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Research Article

The effects of diffuser profile on the performance of the liquid-gas ejector

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ABSTRACT

Kinetic energy originating from liquid jets at high speed can be used as an energy source for liquid-gas ejector devices. An ejector is a tool often used to support one of the processes in the industry, such as vacuum process, desalination, distillation, and refrigeration. The ejector consists of several main components: the nozzle, suction chamber, mixing chamber or throat, and diffuser. These components influence each other, so that system performance is sensitive to the performance of these components. The diffuser functions as a dynamic head converter into a static head. Its performance is affected by its dimensions, so it needs to be investigated. This study aims to determine the effect profile of a diffuser with a divergence angle of 2β 7° and a diffuser with a tiered divergence angle of 2β. This study uses an experimental method with a motive flow pressure for the primary fluid of 201.32 kPa. This study found that changes in length and the angle of divergence of the diffuser affect the value of the pressure recovery coefficient and efficiency.

1. INTRODUCTION

The kinetic energy originating from liquid jets at high speed can be used as an energy source for liquid-gas ejector devices [1]. Henry Giffard was the first inventor of the ejector in 1858, which was used in steam engines to replace the mechanical pump to supply water to the boiler. The ejector is a type of pump with a venturi principle in its application using a convergent-divergent nozzle [2]. An ejector is a tool often used to support one of the processes in the industry, such as vacuum process, desalination, distillation [3-4], and refrigeration [5-6]. In its application in the industry, ejectors can be classified based on stage, primary main fluid, and nozzle position. Ejector single-stage, multi-stage noncondensing, multi-stage condensing, and multi-stage with both condensing and multi-stage condensing are ejector classifications based on stage or stage. Liquid-jet ejectors, steam jet ejectors, and combined liquid-jet ejectors are classified according to the principal fluid [7]. Constant pressure mixing ejectors and area mixing ejectors are classifications of ejectors based on nozzle position [8-9].

The ejector has two intake ports; the primary high-pressure flow discharge is used to drain the secondary lower flow, where the flow mixes inside the ejector and is then discharged at back pressure [10]. The main fluid is converted into high-velocity energy, which will cause a vacuum in the suction chamber. Then, the fluids will be mixed and re-compressed to become back-pressure energy by converting velocity energy [11]. Convergent-divergent nozzles are used at the ejector to generate a venturi effect on the diffuser; the diameter on the surface of the diffuser is increasingly concave, resulting in a venturi effect which makes the pressure decrease so that a vacuum condition will occur [12]. The ejector has several main components, i.e., the nozzle, suction chamber, mixing chamber or throat, and diffuser [13-14]. The ejector's nozzle controls and converts fluid energy from pressure to speed. The suction chamber is an ejector component that functions as a meeting place for the primary and suction fluids. A mixing chamber or throat is an ejector component where the primary and suction fluids are mixed [15-16].

A diffuser is an expansion or increase in area intended to reduce velocity to restore flow pressure. The diffuser is the part used as an outlet on the ejector [17-18]. The rate of the fluid flowing through the diffuser section has a subsonic speed because it has passed the throat section [19-20]. The diffuser produces high pressure due to the decreased velocity of the fluid flowing through the diffuser section [21-22]. The flow velocity decreases rapidly inside the ejector after passing through the throat and changes from supersonic to sonic flow velocity [23-24]. The diffuser is one of the ejector components, where the flow leading from the throat is the froth flow. This is due to the principle of momentum transfer between the main flow and secondary flow, and it causes a change in the flow pattern from jet flow to froth flow [25]. The diffuser's performance on the flow pattern has been studied [26-27], and these studies concluded that the flow pattern affects the performance reduction of the diffuser. The dynamic head could change to a static head because there is a diffuser with an increasingly large cross-sectional area, causing a change in velocity [28].

The divergence angle in the diffuser's cross-sectional area greatly influences the separation of the streams [29]. Still, no flow separation will occur if the divergence angle is less than seven degrees [30]. From the introduction above, this research focuses on testing the ejector and determining the effect of a diffuser with a divergence angle of 2β 7° and a diffuser with a profile of a tiered 2β angle of divergence.

