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An Investigation on the Effects of Injection Spray Cone on Propulsive Droplets in a Duct

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***Abstract*—**This paper addresses one important aspect of combustion system analysis, the spray evaporation and dispersion modeling. In this study we assume an empty cylinder which is as a simulator for a ramjet engine and the cylinder has been studied by cold flow. Four nozzles have the duties of injection which are located in the entrance of cylinder. The air flow comes into the cylinder from one side and injection operation will be done. By changing injection velocity and entrance air flow velocity, we have studied droplet sizing and efficient mass fraction of fuel vapor near and at the exit area. We named the mass of fuel vapor inside the flammability limit as the efficient mass fraction. Further, we decreased the initial temperature of fuel droplets and we have repeated the investigating again. To fulfill the calculation we used a modified version of KIVA-3V.

***Keywords*—**Ramjet, droplet sizing, injection velocity, air flow velocity, efficient mass fraction..

I. INTRODUCTION

THE demand for high-performance and improved-safety propellants for various rocket and ramjet motor applications has been constantly increasing during the last decades.Liquid fuel spray combustion involves different complicated and inter-related processes such as atomization, subsequent droplet breakup and collisions, vaporization, fuel vapor-air mixing, and finally chemical reactions. Understanding these processes and being able to represent them in the context of a CFD simulation program is of great importance both for researchers and for the industry. CFD offers a significant and a powerful tool to evaluate the operation of practical combustion systems and helps designers of these systems to come up with modified versions that have better performance characteristics. Different previous researches investigate, both experimentally and by numerical simulation, the vaporizing sprays and the droplet interaction under different operating conditions; see for example references [1–7]. Droplet evaporation is of importance in, for example, process operations, liquid hydrocarbon combustion, and meteorology. Evaporation of a single isolated liquid droplet injected into an infinite stagnant gas has long been a subject of study; recent reviews of this activity have been given by Kent [8] and Williams [9]. Fuel jet injection plays a major role in the design of air breathing engines such as ramjets or scramjets. Extensive studies must be conducted into the effects of various injection parameters. Thrust vector control, afterburners, and liquid surface injections for cooling purposes and external burning in the wake of projectiles. In the case of ramjets or scramjet engines, the fuel is usually injected from a wall or strut across an air flow. Ramjet engines have a special place in ultrasound flights as the producers of propulsion. Many researches about these engines show the importance of various parameters which affect on efficiency among which, the role of combustion chamber is very specific this is because of complexity of flow physics inside the combustion chamber. Combustion phenomenon is very unintelligible; therefore fully simulation of flow in this process needs a large amount of cost and time. Many studies in this field show that, one of the effective steps in order to evaluate the operation of combustion chamber is the determination of injection velocity and also air flow velocity which affect on vaporization rate and quality of air-fuel mixture and hence on efficiently of engine. In the present study we have numerically integrated the efficient mass fraction and diameter of propulsive droplets, both for variable properties and for properties using various reference state schemes. We shall show the best quantity of injection velocity as well as effects of injection velocity and entrance air flow velocity on droplets sizing and efficient mass fraction. Further we will decrease the initial temperature of fuel droplets and we have repeated the investigating again.

II. NUMERICAL MODELING

A. Mesh Generation

The KIVA-3 formulation is based on (x,y,z) Cartesian coordinates. Rather than being confined to one logical block of cells in (i,j,k) space to encompass the entire region to be modeled, however, the geometry of a KIVA-3 mesh is composed of any arbitrary number of logical blocks that are patched together in a completely seamless fashion.

With regard to the injection initial conditions, the dimensions of the computation domain are selected. As the injection velocity, or fuel total mass, increases, a larger domain of computation should be considered.

B. Boundary Conditions

In this study, we considered a duct with 10cm diameter and 40cm length which is shown in figure1. Four nozzles with 90 degrees distance from each other were placed on top of the cylinder. The fuel is gasoline and the pressure of inlet air flow is 1atm and the temperature is 300 K also.

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As the boundary conditions, we applied “pressure inflow” for the entrance air flow velocity, “solid” for wall of the cylinder (Fig 1), and “pressure outflow” for the propulsive surface.

