

INVESTIGATION OF THE EFFECT OF TWO-COMPONENTS INJECTORS ARRANGEMENT ON INJECTING RATE IN THE COMBUSTION CHAMBER OF A LIQUID PROPELLANT ENGINE

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Abstract. *In liquid propellant engines, the propellants (fuel and oxidizer) after passing the injectors, are injected to combustion chamber. Generally, in liquid propellant engines, two types of injectors – direct flow and centrifugal flow – are used.*

The direct flow injector, actuates as an orifice. The input flow to a centrifugal injector, gets the angular momentum and goes out conically. The angular momentum causes the powdering of output fluid. The injecting cones collide to each other and the mixing operation is accomplished. The mixing and powdering of droplets in the centrifugal injectors are accomplished better than the direct flow injectors. To this reason, in modern liquid propellant engines, the centrifugal injectors are used. The centrifugal injectors are divided to two types : one component and two components. At one component injectors, the fuel and oxidizer are injected separately, but at two components injectors, both oxidizer and fuel are injected from a complex structure.

The injection rate at injector plate, is one of the effective parameters on wall's cooling, combustion stability and propulsive force (thrust) in the combustion chamber. In order to attaining the suitable injection rate, the effect of injector arrangement must be investigated. In this paper, after designing five different plans, the optimum injection rate has been investigated and selected. The method is the meshing of injector plate, determining the input value of oxidizer and fuel rates into each element and then computation of injection rate by means of a computer code.

The mentioned code computes the distribution of flow rate at the lateral section of combustion chamber by using the geometric conditions of injector plate, the position and the flow rate of injectors. This code is usable for all kinds of one and two components injectors and has been validated by using of experimental test possibilities and the error has been lower than six percent.

1 INTRODUCTION

In liquid propellant engines, the propellants (fuel and oxidizer) after passing the injectors, are injected to combustion chamber. Generally, in liquid propellant engines, two types of injectors – direct flow and centrifugal flow – are used (figure 1).

Up to now, much researches have been done on the injection distribution on one component injectors^{2,3}. In accordance with the reference method, a computer code has been prepared. This code has been validated by using of experimental test possibilities and the error has been lower than six percent.

The mentioned code computes the distribution of flow rate at the cross section of combustion chamber by using the geometric conditions of injector plate, the position and the flow rate of injectors. This code is usable for all kinds of one and two components injectors.

The direct flow injector, actuates as an orifice. The input flow to a swirl injector, gets the angular momentum and goes out conically. The angular momentum causes the powdering of output fluid^{6,7,8}. The injecting cones collide to each other and the mixing operation is accomplished. The mixing and powdering of droplets in the swirl injectors are accomplished better than the direct flow injectors^{4,5}. To this reason, in modern liquid propellant engines, the centrifugal injectors are used. The swirl injectors are divided to two types : one component and two components. At one component injectors, the fuel and oxidizer are injected separately, but at two components injectors, both oxidizer and fuel are injected from a complex structure^{9,10}.

2 GOVERNING EQUATIONS AND ANALYSIS

Experimentally has been proved that for a injector plate with centrifugal injectors, the curve of mass flux distribution around the injector, is an exponential curve (guass function). The mass flux distribution around the injector has been presented in figure 2¹.

$$\frac{d\dot{m}_{el-inj}}{dA} = ke^{\left(\frac{-r^2}{2H^2}\right)} \quad (1)$$

\dot{m}_{el-inj} is the input flow rate into an element, r is the distance between element and injector (figure 3) and H is the average distance between two injectors and k is a constant number. For obtaining k , it can integrate from two sides of expression (1).

$$\dot{m}_{el-inj} = \iint ke^{\left(\frac{-r^2}{2H^2}\right)} dA \quad (2)$$

In polar coordinate system, with assumption that the center of coordinate system is on the element center, the above mentioned formula can be expressed as follows :

$$\dot{m}_{el-inj} = k \iint e^{\left(\frac{-r^2}{2H^2}\right)} R dR d\theta \quad (3)$$

With integrating in the infinity interval, the expression (3) becomes like as following relation :

$$\dot{m}_{el-inj} = k \int_0^{2\pi} d\theta \int_0^{\infty} e^{\frac{-r^2}{2H^2}} R dR = 2k\pi H^2 \quad (4)$$