2. MATERIALS AND METHODS

Tests were carried out to determine the effect of a diffuser with a divergence angle of 2β 7 ° and a diffuser with a tiered divergence angle of 2β on the performance of the liquid gas ejector.

2.1. Preparation

In this research, the design of the testing device was carried out on a laboratory scale where manufacture and assembly could be carried out using simple manufacturing tools. The geometry of the diffuser itself was made with the help of 3d cad software, which can be seen in Figure 1 for a diffuser with a divergence angle of 2β 7° and in Figure 2 for a diffuser with a tiered 2β divergence angel. The manufacturing process was carried out using 3D printing with a filament base material. The equipment used in research is generally divided into three types: equipment for designing laboratory-scale ejector-testing devices, manufacturing or manufacturing processes in assembling ejector-testing devices and measuring instruments used in the testing process. The ejector consists of several components: the suction chamber, nozzle, throat, and diffuser. The dimensions of the test components can be seen in Table 1.

Table 1. Dimension ff liquid gas ejector.

No	Component	Design
1	Nozzle	Conical diameter 0.01 m
2	Suction chamber	Inlet diameter 0.09 m Outlet diameter 0.043 m Length 0.209 m
3	Throat	Diameter 0.019 m Length 0.34 m
4	Diffuser	Divergence angle (2β) = 7° Divergence angle (2β) = Tiered

The test gauge includes a water flow meter, which measures the volumetric flow rate of incoming water. The air flowmeter serves to measure the rate of airflow through the pipe. A pressure gauge measures the water pressure that will pass through the ejector. The vacuum gauge serves to measure the vacuum that occurs in the ejector. A stopwatch serves to measure the length of time required in the testing process. Pressure sensor MPX 5100 DP functions to measure the pressure of mixed fluids. Coolterm software is used to read the analogue data sent by the MPX 5100 DP pressure sensor. The data taken as a reference in this study is the discharge main flow (Q_m), which is read by a water flow meter; suction discharge (Q_s), which is read by the air flowmeter measuring instrument, main flow pressure (P_m) which is read on the pressure gauge, suction pressure (P_s) read on the vacuum gauge, and the discharge pressure read on the MPX sensor.

2.2. Experiments

In the experimental setup, the test was carried out schematically with a liquid gas ejector configuration of the downstream type, as seen in Figure 3.

The centrifugal pump transfers the main fluid in the form of water from the water tank through the stop faucet 1.5 inches toward the nozzle. The TUF 200m Ultrasonic Flowmeter measures the water discharge, and the air flowmeter measures the incoming air discharge (Qs). Vacuum pressure (P_s) is measured using a vacuum gauge, and main flow pressure (P_m) is measured using a pressure gauge. The suction chamber, throat, and diffuser sections have several MPX5100DP pressure sensors. The MPX5100DP pressure sensor in Figure 4 is a strain gauge made of silicon with a piezoresistive transducer type integrated into the chip, which can work at a pressure of 0 KPa-100 KPa or 0 Psi-14.5 Psi with an output voltage of 0.2 volts-4.7 volts. The MPX5100 sensor is equipped with a calibrated, temperature-compensated, and signal-conditioned chip [31], which is connected to data acquisition on the Arduino Mega 2560 hardware, which is an Arduino-based microcontroller that uses the ATmega2560 chip. Arduino has many I/O pins, namely 54 digital I/O pins consisting of 16 analogue input pins, 15 pins are PWM, and four pins are UART (hardware serial port). Arduino Mega 2560 has a USB port, 16 Mhz oscillator, ICSP header, DC power jack, and reset button. Figure 4 shows the Arduino Mega 2560, which can be powered using a USB or external power. External power can be obtained from a battery or AC-DC adapter. Arduino Mega 2560 operates with a power of 6 V-20 V. After that, it was connected to the CoolTerm software, which is a simple serial port application that is used for the needs of exchanging data connected to serial ports such as robot kits, microcontrollers, servos, and others.

