Journal of Technology and Innovation 12[30]1-7: e11230107
Article

Design and simulation of gas mixing valve

Diseño y simulación de una válvula mezcladora de gas

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Classification:

Area: Engineering
Field: Engineering
Discipline: Mechanical Engineering
Subdiscipline: Fluids

https://doi.org/10.35429/JTI.2025.12.30.1.1.7
History of the article:
Received: July 01, 2025
Accepted: September 30, 2025

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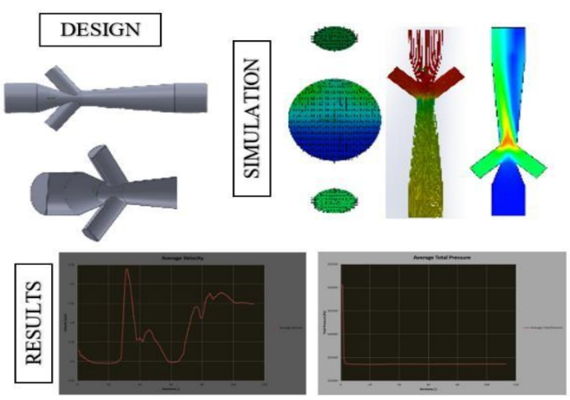
Abstract

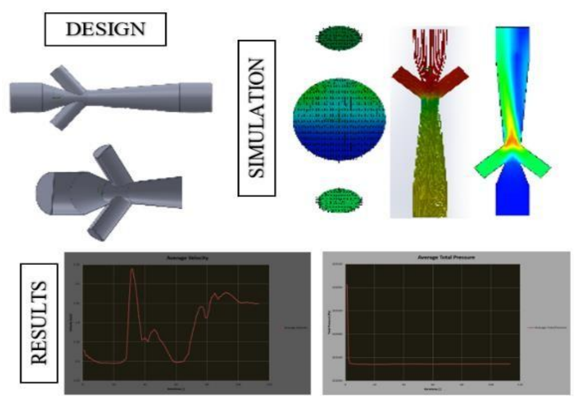
This study presents a design methodology for a mixing valve for two gases. The first of the gases have an ultra-low pressure and velocity, while the second have a fastest mobility. Taking advantage of the Bernoulli effect, a Venturi-type mixer is implemented to take advantage of the fast speed primary gas to create a slightly suction to move the secondary gas. To validate this methodology, simulation results of the designed valve are shown. According to the results, the suction present in the low pressure line is enough to dislodge the secondary gas without cause vacuum.



Bernoulli effect; Venturi; gas mixing valve

Resumen

En el presente estudio se aborda la metodología de diseño de una válvula mezcladora de gases, uno de los cuales posee características de presión y velocidad muy bajas, mientras que el otro presenta una velocidad mayor. Aprovechando el efecto Bernoulli, se empleó un mezclador tipo Venturi con el fin de aprovechar la velocidad del fluido principal para provocar una ligera succión que moviera al gas secundario. Para validar la metodología presentada, se simuló la válvula mezcladora. Los resultados mostraron que la succión en la línea de baja presión es suficiente para desalojar el gas secundario sin crear un vacío.



Efecto Bernoulli; Venturi; Válvula mezcladora de gases

Area: Development of strategic leading-edge technologies and open innovation for social transformation

Citation: Vázquez-Carreón, José Roberto, Cisneros-Sinencio, Luis Fortino, Arvizu-Rodríguez, Liliana Elizabeth and González-Hernández, José Genaro. [2025]. Design and simulation of gas mixing valve. Journal of Technology and Innovation. 12[30]1-7: e11230107.

Introduction

Gas mixing is a practice that has been used in recent years in different contexts, providing a homogeneous gas mixture of different gaseous sources. Applications for this valve range from the pharmaceutical industry to mix and package medicines, to automotive to mix fuel with oxidants.

As a case of study, a valve to be used in the oil refining industry is proposed. The valve will take residual gas from different stages of the refining process to be mixed with a like with gaseous fuel. This fuel can be propane or natural gas used for heating in the same process. This way, user can take advantage of the energetic potential of harmful gases that otherwise would be thrown to the environment. As the source of the secondary residual gas is not constant and its availability depends on the process, the valve should be designed assuming a very small amount of gas present in the line. A slight suction should be applied to the line in order to transport the secondary gas to the valve. However, this suction should not be strong enough to pull the raw materials for the corresponding process stage.