Consequently, the constant factor k is determined as follows :

$$k = \frac{\dot{m}_{el-inj}}{2\pi H^2} \quad (5)$$

As a result, the formulation (1) can be expressed as follows :

$$\frac{d\dot{m}_{el-inj}}{dA} = \frac{\dot{m}_1}{2\pi H^2} e^{\left(\frac{-r^2}{2H^2}\right)} \quad (6)$$

By using relations (2) and (5), the distribution of input flow rate into an element of an injector is expressed as follows :

$$\dot{m}_{el} = \left[\frac{\dot{m}_{inj}}{2\pi H^2} \right] \iint e^{\left(\frac{-r^2}{2H^2}\right)} dA \quad (7)$$

In cartesian system, the form of above expression is as follows :

$$\dot{m}_{el} = \left[\frac{\dot{m}_1}{2\pi H^2} \right] \iint e^{\left(\frac{-(X^2+Y^2)}{2H^2}\right)} dXdY \quad (8)$$

In this expression, X and Y are the horizontal and vertical distances between element and injector, respectively.

With due consideration to expression (8), the input flow rate into an element due to an injector is obtained. With computing the input flow rate into each element, the total flow rate of fuel and oxidizer can be obtained.

In order to computing the distribution of fuel and oxidizer flow rates for each element, at first the computational plate, is grided and then the value of input flow rate of fuel and oxidizer is computed from solving the equations (3) or (8). The input data for these computations are : (a) the position of injectors (b) the flow rate of fuel and oxidizer injectors (c) the average distance between two injectors (d) the primary and final radius and angle of computational plate. (e) for creating the grid, number of divisions at radial and circumferential directions, is obtained after meshing the plate on the basis of input data, calculation of the center coordinates of each element and input flow rate of oxidizer and fuel via each injector.

The input flow rate of fuel and oxidizer into each element is obtained by using the summation of surrounded injectors.

The ratio of oxidizer to fuel flow rate and flow rate for each element can be obtained by using of expressions (9) and (10).

$$\left(\frac{O}{F} \right)_{el} = \frac{\dot{m}_{Ox}_{el}}{\dot{m}_{Fu}_{el}} \quad (9)$$

In this equation, $\left(\frac{O}{F}\right)_{el}$, $\dot{m}_{Ox})_{el}$ and $\dot{m}_{Fu})_{el}$ are the ratio of oxidizer to fuel flow rates, oxidizer and fuel flow rates respectively.

$$q_{el} = \frac{\dot{m}_{el}}{A_{el}} \quad (10)$$

In this equation q_{el} is the mass flow rate into each element, \dot{m}_{el} is the total input flow rate and A_{el} is the element area.

For determining the combustion stability inside the combustion chamber, another parameter is defined that is named relative flux of combustion chamber. This parameter is obtained by dividing the mass flux to combustion chamber pressure (P_{cc}).

$$\bar{q}_{el} = \frac{q_{el}}{P_{cc}} \quad (11)$$

For combustion stability, the value of relative flux must be [2] : $0.8 \leq \bar{q} \leq 1.3$

After specifying the ratio of oxidizer to fuel flow rates, mass flux and relative flux, the alterations curve must be plotted.

On the basis of Experience, from the view point of cooling, the suitable alteration curve of “oxidizer to fuel” flow rate ratio (O/F) and value of flow rate (q) must be similar [fig. 4].

With this distribution, the equilibrium ratio (α) at the center part of combustion chamber, far from the walls, is near to one and at the adjacent of walls, where the wall cooling is important, is in the fallow interval : $0.2 \leq \alpha \leq 0.4$

3 ARRANGEMENT SELECTION

The arrangements that designer can select for injector plate are various, but generally each arrangement is a combination of three main arrangements : checkered, honeycomb and concentric.

The used injectors in this analysis are two components swirl injectors, therefore from the viewpoint of injection rate, it is better that to use the concentric or honeycomb arrangement. The reason of this subject is equality of distance between injectors in this arrangement. In this paper for correct comparison, the arrangements that are used for one component injectors have been used. At all of investigated arrangements, the total passed flow rate from injector plate and the ratio of oxidizer to fuel flow rate have been considered as a constant value.

