

## Research Article

# CFD Simulation of Pressure and Velocity Drop on Y-Type Fuel Injectors

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Hydrocarbon injection is an important stage in combustion, where the atomisation process is involved the atomisation process which consists of disintegrating the fuel into small droplets, through an injector to add more transfer area, the fuel, through an injector to add more transfer area. The size of droplet size generated by the injector must be less than  $80\ \mu\text{m}$  to ensure good combustion and avoid combustion and avoid pollutants such as CO and NOx. This research worked with ethanol, a low-emission hydrocarbon, which has a high viscosity which makes it difficult to achieve the correct droplet diameter. This type of study needs to be both theoretical and experimental with simulation being a great tool to replace the latter. The finite element method included in the Flow Simulation package of the SolidWorks software was used in this research. The Flow Simulation package of the SolidWorks software was used, where a Y-type injector was sketched to be evaluated. The dynamic simulation helped to measure the velocity field, at the outlet of the air nozzle, a cavity with a diameter of 0.4 mm, which helps to increase the kinetic energy of the air. The kinetic energy of the fluid obtains the highest values of the Mach number in this area.

## 1. Introduction

Since the 19th century, mankind has been using oil as a fuel. However, this resource is becoming scarce on our planet. The new vision of sustainability demands that any process is in harmony with the environment, society, and the economy and needs new alternatives that address these three parameters [1]. We are currently talking about alternative fuels, which offer a very interesting alternative to diesel in terms of emissions, wear and tear cost, and availability. Injectors are responsible for the atomisation of the fuel for a combustion process in an engine or a furnace. Atomisation is a process characterised by the transformation of a mass of liquid into a spray or other physical dispersion of droplets in a gaseous atmosphere. This is accomplished by the kinetic energy carried by the fluid [2]. The study of injectors for alternative fuels such as biodiesel ethanol and pyrolytic oil is a very important line of research in recent years since its progress

provides alternatives to industrial processes [3]. Y-type injectors are widely used in a steam generation used in steam generation, electric power generation, and furnaces where they serve the function of atomising small droplets of the liquid fuel to be fed into the combustion chamber. Most of the currently used fuels currently used, such as diesel, fuel oil, jet fuel, and petroleum, are alternatives that have caused a lot of damage to our planet. In view of the population being dependent on energy, new solutions have hydrocarbons such as methanol, hydrogen, propanol, and biodiesel which are alternatives to be able to continue to generate the necessary energy but without polluting [4]. These new alternatives require technological changes in the accessories that are part of the combustion process. In this work, we do not focus on the atomisation in the injector, for which it will be necessary to study the main parameters that influence this process. One of these renewable fuels is ethanol, which can be produced from a large number of fuels. Bioethanol has the

same characteristics and chemical composition as ethanol as it is the same compound. Bioethanol has to be obtained from biomass and cannot be obtained from petroleum. These studies require a theoretical and experimental and experimental analysis of the different variables involved in the atomisation process. The works cited above compare numerical results with experimental data of injection systems. The fundamentals of fluid mechanics can be applied to discover how much energy is needed to achieve the required velocities and adequate pressure to achieve adequate atomisation. The flow in an injector was analyzed which used a computer model and the CFD program model, and the CFD program FIRE, to find the flow rate.

## 2. Material and Methods

The present study shows a graphical analysis using computational fluid dynamics (CFD) which is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyse fluid flow problems. This work requires a computer which will be used to perform millions of calculations required to simulate the interaction of ethanol and air inside the injector cavities. It should be noted that even with simplified equations and with a suitable high-performance computer, only approximate results for most iterations were obtained. SolidWorks helps mechatronic systems be developed from beginning to end. In its initial stage, the software is used for planning, conceptualizing, visualizing, modeling, assessing feasibility, prototyping, and managing projects. As a result, mechanical, electrical, and software elements are designed and constructed via the software. The method consists of discretising a region of space by creating a spatial grid, by dividing a region of space into small control volumes. It is solved in each of them, and the discretised conservation equations are then solved in each so that in effect, an algebraic matrix is an algebraic matrix in each cell iteratively until the residual is sufficiently small [5].

The equations for continuity, momentum, energy, turbulent kinetic energy, and energy by turbulent dissipation are given in equations (1)–(5).