As the purpose of this valve is to burn the residual gas together with the fuel in the primary line, there is no need for the gas to be homogeneously mixed. Instead, the efforts of this methodology are oriented in order to effectively dislodge the residual gas from the corresponding line without creating a vacuum that negatively affect the process.

Venturi Effect

To take advantage or the venturi effect, a venturi tube is constructed. The structure of the venturi tube is a short pipe with a narrow and restricted inner surface, commonly used to accelerate the fluid working as a functional pump. This device, designed by Giovanni Battista Venturi, has a constricted throat in the center. When fluid enters this throat, the flow through it accelerates and the pressure decreases. This device is meticulously designed to take advantage of the effects of narrow channels and restricted fluid movement. This way, the Venturi tube is a configuration used to modify the speed of a fluid. Venturi tubes are a popular option for a wide variety of processes: from high precision measurement of fluid behavior to the modification of the dynamics of a fluid.

Characteristics of the Venturi tube

As shown in Figure 1, the venturi tube is constructed with three fundamental parts. Each of these parts guarantee the characteristics and behavior of the device. The sections on the venturi tube are:

- Convergent inlet section
- Throat section
- Divergent outlet section/coning section

Box 1

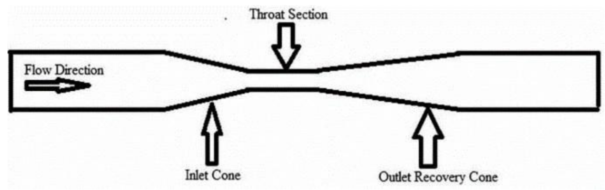


Figure 1
Basic model of a Venturi meter

The convergent inlet cone is the region where the cross-section of the inlet pipe is conically reduced for its connection to the throat, resulting in a progressive decrease in cross-section from one end to the other.

This component is attached to both the inlet pipe and the cylindrical neck. According to the ASME manual [ASME MFC-3M-2004, 2004], the angle of convergence is set at a range of 20 to 22°, while the flow length is 2.7[Dd], where D represents the diameter of the inlet section and d corresponds to the diameter of the throat. The convergent region is connected to the throat region of the inlet pipe at the lower end. Due to the reduction of the cross-sectional area, the fluid experiences an acceleration and the static pressure decreases.

The maximum angle of the cone of the convergent area is limited to avoid the vena contract, so that the flow area will be minimal in the throat. The convergent angle is considered to be a function of the β ratio, as well as the Reynolds number.

The ratio between the diameter of the throat and the diameter of the inlet pipe is often referred to as the β ratio. The β ratio acts as a physical parameter of utmost importance in the design of a Venturi meter. Any modification in the Reynolds number or in the β ratio affects the most efficient convergent angle for that specific Venturi.

ISSN: 2410-3993.
RENIECYT: 1702902

The throat section is the central part of the Venturi tube and has the smallest cross-sectional area. In general, the length of the throat is proportional to its diameter. As a rule of thumb, the diameter of the throat varies between 0.25 and 0.75 times the diameter of the inlet pipe, although, in most cases it is close to 0.5 times that diameter.

It is important to emphatize that the diameter of the throat remains constant throughout its length.

The divergent outlet section/coning section is the last part of the instrument, connected to both the throat cylinder and the pipe outlet. The diameter of this section increases gradually; according to the ASME manual, the divergent section should have an angle of 5-13°.

This diverging angle, which is smaller than the converging angle, is used to prevent the flow from separating from the walls and to prevent the formation of eddies. In order to find the optimum angle for the Venturi recovery cone, Sharp et al. [2018] found the optimum angle to minimize pressure drop.

Design of Gas Mixing Valve

The design of the gas mixing valve has been developed strictly in accordance with the parameters established by the ASME, respecting the fundamental principles of Venturi design.

For the simulation, three basic models have been used: the conventional Venturi model [a], the modified model of the suction port at 50° [b] and a third model [c] that incorporates modifications in its structure and adds a second suction port at 50°. The design of the gas mixing valve has been meticulously conceived in strict compliance with the parameters established by the ASME.

