injector rotation chamber also increases the time to reach steady state [15].

Glogowski et al. [18] and Ferraro et al. [19] measured the spray droplet diameter size, mass flow rate and characteristic velocity efficiency of a shear coaxial injector with the same dimensions as the gas generator injector in the main SSME space shuttle engine. Mayer et al. also investigated the decomposition mechanism in shear coaxial injectors and the effect of injection density on spraying pattern. They reported that the internal turbulence of the liquid jet was an important factor in the decomposition of the liquid jet [20] & [21]. Using this information, Dohun Kim et al. In an article entitled "Combustion properties of a coaxial porous injector" hypothesized that by increasing the momentum transmission, atomization and mixing in the axis region could be improved [10]. In this paper, a coaxial porous injector is made to inject a conventional gas jet perpendicular to the central liquid jet to efficiently transfer the gas jet momentum to the liquid jet. To inject the gas radially, they used the Taylor-Colic flow [22], which describes the region of the flow injected through the wall of the cylinder. The main shape of the coaxial porous injector made by Dohun et al. was similar to the shear coaxial injector, except that this injector was made of a porous metal cylindrical area from which gas was injected radially. As the radial gas jet strikes the coaxial jet from the inner surface of the porous cylinder, the radial motions are transmitted effectively. Dohun Kim et al. hypothesized that atomization should be improved. The passage of flow through porous materials has the following advantages:

- High uniformity of mass injection from a wide area
- Adjusting the pressure drop by changing the pore size of the porous material
- Possibility to use transpiration cooling
- Acoustic instability damp upstream of porous media

Porous materials also have some inherent flaws, such as: low structural strength, poor ductility and machinability and high pressure drop. Other research has been done on porous materials from injectors and liquid rocket engines. The conceptual design and experimental results of the pressure drop were examined by Bazarov [23]. In addition, porous material was used as the injector exposure face plate for several RL10 and SSME commercial liquid rocket engines, in which part of the fuel is injected through the porous face plates to increase surface cooling [24].

In this section, a small-scale porous injector and combustion chamber were constructed and gaseous nitrogen oxide (N_2O) and liquid ethanol (C_2H_5OH) were selected as fuel. Several hot and cold spray tests were performed to observe the characteristics of small-scale coaxial porous injectors [10].

Structure of injectors

In this study, two injectors with the same axial flow were made. These two injectors differ only in the presence of porous material (Figure 8). In a shear coaxial injector, the gas fluid exits axially from the annular gap between the liquid fluid outlet and the injector wall. While in the coaxial porous injector, the gaseous fluid is injected from the porous area perpendicular to the liquid jet. The porous material used in the coaxial porous injector is made of stainless steel with an mean pore diameter of 90 micrometers [10]. The geometry dimensions of both injectors are given in Figure (9).

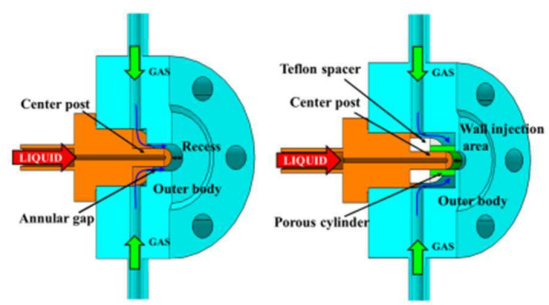

Figure 8 - Schematic of a typical shear coaxial injector (left) and a schematic of a coaxial porous injector (right) [10]

Combustion chamber structure

To measure the combustion efficiency of two injectors, a small-scale combustion chamber with a water-cooled nozzle cooling system was designed and built. The chamber was made of

stainless steel tube with a thickness of 1.7 mm, generally 160 mm and an inner diameter of 22 mm. Gaseous nitrogen oxide and liquid ethanol were used as fuel.