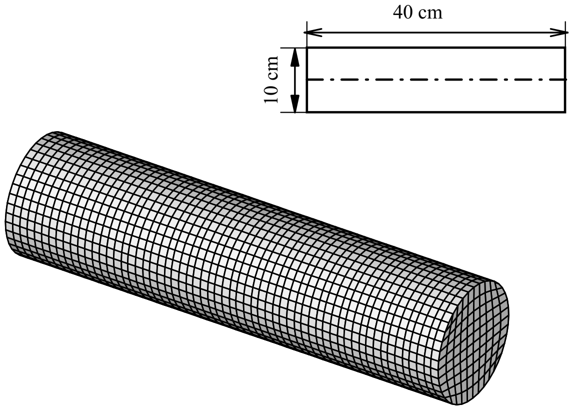

Fig 1. The sample mesh

III. SOLVING PATTERN

The time of solving has considered 1 second and the time of fuel injection is 0.02 second after solving beginning in due to the fact that the flow in cylinder becomes pervasive. All of calculations have been done by KIVA-3V code which modified for this purpose.

IV. RESULTS

In this paper, we calculated efficient mass fraction and fuel propulsive droplet sizing in the bellow conditions; first, injection velocity of 25 m/s and air flow velocity of 30 m/s. Then in the second condition, the entrance air flow velocity has been kept constant and then we increased injection velocity to 30, 35, 40, 45, 50 and 55 m/s respectively.

We have divided this study into 2 parts. In the first part, we have done above conditions on initial temperature of fuel injected droplets of 300 K and in the second part we have considered this parameter equals 295 K.

A. Part I

For this part a complete format of initial conditions has been illustrated in table I.

TABLE I
INITIAL CONDITIONS

Fuel Droplets	
Total fuel mass flow	35 g/s
Temperature	300 K
Injection angle	45 degree (counter flow)
Initial Sauter radius	0.02 cm
Air flow	
Temperature	300 K
Pressure	1 atm
Velocity	30 m/s

TABLE II
FUEL PROPULSIVE DROPLETS SIZING IN AIR FLOW VELOCITY OF 30 (M/S)

	Injection velocities (m/s)					
	30	**35**	**40**	**45**	**50**	**55**
Mean diameter (µm)	61.8	47	44.2	40.2	37.6	24
Mean efficient mass fraction (percent)	50.2	52.7	57.1	59.2	62	64

Also, as the second condition, we have grown the entrance air flow velocity from 30 to 36 and 40 m/s correspondingly and repeated previous analysis again.

TABLE III
FUEL PROPULSIVE DROPLETS SIZING IN AIR FLOW VELOCITY OF 36 (M/S)

	Injection velocities (m/s)					
	30	**35**	**40**	**45**	**50**	**55**
Mean diameter (µm)	42.8	39.4	30.2	24	22.2	20.8
Mean efficient mass fraction (percent)	43.1	45.5	48.3	50.1	54.4	56.8

TABLE IV
FUEL PROPULSIVE DROPLETS SIZING IN AIR FLOW VELOCITY OF 40 (M/S)

	Injection velocities (m/s)					
	30	**35**	**40**	**45**	**50**	**55**
Mean diameter (µm)	31.4	30.2	23.2	19.26	19.06	18.8
Mean efficient mass fraction (percent)	39.3	42.3	43.6	47.5	48.3	50.1

B. Part II

In this part, the initial temperature of fuel droplets has been considered 295 K and previous operations have repeated.

TABLE V
FUEL PROPULSIVE DROPLETS SIZING IN AIR FLOW VELOCITY OF 30 (M/S)

	Injection velocities (m/s)					
	30	**35**	**40**	**45**	**50**	**55**
Mean diameter (µm)	55.6	54.2	50.0	44.6	36.0	33.2
Mean efficient mass fraction (percent)	46.0	47.7	53.0	54.0	57.2	57.6

After this analysis likes part I, we have surged the entrance air flow velocity from 30 to 36 and 40 m/s correspondingly and repeated previous analysis again.