Continuity

$$\frac{\partial}{\partial x_i} (\rho u_i) = 0. \quad (1)$$

Momentum

$$\frac{\partial}{\partial x_i} (\rho u_i u_k) = \frac{\partial}{\partial x_i} \left( \mu \frac{\partial u_k}{\partial x_i} \right) - \frac{\partial P}{\rho x_i}. \quad (2)$$

Energy

$$\frac{\partial}{\partial x_i} (\rho u_i t) = \frac{\partial}{\partial x_i} \left( \frac{\partial t}{\partial x_i} \frac{k}{c_p} \right). \quad (3)$$

Turbulent kinetic energy

$$\frac{\partial}{\partial x_i} (\rho u_i k) + \frac{\partial \rho k}{\partial t} = \frac{\partial}{\partial x_i} \left( \left( \mu + \frac{u_t}{\sigma_k} \right) \frac{\partial}{\partial x_i} \right) + S_k. \quad (4)$$

Energy by turbulent dissipation:

$$\frac{\partial}{\partial x_i} (\rho u_i \varepsilon) + \frac{\partial \rho \varepsilon}{\partial t} = \frac{\partial}{\partial x_i} \left( \left( \mu + \frac{u_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_i} \right) + S_\varepsilon. \quad (5)$$

Here,  $P_B$  represents the generation turbulent due to the forces off low at and can be written as

$$P_B = -\frac{g_i}{\sigma_B} \frac{1}{\rho} \frac{\partial \rho}{x_i}, \quad (6)$$

where " $g_i$ " is the component of gravitational acceleration in the direction  $x_i$ , the constant  $\sigma_B = 0.9$ , and the constant  $C_B$  is defined as  $C_B = 1$  when  $P_B > 0$ , or otherwise 0

$$f_1 = 1 + \left( \frac{0.05}{f_\mu} \right)^3, \quad (7)$$

$$f_2 = 1 - \exp(-R_T^2).$$

The constants  $C_\mu$ ,  $C_{\varepsilon 1}$ ,  $C_{\varepsilon 2}$ ,  $C_\varepsilon$  and  $C_k$  are empirically defined. In AppFlow Simulation, the typical values used are as follows:

$$\begin{aligned} C_\mu &= 0.09, \\ C_\varepsilon &= 1.3, \\ C_{\varepsilon 2} &= 1.92, \\ C_{\varepsilon 1} &= 1.44, \\ C_k &= 0. \end{aligned} \quad (8)$$

The evaluation of the mean mass requires a formula already developed by Wigg (1959), who analyzed the mechanism of atomisation with air jets, emphasising the importance of the kinetic energy of the atomising air, and indicated that the energy difference between the air jet in the inlet and the emerging spray is a dominant factor affecting the mean droplet diameter. In 1964, using experimental data from other researchers on the atomisation of viscous liquids and air in Y-type injectors, Wigg succeeded in deriving a dimensionless expression which allows to evaluate the mass median diameter of the spray droplets [5]:

$$D_{MMD} = \frac{200V^{0.5} m_F^{0.1} (1 + m_F/m_A) 0.5h^{0.1} \sigma^{0.2}}{\rho AT^{0.3} \Delta U}, \quad (9)$$

where  $D_{MMD}$  = mass mean diameter of the spray drops ( $\mu m$ ),  $V$  = kinematic viscosity of ethanol (cSt),  $m_f$  = mass flow of ethanol (g/s),  $m_A$  = air mass flow (g/s),  $h$  = chamber diameter mixture (cm),  $\sigma$  = surface tension of ethanol (dynes/cm),  $\rho AT$  = air density ( $g/cm^3$ ), and  $\Delta U$  = air speed of atomization (m/s).

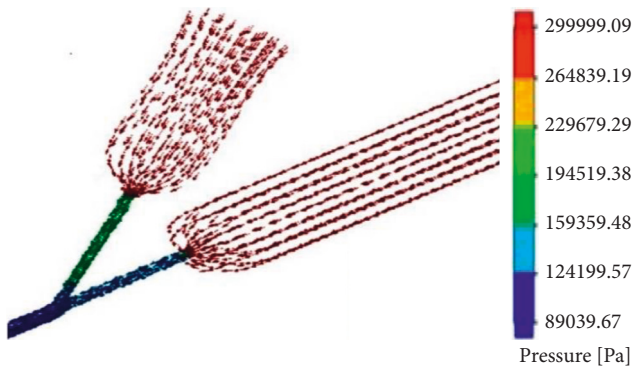


FIGURE 1: Isometric view of air at 300 kPa with the flow of fuel of 0.18 g/s. The values needed to evaluate the Wigg equation were taken from the tables predetermined by the software V 1.451423 (cSt).  $m_F$ : 0.20 (g/s);  $h$ : 0.040 (cm);  $\sigma$ : 22.3 (dynes/cm).

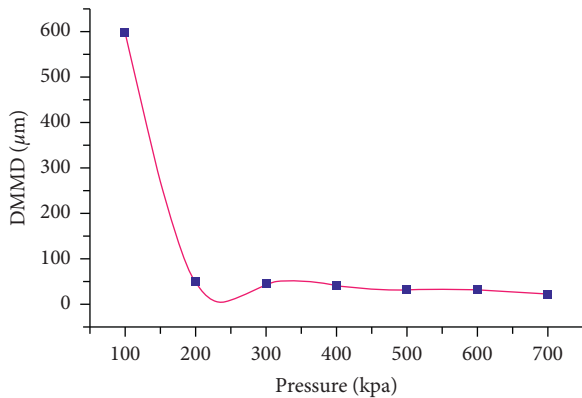


FIGURE 2: Dependence of the mass mean diameter and the stagnation pressure of the air.