The design point is as follows: Combustion chamber pressure was 10 bar, fuel mass flow rate was 18.7 g/s and oxidizing to reducing ratio was 5.68. The theoretical characteristic speed of 1549.3 m/s was calculated. Nozzle throat diameter was 6.07 mm, convergent-divergent nozzle outlet diameter was 10.3 mm, convergence angle was 30 °, nozzle divergence angle was 15 ° and nozzle to throat ratio was 13.14, which is higher than usual that is between 2-5 [17]. Figure (10) shows a schematic of the combustion chamber built.

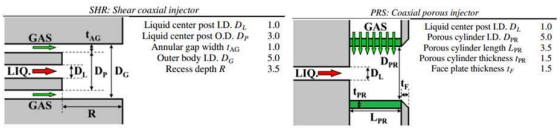

Figure 9 - Important dimensions in the geometry of two injectors used in hot tests [10]

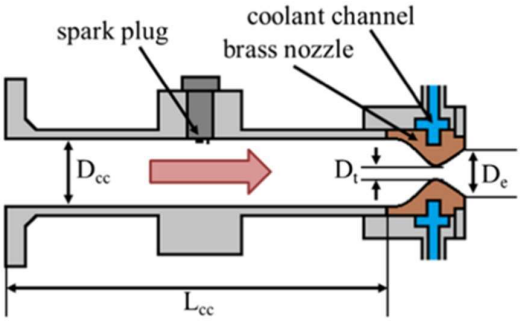

Figure 10 - Schematic of a small-scale combustion chamber [10]

Experimental performance conditions

The mixing process of shear coaxial injector and coaxial porous injector occurred in two areas: 1) the recess area, where the liquid and gaseous fuel coaxial jet first came into contact, and 2) downstream of the injector tip, where the gas jet expands in a radial direction. Most mixing is due to the shear force and the aerodynamic drag force. The injectors used in this experiment had the same injector tip area, where the fuel was discharged. This means that the fuel injection speed depends only on the mass flow rate, not the injector types, assuming the ambient pressure and density of the fuel components are equal. Therefore, under the same operating conditions for both injectors, the results of using a porous injector will be visible.

In the present study, hot tests were performed using nitrogen-ethanol oxide propellants in a ratio of 2 to 7 and for different values of momentum at the injector tips. Images of injection spray cold tests were also taken for different momentum and two injector tips.

Hot test results

Figure (12) shows a clear picture of combustion and combustion exhaust at operation point close to the design, which shows a clear diamond shock wave. The experimental conditions are described in the diagram (Figure 13) for the ratio of different compounds according to the amount of momentum of the fluid.

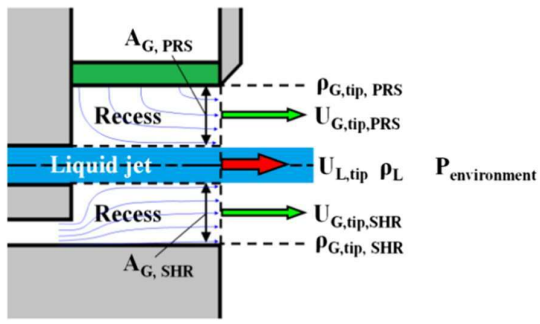

Figure 11 - Similarity of injection conditions at injection boundaries of shear coaxial injectors (SGR) and coaxial porous injectors (PRS) [10]

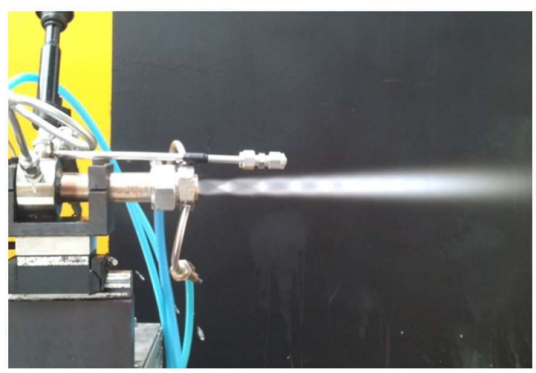

Figure 12 - Combustion exhaust image at operation point close to the design [10]