To this end, three simulation models have been used: the first [a] is based directly on a conventional Venturi model; the second [b] has modified the suction port to 50° taking into account the ASME parameters; and finally, the third model [c] has been designed to be more efficient than the previous two, modifying its structure and adding a second suction port at 50°

Box 2

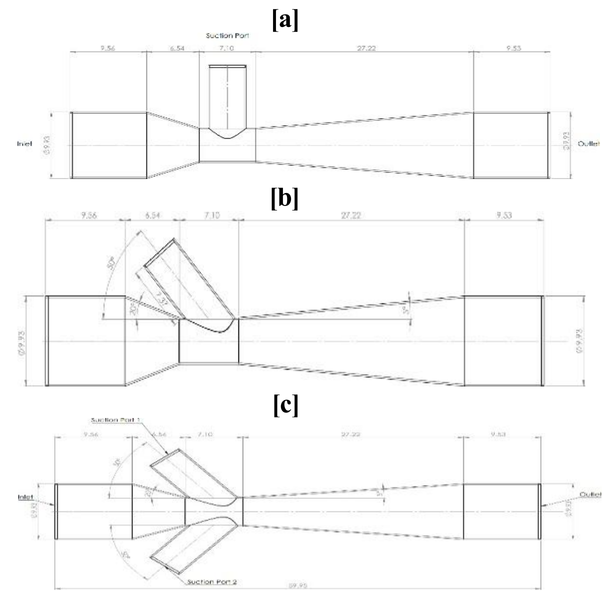


Figure 2
Models of gas mixing valve

As we know, the pressure in a pipe in relation to the speed of the flow is described by Bernoulli's equation.

$$P + \tfrac{1}{2} \rho v^2 + \rho g h = constante \qquad [1]$$

The present study addresses the analysis of fluid behavior under restricted flow conditions, taking as a reference the principles of Bernoulli and Venturi. In this sense, the reduction of the pressure of a fluid when subjected to a narrow section of a tube is examined, as well as its behavior at the moment of reaching said change of speed. This analysis is based on the aforementioned principles and on the following expression:

$$P_1 + \tfrac{1}{2} \rho v_1^2 = P_2 + \tfrac{1}{2} \rho v_2^2 \qquad [2]$$

Experimental facility

To proceed with the final design of the valve, the initial value of the Venturi convergence angle was taken as the range established by the ASME, which ranges between 20° and 22° as optimal values. Consequently, the minimum value of 20° was adopted.

With regard to the valve's diverging angle, the minimum optimum value according to ASME was taken, set at 5°. Finally, for the suction ports, 50° was assigned for both ports. The dimension values used for the valve are listed below.

ISSN: 2410-3993.
RENIECYT: 1702902

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Simulation of Gas Mixing Valve

The simulation was carried out using SolidWorks, a program recognized for its efficiency in the design of Venturi mechanisms. The simulation was carried out for each of the models represented in Fig 2. Subsequently, the pressure and velocity of each of them were compared with each other. As can be seen in Fig. 2, model [a] has a suction port and an angle of 90°. In model [b], there is a suction port and an angle of 50°. Finally, the most effective model is characterized by the addition of a second suction port with an angle of 50°.

Parameters of the Simulation

In order to estimate the simulation parameters, values close to a real case have been used, in which the combination of two gases is required: one of low pressure and speed, and another of high pressure and speed, with the aim of achieving stability during the gas mixing process

Box 3

Figure 3

The International System of Units has been selected as the main parameter to be used in the simulator as the main measurement system for the model [although it could be any other measurement system]

Source: Own elaboration

Box 4

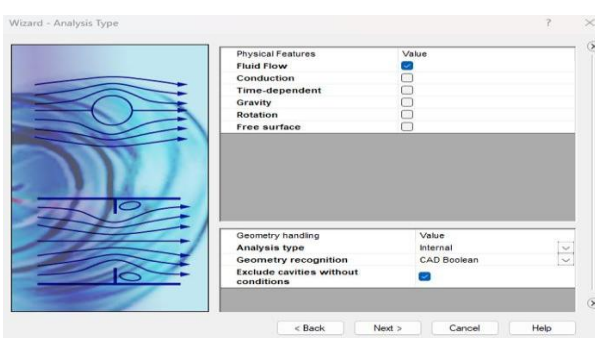

Figure 4

Subsequently, the type of analysis to be carried out is selected. In this case, it is of interest to know the behavior of the flow of a fluid, be it gas or liquid or any other fluid.