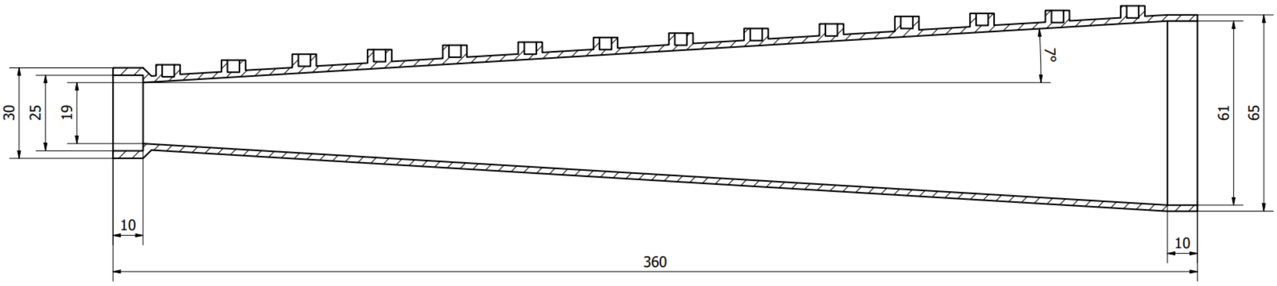

Figure 1. Diffuser with a divergence angle of 7°.

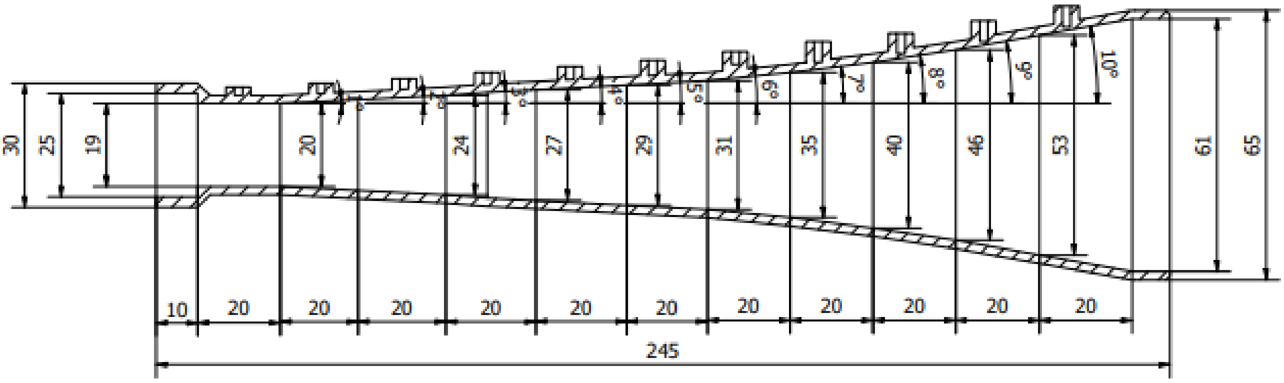

Figure 2. Diffuser with a tiered divergence angle.