The total fuel mass flow was kept constant at 5% performance at the design point. Combustion pressure and nitrous oxide temperature in upstream of the injector were measured for each test case. The magnitude of the measured momentum was slightly larger than the theoretical value in the whole range of changes in the oxidant to reducing ratio (O / F). This was because the combustion pressure was less than the estimated

value and there was a measurement error in the nitrogen oxide mass flow rate, which was calculated from a constant mass density and flow rate. Figure (14) shows the hydraulic parameters of the two injectors tested. At equal mass flow rates, the coaxial porous injector shows a greater pressure drop. This means that for a momentum equal to the exhaust gas from both injectors, the amount of energy required by the porous injector is greater. This is because of the high losses due to the viscosity of the fluid passing through the porous media. To prevent this from happening, the following steps can be taken:

- Increasing the diameter of the porous cylinder
- Increasing the length of the porous cylinder
- Increasing the porous percentage of the material used in the porous cylinder

Among these methods, the first and third methods will reduce the strength of the porous cylinder.

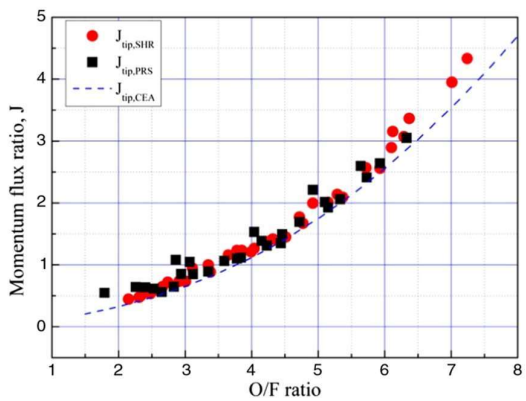

Figure 13 - Diagram of experimental operating conditions of two injectors in hot tests and theoretical curves [10]

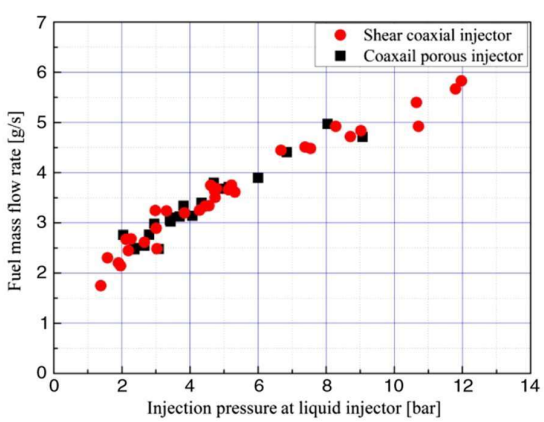

Figure 14a - Mass flow of fluid in terms of liquid fluid pressure [10]