Source: Own elaboration

Box 5

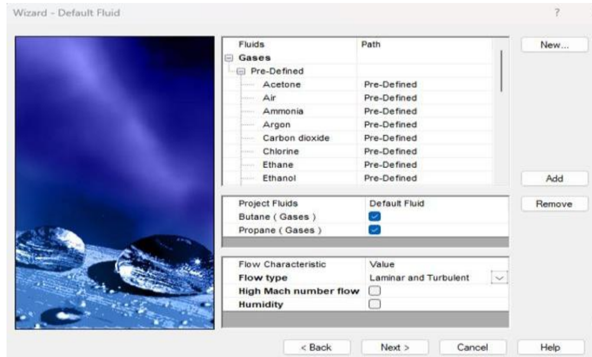

Figure 5

Subsequently, the type of fluid that will be channeled through the valve is selected. On this occasion, two gases, propane and butane, have been used in order to carry out a preliminary evaluation and observe their behavior.

Source: Own elaboration

Box 6

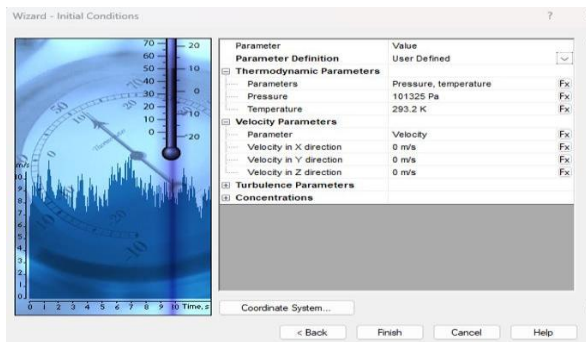

Figure 6

Finally, atmospheric pressure and temperature were determined as initial parameters, since in this case no conditions other than atmospheric conditions are observed.

Source: Own elaboration

Comparison of initial and optimized structure

To carry out the simulation, the same input and output values were used for each of the models, obtaining the speed and pressure parameters for each of them. The gas entering the valve, classified as a low-consumption gas, will have an almost zero speed. For the simulation, it was assigned an initial value of 0.2 m/s. On the other hand, the gas in the suction port will act as our main gas inside the Venturi chamber. In this case, it was assigned an initial value of 5 m/s. With regard to the variations, taking into consideration the recommendations of the ASME, a comparison can be seen between each of them, which are shown in Fig.7 and Fig.8.

ISSN: 2410-3993.
RENIECYT: 1702902

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Box 7

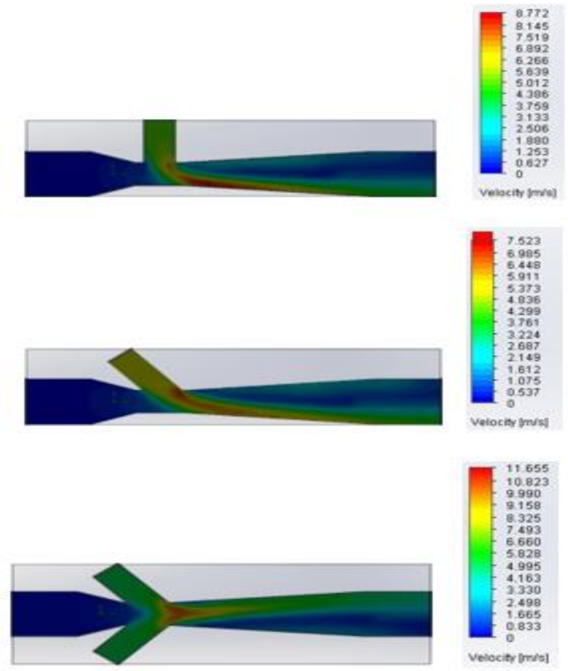

Figure 7

Comparison of the maximum and minimum speeds of the models.