In figure 5, the selected arrangements have been presented and numbered from 1 to 5. At presented arrangement, the equilibrium ratio beside combustion chamber wall is $\alpha = 0.4$, at the midsection $\alpha = 0.6$ and at the central part is $\alpha = 1.0$ (figure 6). In table 1, the characteristics of proposed plates have been presented.

4 THE RESULTS OF COMPUTER CODE EXECUTION

With due consideration to results of computer code, some notes can be pointed as follows :

- a) With due consideration to the distribution of the ratio of oxidizer to fuel flow rate on cross section of combustion chamber (figure 7), from the view point of specific impulse generation, plates 1 and 3 are better. Becoming more of this ratio beside the walls, renders difficult cooling of internal shell of combustion chamber. Because essentially according to combustion relations at stoichiometric value, addition to specific impulse, the temperature of combustion products are in a upper level.
- b) One of important effects of flow mixing in the central and lateral regions is the heating of combustion chamber's wall due to heat transfer between these regions. Therefore with due consideration to the necessity of avoiding the central and lateral flow mixing, the value of \bar{q} at central region must be different from the value of \bar{q} at the lateral region (about 180%). Therefore \bar{q} related to plates (1) and (3) is not acceptable.
- c) The uniformity in distribution of injection at different area of plate, with due consideration to the direct effect on combustion delay times, is an effective factor in exciting relative to high frequency instability. Therefore the nearness of \bar{q} at different area of injector plate is not desirable. Then the injector plates 2, 4 and 5 are better. From this view point, the existence of anti-pulsation plates (baffles) because of nonuniformity creation of \bar{q} at different areas are more desirable (figure 9). But the experience of these plates haven't effect on the distribution of oxidizer to fuel flow rate ratio and because of existence of baffles, the distribution of temperature on plate does not change (figure 10).
- d) Figure 8 illustrates that at central region , concentric arrangement has greater \bar{q} as compared with honeycomb arrangement. But experience has proved in case that injectors have equal distance, the distribution of oxidizer to fuel flow rate ratio is better, therefore injector plate 5 because of having honeycomb arrangement at center, is better.

5 CONCLUSION

The purpose of this research is selection of the best arrangement of injector plate (from viewpoint of cooling and suitable injection). This research was accomplished for 5 different arrangements.

With due consideration to computer code results, arrangements 1, 2 and 3 were not suitable and arrangements 4 and 5 were desirable. But which of these two plates (4 or 5) is more desirable ? the answer of this question needs an experimental work.

From the viewpoint of technology, arrangement 5 is more suitable, because selected distance at arrangement 5 is more than arrangement 4 and the operation of injector assembling at central region is easier.

In table 2, the comparison between values of selected injector plates 4 and 5 have been presented.

These injector plates have been designed for conditions that combustion stability haven't been suitable.

It must be mentioned that at new design of injector plate, the value of \bar{q} has reached from

0.79 (old design) to 1.2 (approximate value) and new plate from the viewpoint of stability has suitable conditions.

Injectors Mean Distance	Anti-pulsation Plate	Type of Injectors Arrangement			Number of Injectors				No.
		Lateral Region	Mid Section	Central Region	Total	Lateral Region	Mid Section	Central Region	
23	Cross	Concentric	-	Concentric	296	60	-	236	1
20	-	Concentric	Concentric	Honeycomb	463	138	114	211	2
21	Solar	Concentric	-	Concentric	307	60	-	247	3
19	Solar	Concentric	Concentric	Concentric	469	138	114	217	4
20	Solar	Concentric	Concentric	Honeycomb	463	138	114	211	5

Table 1 : The characteristics of proposed plates

Arrangement 5	Arrangement 4	↓ Parameter
1.2337	1.2618	Mean Value of Injection Rate (flux)
0.42681	0.196254	Standard Deviation

Table 2 : The Comparison between values of relative flux

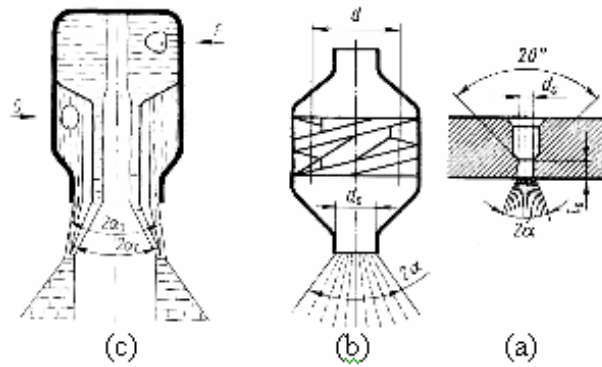


Figure 1 :