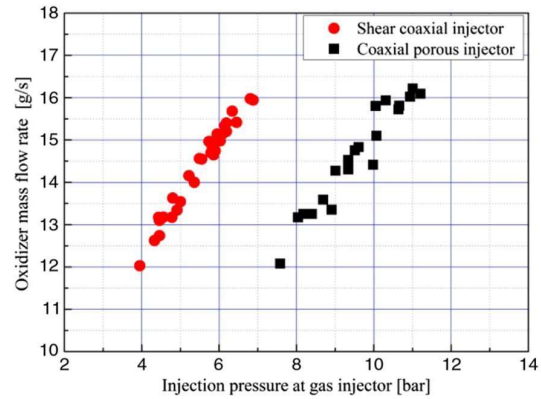

Figure 14 b - Flow rate of oxidizing mass in terms of liquid fluid pressure

The results of the hot tests are shown in Figures (15) to (17). The characteristic velocity changes in terms of the ratio of compounds in a good range corresponded to the values calculated by the numerical method. In most tests, the coaxial porous injector showed a higher characteristic velocity than the shear coaxial injector, and the difference between the two injectors increased as the composition ratio decreased (figure 15). This behavior became clear when the efficiency diagram of the characteristic velocity curve was drawn. The characteristic velocity efficiency is the result of dividing the theoretical characteristic velocity value by the characteristic velocity obtained from the hot test results. As it was expected, injection at higher fluid momentum rates resulted in better atomization and mixing, and the combustion efficiency of the coaxial porous injector improved with increasing momentum. According to Figure (16) in relation to the coaxial porous injector, the amount of fluid momentum had less effect on the characteristic speed compared to the shear coaxial injector.

Cold test results

The macroscopic structure of two injectors spray was observed at ambient pressure. Water and gaseous argon were used to simulate fuel components for cold testing. Although the spray design in real conditions compared to the cold test mode will be different in this experiment, it is expected that the spray in ambient conditions could provide suitable clues to explain the increased combustion efficiency of the coaxial porous injector during hot tests. The mass flow rate was constant during the cold test (2.8 kg/s) and the liquid Reynolds ratio was 5074. The cold test

results shown in the 6 images in Figure (18) are taken for low momentum values in both injectors.

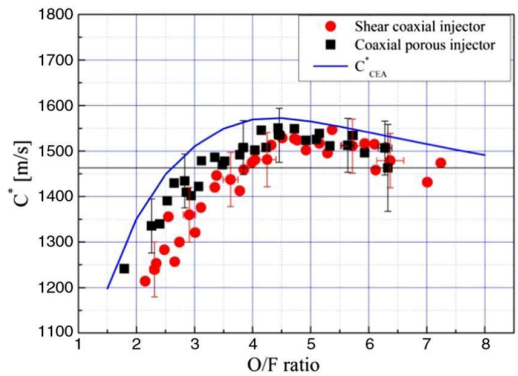

Figure 15 - Characteristic velocity changes in terms of the ratio of compounds for the two injectors [10]

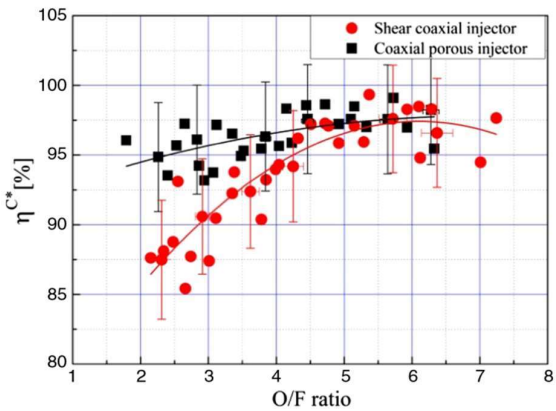

Figure 16 - Characteristic speed efficiency curve in terms of changes in fuel components [10]

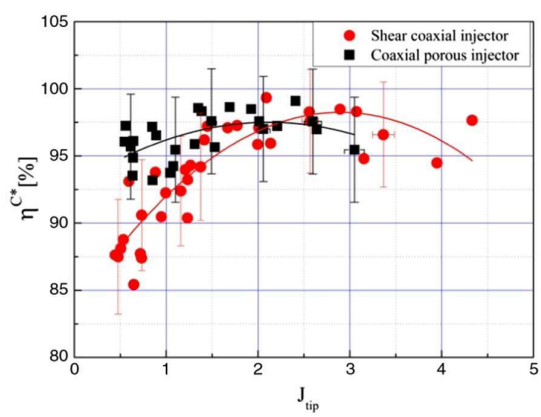

Figure 17 - Characteristic velocity efficiency curve in terms of fluid momentum changes at the injector tip [10]