TABLE VI
FUEL PROPULSIVE DROPLETS SIZING IN AIR FLOW VELOCITY OF 36 (M/S)

	Injection velocities (m/s)					
	30	**35**	**40**	**45**	**50**	**55**
Mean diameter (µm)	42.2	39.4	27.4	25	22.2	19.72
Mean efficient mass fraction (percent)	39.9	42.8	44.0	47.4	49.9	51.8

TABLE VII
FUEL PROPULSIVE DROPLETS SIZING IN AIR FLOW VELOCITY OF 40 (M/S)

	Injection velocities (m/s)					
	30	**35**	**40**	**45**	**50**	**55**
Mean diameter (µm)	26.4	24.6	20.2	19.46	17.02	15.4
Mean efficient mass fraction (percent)	35.7	38.8	40.09	42.4	46.0	47.4

V. DISCUSSION

A. Propulsive Droplets sizing

According to the tables I to VII, with increase of injection velocity, the mean diameter has decreased. As we can see, with increase of injection velocity from 30 to 35, 40, 45, 50 and 55 m/s respectively, the mean diameter has fallen gradually. This manner is indefeasible in all of entrance air flow velocities. For example, decreasing of fuel propulsive droplet sizing by increasing of injection velocities in entrance air flow velocity of 36 m/s has been shown in figure 2.

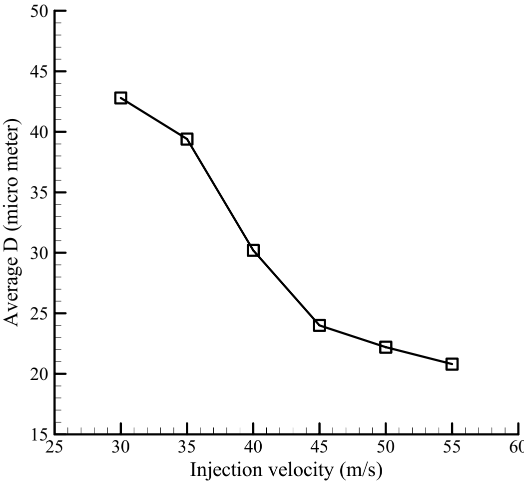

Fig. 2 Effect of injection velocity on mean diameter of droplets.

In accordance with figure 2, in the air flow velocity of 30 m/s, by raising the injection velocity, the mean diameter has fallen sharply from 61.8 to 24 µm. Also, in air flow velocity of 36 and 40 m/s respectively, the mean diameter of droplets has decreased gradually up to injection velocity of 40 and 45 m/s correspondingly. But after that, it has been become constant approximately. In below some comparing graphs have been given.

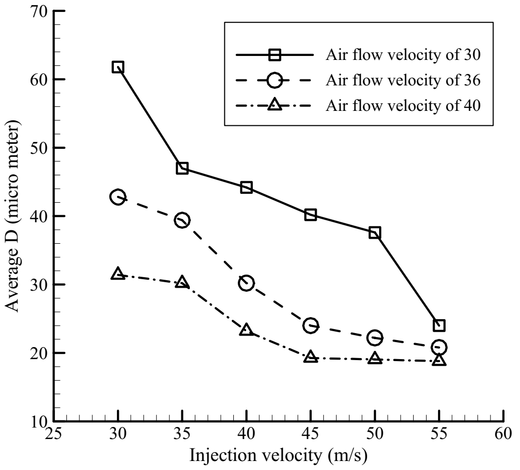

Fig. 3 The mean diameter of droplets in different injection velocities (initial temperature of fuel droplets is 300K)

In accord with fig. 3, by rising of injection velocity, the mean diameter of droplets has lowered; however, the least mean diameter in these three cases is nearly 20 µm.

B. Efficient mass fraction

In fig 4, the fluctuations of mean efficient mass fraction in different injection velocities have been shown. In all conditions, with increase of injection velocity, the mean efficient mass fraction has surged. But according to figure 4, efficient mass fraction has a reverse respect with inlet air velocities.