### 3. Results and Discussion

The Y-type fuel injector in use was dimensioned in such a way that it operates at a power to operate at a thermal power of 10 kW and an ethanol mass flow rate of 0.20 g/s. The nozzle of the air and ethanol injector nozzle is 0.4 mm in diameter. The mixing chamber where the flows converge has a diameter of 0.40 mm and a length of 1.5 mm [6]. First of all, the injector was sketched out with the measurements mentioned in the programme, and then the boundary conditions were on the thickness covering the fluid inlet were introduced [7]. For the ethanol, the boundary conditions were set to 0.20 g/s introduced for the ethanol lid, while for the air the stagnation pressures were varied in order to appreciate their influence on GLR,  $D_{MMD}$ , and velocity [8]. The diameter of a droplet can be measured using several different methods. As industrial methods for measuring spray droplet size, immersion sampling and laser analyzers are used. The values needed to evaluate the Wigg equation were taken from the default tables predetermined by the software [9]. An isometric view of air at 300 kPa with a flow of fuel of 0.18 g/s is shown in Figure 1.

Figure 2 shows the dependence of the mass mean diameter and the stagnation pressure of the air. In this study, it

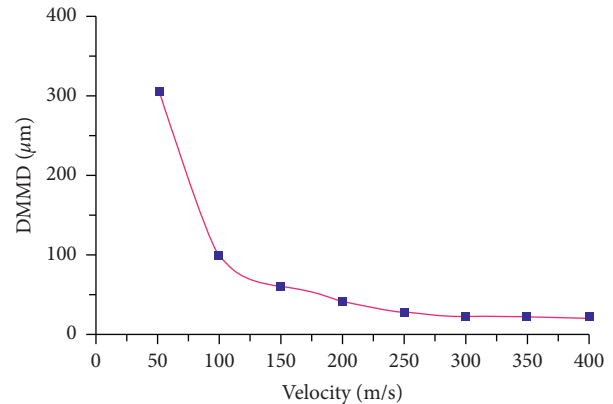


FIGURE 3: Dependence of the mass mean diameter and the speed of entry into the chamber.

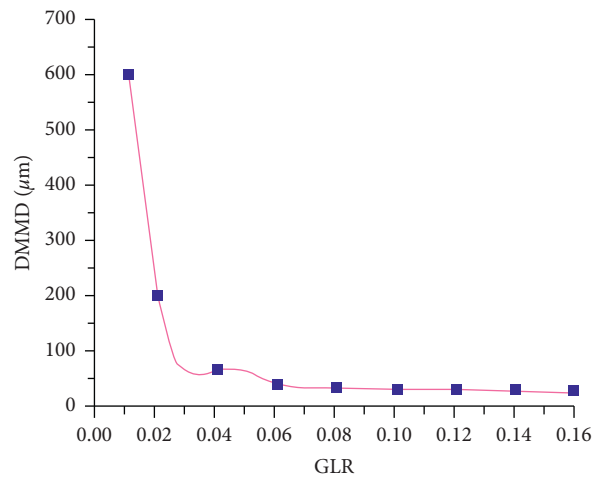


FIGURE 4: Dependence of the mass mean diameter and the GLR.

was found that for air stagnation pressures higher than 200 kPa, the droplet diameter is optimal and that for pressures approaching atmospheric conditions, such as pressures less than 180 kPa, the results are technically inefficient to achieve good atomisation.

Figure 3 shows the dependence of the mass mean diameter and the speed of entry into the chamber. The results show the velocity at the nozzle outlet of the nozzle exit achieves a better atomisation diameter when closer to the sonic regime obtaining values of around 15  $\mu\text{m}$ .

Figure 4 shows the dependence of the mass mean diameter and the GLR. It was confirmed that values should be within the 0.10–0.20 GLR range. However, the range proposed in this study is much wider for ethanol with high atomisation performance in the range of 0.040–0.20 of GLR [10].

### 4. Conclusions

The simulations carried out by the software Flow Simulation for a type Y injector with thermal power of 10 kW and a constant mass flow rate of 0.20 g/s obtained three important graphs for the characterisation of this type of injector using

ethanol as fuel. In this study, it was found that for air stagnation pressures higher than 200 kPa, the droplet diameter is optimal and for pressures approaching atmospheric conditions, such as pressures less than 180 kPa, the results are technically inefficient to achieve good atomisation. The results show the velocity at the nozzle outlet of the nozzle exit achieves a better atomisation diameter when closer to the sonic regime obtaining values of around 15  $\mu\text{m}$ . In addition, it was confirmed that values should be within the 0.10–0.20 GLR range. However, the range proposed in this study is much wider for ethanol with high atomisation performance in the range of 0.040–0.20 of GLR.

### Data Availability

The data used to support the findings of this study are included in the article.

### Conflicts of Interest

The authors declare that they do not have any conflicts of interest regarding the publication of this paper.

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