These images show a noticeable difference in the fluid rupture stage of the two injectors. In Figure (18a) the fluid core near the injector is not ruptured. In contrast, in the coaxial porous injector (Figure 18b), the interaction of the liquid jet and the gas jet starts upstream and the undecomposed fluid core is not seen at the injector tip. In the downstream area for both the coaxial porous injector and the shear coaxial injector, the droplets were dispersed by aerodynamic drag force. By increasing the momentum of the injector tip, the diffusion angle of the shear coaxial injector spray decreases with the entry of the ambient gas jet. However, the injection of the coaxial porous injector shows a completely different form of decomposition. The liquid mass did not appear throughout the experimental conditions, and the liquid jet appeared to be almost decomposed in the recess area. As a result, the coaxial porous injector showed much better breakup performance than the shear coaxial injector, especially in low fluid momentum conditions. It can be concluded that the momentum transfer between gas and liquid jet is improved by radial injection in the sub-area of the coaxial porous injector and consequently increases the combustion efficiency.

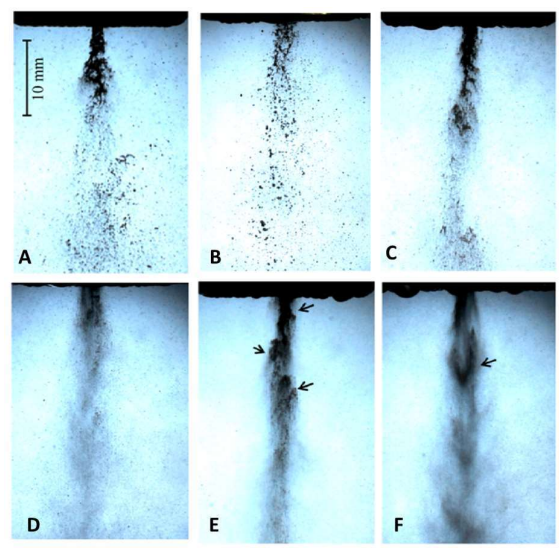

Figure 18 - Changes in the spray pattern of injectors in ambient conditions (gaseous argon and water) Liquid mass flow rate of 2.8 g/s (constant) Speed in exiting the injector = 4.52 m/s) [10] (A) Shear injector, ratio of compounds 6.97 ,Momentum value 0.109, (B) Porous injectors, ratio of compounds 7.43 ,Momentum value 0.117, (C) Shear injector, ratio of compounds 10.39 ,Momentum value 0.244, (D) Porous injectors, ratio of compounds 11.87 ,Momentum value 0.299, (E) Shear injector, ratio of compounds 16.09 ,Momentum value 0.586, (F) Porous injectors, ratio of compounds 17.95 ,Momentum value 0.684

Results analysis

In a modern shower head microinjector system, the measured temperatures for the nozzle throat section with a special combustion chamber cover are reasonably low. This indicates a high-efficiency combustion. The technology of making this type of injector head, although simple, is time consuming and the cost will be greatly increased to achieve high drilling accuracy. Also, due to the type of injection in this type of injector head, if used for more continuous operation of the engine, wall compatibility tests and injector face plate should be performed. According to the efficiency diagrams, the combustion process is performed completely with a good approximation, which is a result of the distribution of homogeneous mass flow of fuel in the combustion chamber. Finally, due to the uniformity of temperature graphs in terms of total mass flow, the success of this type of injector head in preventing the formation of areas with different mixing ratios or hot spots in the combustion chamber is evident. If it shows good compatibility in modern shower head injectors experiments with reversible cooling (due to the increase in the average temperature of the inlet fuel), it is considered as a suitable option for use in the high-thrust propulsion class. Also, the capability of gas consumption in this type of injector is questionable, because the coaxial injectors have a certain amount of drop according to the geometric parameters, which limits the flow through them, and this is a weakness for this type of injector face plate.