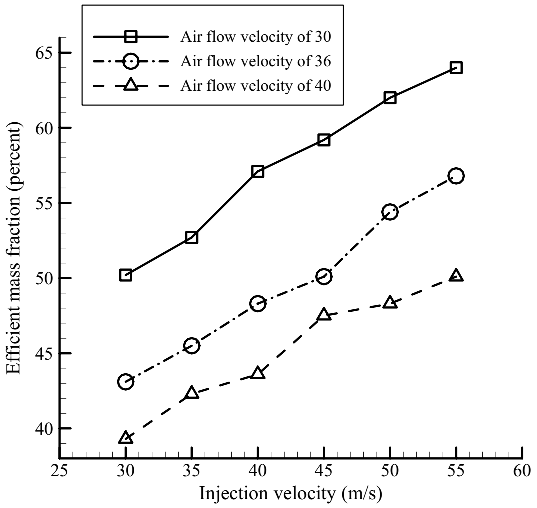

Fig. 4 The variation of efficient mass fraction in different injection velocities (initial temperature of droplets is 300K).

As indicated in figure 4, by rising the entrance air velocity from 30 to 36 and 40 m/s respectively, the efficient mass fraction has decreased gradually. For instance, in injection velocity of 45 m/s, the efficient mass fraction has been near 60 percent in injection velocity of 30 m/s, and by growing entrance air velocity to 36 and 40 m/s correspondingly, the efficient mass fraction has lowered to 50 and 45 percent respectively.

C. Initial temperature of fuel droplets

In table V to VII, the mean diameter of propulsive droplets sizing and efficient mass fraction have been illustrated in initial fuel temperature of 295 K. By a comparison between tables II to IV and V to VII, we can understand, with 5 degrees falling of the initial temperature of fuel droplets, the efficient mass fraction have decreased palpable.

Figure 5 shows the effects of initial temperature of fuel droplets on efficient mass fraction. According to figure 5, by growing of injection velocity, the efficient mass fraction has mounted progressively. Also, with increase of fuel droplets temperature, this quantity has increased gradually. For example in injection velocity of 40 m/s , entrance air flow velocity of 30 m/s and initial fuel temperature of 295K, the efficient mass fraction is about 53 percent, whereas, it is about 57 percent in initial temperature of 300K. In accordance with table II to VII, with 5 degrees growth in initial temperature of fuel droplets, the mean diameter of propulsive droplets has altered, but this variation is negligible.

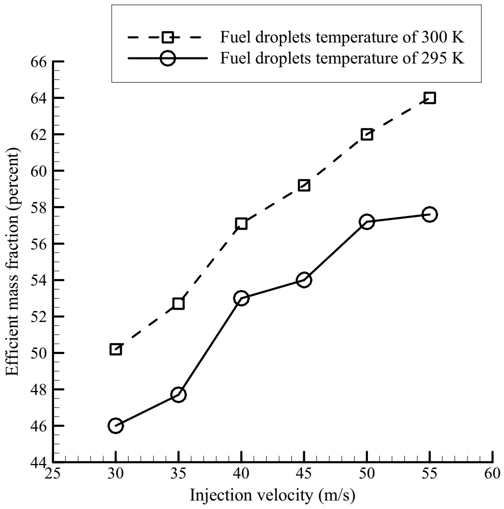

Fig. 5 A comparison between initial fuel temperature of 300K and 295K (entrance air flow of 30).

VI. CONCLUSION

The effect of injection velocity and entrance air flow velocity on fuel propulsive droplet sizing and efficient mass fraction were studied by a numerical procedure. Further we investigated the effects of initial temperature of fuel droplets on efficient mass fraction too. The consequences show, by growing the injection velocities from 30 to 35, 40, 45, 50 and 55 m/s, the average diameter of droplet sizing has lowered gradually. About effect of entrance air flow velocities on fuel propulsive droplet sizing, the results show, with increase of air flow velocities from 30 to 36 and 40 m/s correspondingly, the efficient mass fraction has decreased and it has a reverse respect with inlet air velocities. In addition, with 5 degrees growth in initial fuel temperature, from 295 K to 300 K, the efficient mass fraction has increased.

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