- a) Direct flow injector
- b) One-component swirl injector
- c) Two-components swirl injector

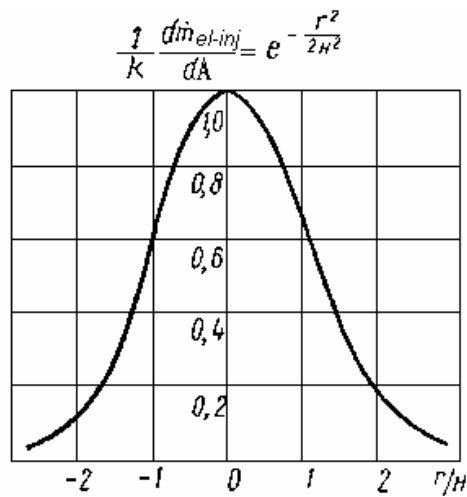


Figure 2 : Curve of flow rate distribution around the injector

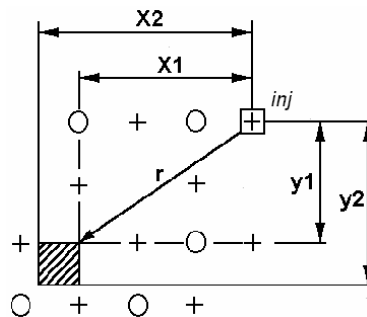


Figure 3 : Presentation of parameter r in expression (1)

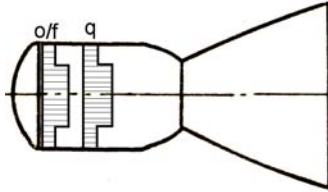


Figure 4 : Alteration of “oxidizer to fuel” flow rate ratio (O / F) and value of flow rate (q) at cross section of combustion chamber