In a comparison between two injector elements by Dohun Kim et al. , it was found that the coaxial porous injector had a higher combustion efficiency, even for a low oxidant to reducing ratio with a low fluid momentum in exiting the injector tip. Also, the characteristic velocity of the porous injector was less affected by the spray conditions. From the cold test results, it was observed that the fluid rupture occurs in the area near the porous injector tip, while this rupture occurred at a greater distance from the shear coaxial injector tip. Therefore, the design of the coaxial porous injector presented in Section 5 provided better conditions for atomization. Using these results, it can be stated that a shorter combustion chamber can be used with the help of coaxial porous injectors, and due to the homogeneous emission of fuel, the probability of engine explosion will decrease because the fuel retention time in the chamber will be reduced. Therefore, this type of injector is suitable for rocket engines with gas reducing and oxidizing liquids. In general, it can be used for rocket engines with closed-cycle system. In these systems, a part of the fuel that is incompletely ignited in the gas generator to produce fuel pumping force, is injected into the main combustion chamber through this type of injector to complete the combustion process and create a thrust. In addition, the effect of PRS injector geometries such as diameter and porous element length on spray properties, combustion performance and stability has been investigated in the by Dohun Kim et al [25].

In a porous injector face plate system, depending on the injection conditions, many instabilities with different wavelengths may occur. Porous injectors at very low velocity ratios in combination with relatively small oxygen jet diameters lead to jet decomposition, which is mainly driven by heat transfer and internal turbulence of the liquid oxygen jet. The contact time between the oxidizer and the fuel is greatly increased with an injector with an average injection speed of about 20-50 m/s instead of 100-200 m/s for a normal coaxial injector,. Due to the slower injection of liquid oxygen, the injection jet disintegrates faster, which can lead to combustion chambers getting shorter and lighter. As the gas velocity increases, the atomization starts from downstream and its diffusion radius decreases.

Although the research presented by Dohun Kim et al. And Ulrich Gotzig et al. in Sections 4 and 5 show very promising results, the concept of porous injection still offers great potential for further optimization. Achieving lower speeds for hydrogen remains an important issue. Also, the need to increase the mechanical strength of the porous surface in the coaxial injector head presented by Dohun Kim et al. and evaluation of its compatibility with the combustion chamber wall remain a challenge.

In the next study, by examining how to use porous material instead of the injector face plate of a space propulsion system and also studying the new designs of the injector face plate, properties such as combustion stability, atomization, pressure drop, load applied to these face plates, etc. are studied according to the achievements of prominent people in this field, such as Johannes Lux, John Deeken, Oscar Haidn and some of the

challenges in this article will be answered and some of the properties of porous material will be stated under the tests performed.

Conclusion

The design of the shower microinjector system has a very good combustion efficiency due to the precise manufacturing technology. Also, according to Figure (4), the potential of using porous material is obvious. Using the design of the shower injector system, the temperature of the combustion chamber was generally lower than the tolerance temperature of the cover used for the nozzle. Also, using two combustion chambers, various tests have been performed to investigate the conditions of cold and hot test spraying of the shower microinjector system, which according to the results of the reviewed article, show the appropriate conditions for using this type of system. Also, the potential of using porous materials in space propulsion injection system was investigated using the results of comparing cold and hot test data of shear coaxial injector and coaxial porous injector. In this comparison, the coaxial porous injector showed a high level of atomization quality at the low momentum of the injector outlet fluid. The advantages of using a coaxial porous injector are as follows:
This porous injector has many features compared to a normal shear injector:

- Increasing the level of contact between fuel components
- Atomization conductivity in general by internal turbulence
- Properties of acoustic damper on porous cylinder
- Increasing combustion uniformity even at low fluid momentums

The use of this porous design also has challenges that will be explored in future articles. According to the research, the ability of this type of injector for use in engines with closed-cycle system is important, but the cost of using these set of injectors together and in the form of injector face plate should be investigated. Also, the quality of combustion and homogeneous distribution of fuel to prevent the formation of hot spots in the chamber, highlights the use of this type of injector for orbital change in micro engines.

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