Source: Own elaboration

Box 8

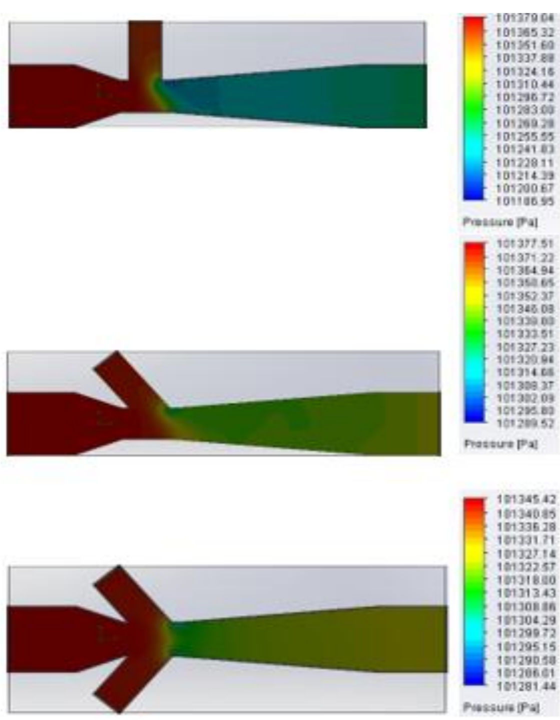

Figure 8

Comparison of the maximum and minimum pressure of the models.

Source: Own elaboration

As can be seen, model [c] exhibits a marked optimization in speed, both at its maximum and minimum and average points, while maintaining a more uniform pressure. The combination of both gases in this case results in significantly higher quality.

As is evident from the comparison, model [c] with an additional suction port distributes the fluid more evenly during the mixing phase. For additional clarity, see Figure 6, which illustrates the efficiency of the model.

Box 9

Table 1

Model [a] with a 90° suction port.

Parameters	Averaged Value	Minimum Value	Maximum Value
Minimum Total Pressure	101281.934	101281.442	101283.290
Average Total Pressure	101338.054	101337.658	101338.533
Maximum Total Pressure	101376.244	101375.404	101377.616
Minimum Velocity	0	0	0
Average Velocity	1.94358335	1.91805349	1.95912524
Maximum Velocity	7.7919682	7.76503024	7.828078233

Source: Own elaboration

Box 10

Table 2

Model [b] with a 50° suction port.

Parameters	Averaged Value	Minimum Value	Maximum Value
Minimum Total Pressure	101291.562	101289.519	101293.447
Average Total Pressure	101350.301	101349.762	101350.727
Maximum Total Pressure	101410.9798	101409.138	101412.888
Minimum Velocity	0	0	0
Average Velocity	2.04578818	1.96138923	2.11772532
Maximum Velocity	8.80264006	8.77666325	8.847917719

Source: Own elaboration

Box 11

Table 3

Model [c] with two suction ports at 50.

Parameters	Averaged Value	Minimum Value	Maximum Value
Minimum Total Pressure	101186.871	101186.652	101187.019
Average Total Pressure	101357.641	101357.495	101357.817
Maximum Total Pressure	101416.068	101415.5629	101416.5983
Minimum Velocity	0	0	0
Average Velocity	2.93038806	2.92422760	2.94466428
Maximum Velocity	11.5634218	11.5438487	11.5793544

Source: Own elaboration

Reynolds Number

The Reynolds number is a key measurement in fluid analysis, as it determines its behavior. In this particular case, it is crucial that the flow is stable to minimize energy losses and guarantee an optimal mixture between the gases. This is essential to create a more orderly environment conducive to chemical reaction.

ISSN: 2410-3993.
RENIECYT: 1702902

To do this, the optimized model was evaluated to determine how it compared with the other two models. The following formula was used for the Reynolds calculation:

$$\boldsymbol{Re} = D * v * p / \mu \quad [3]$$

According to the established parameters, for values of Re lower than 2300, the flow will be laminar. On the other hand, for values of Re higher than 4000, the flow will behave in a turbulent manner.

According to the measurements obtained, the diameter of the pipe is 9.93 mm. Taking this into account, the average speed of the gas is 1450.3 m/s. Likewise, the average density of the gas is 2084.2 kg/m³. Finally, considering the viscosity of the fluid, in this case propane gas, which is 0.00011, the Reynolds number is calculated.