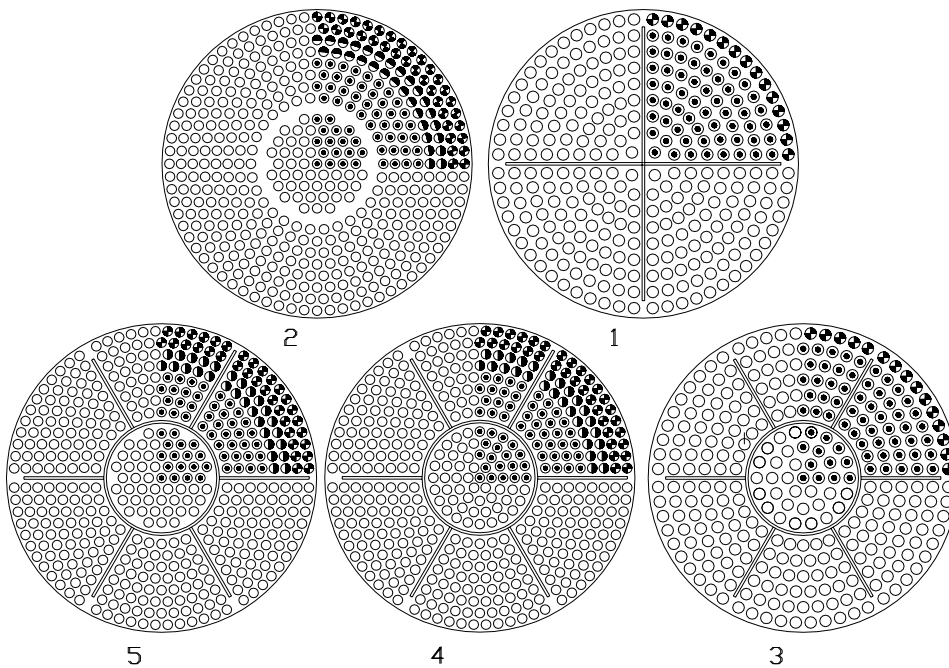


Figure 5 : Types of selected arrangements

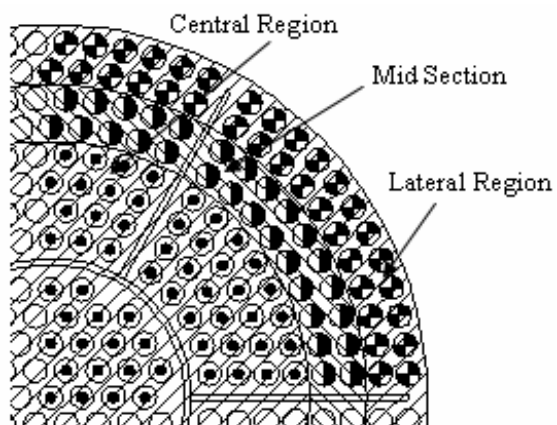


Figure 6 : Presentation of mentioned regions at injector plate

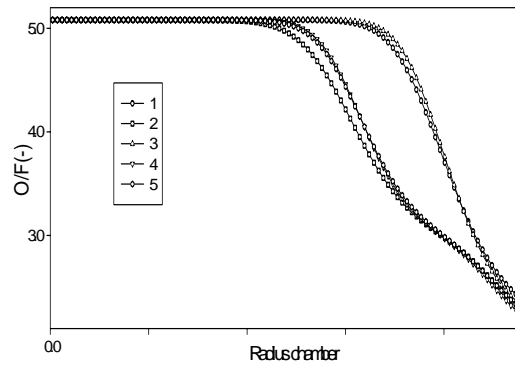


Figure 7 : The ratio of “oxidizer to fuel” vs. chamber radius

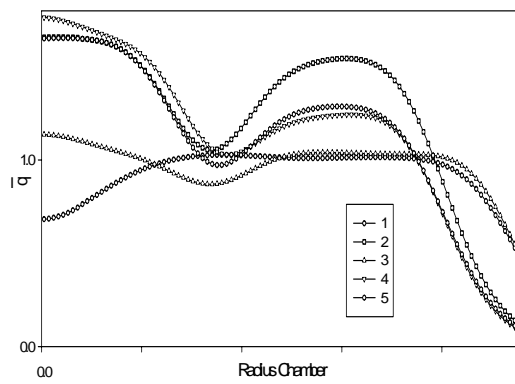
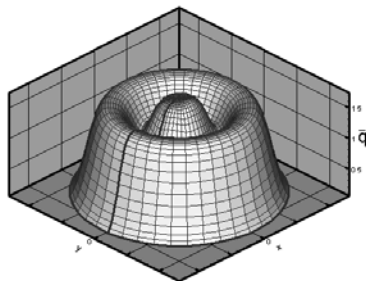
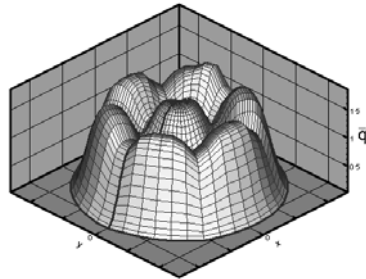


Figure 8 : The relative flow rate vs. chamber radius



(a)



(b)

Figure 9 : The effect of anti-pulsation plates (baffles) on relative flux
(a). Radial baffles (arrangement 3)
(b). Radial and tangential baffles (arrangement 5)

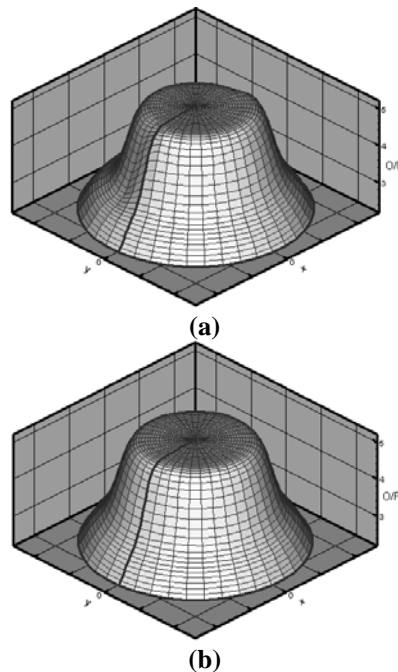


Figure 10 : The effect of anti-pulsation plates (baffles) on ratio of “oxidizer to fuel” flow rate
(a). Radial baffles (arrangement 3)
(b). Radial and tangential baffles (arrangement 5)

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