Box 12

Table 4

Speed and density parameters of the model [c]

	Unit	Averaged Value	Minimum Value	Maximum Value
Average Velocity	[m/s]	1.4503944	1.4471230	1.4601850
Average Density [Fluid]	[kg/m^3]	2.08422	2.084223	2.084224

Source: Own elaboration

After carrying out the relevant measurements and analyses, it has been determined that the value obtained is 272.889 m/s, which is below the 2300 m/s required for the flow to be laminar.

Box 13

Table 5

Reynolds results of the model [c]

	Unit	Averaged Value	Minimum Value	Maximum Value
Reynolds	[m/s]	46.22821	46.06452	46.586711

Source: Own elaboration

Comparative speed test

In this section, we proceed to compare the results of the speed behavior of the three models. In this way, the effectiveness of model [c] is evident in relation to the other two models, reaching a maximum speed of 11.5469 m/s.

Box 14

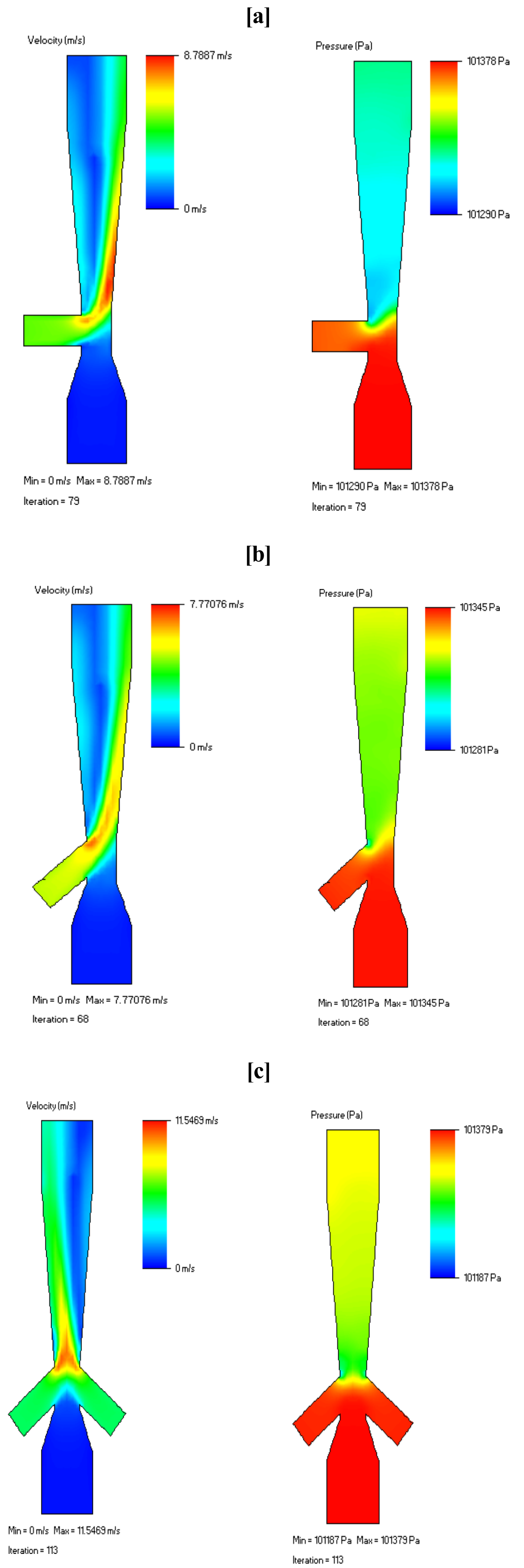

Figure 9

Comparison of results from different Venturi-type gas mixer models.

Source: Own elaboration

ISSN: 2410-3993.
RENIECYT: 1702902

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https://doi.org/10.35429/JTI.2025.12.30.1.1.7

Conclusions

In the present study, the model of three types of venturis for the mixing of two gases, one at low pressure and the other at higher pressure, was implemented in order to efficiently simulate the mixing of the two gases. This allowed for the evaluation of their laminar behavior and the maximum velocity they reach at their critical point. Using this procedure, a comparison was made that demonstrated the effectiveness of model [c], which incorporates a second suction port that allows for a more stable and efficient flow.

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ISSN: 2410-3993.
RENIECYT: 1702902