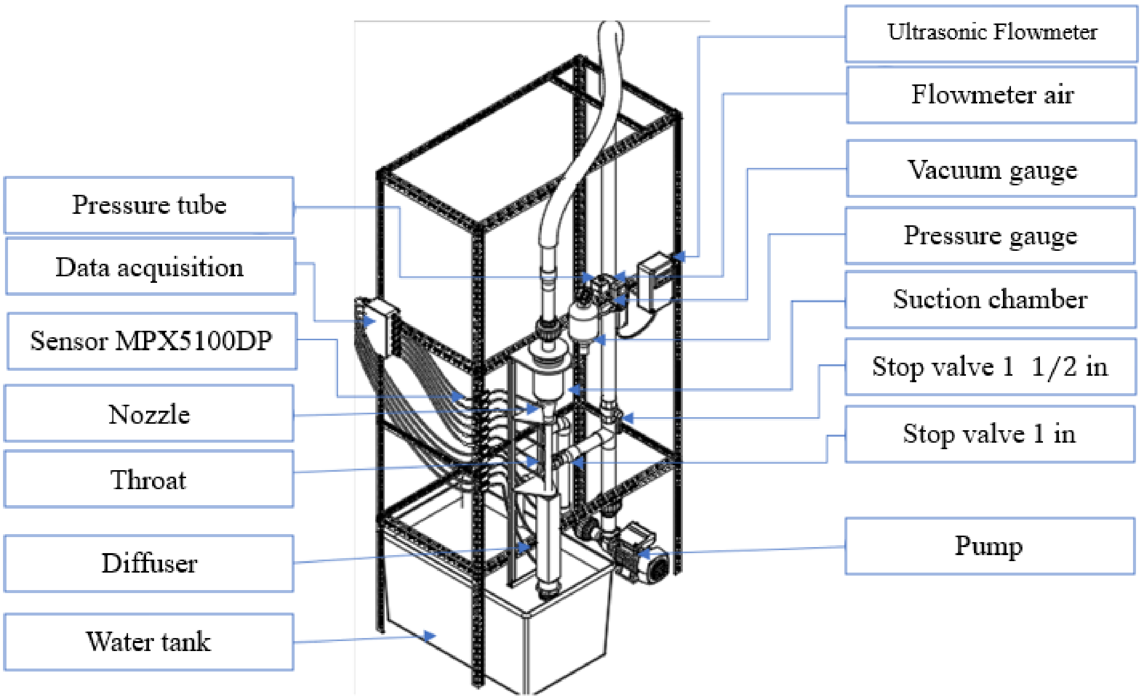

Figure 3. Experimental setup.

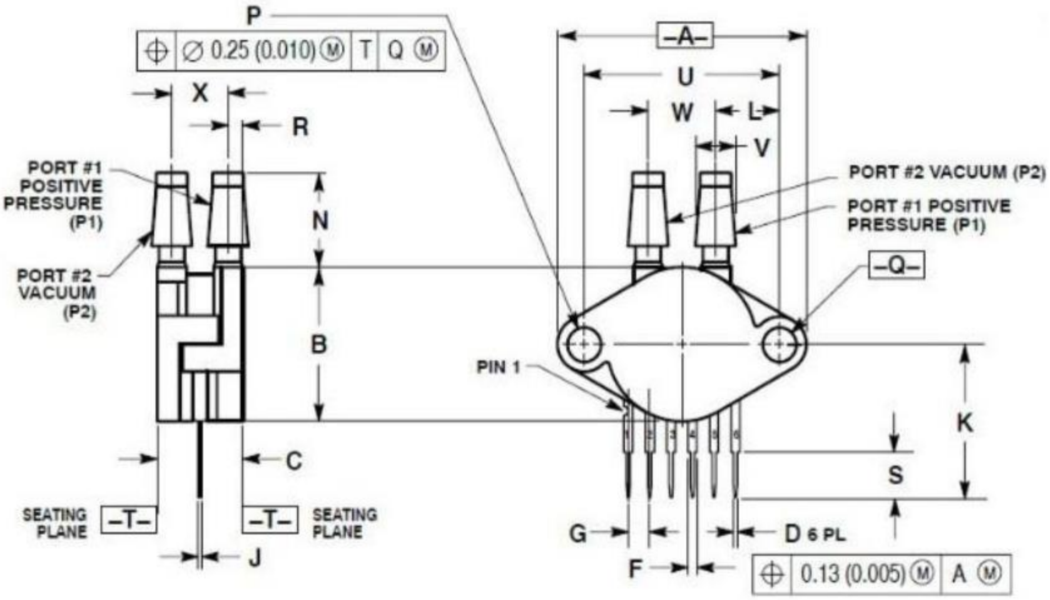

Figure 4. MPX5100 sensor.

2.3. Formulations

Diffuser performance is obtained from the recovery coefficient, which considers the flow's kinetic energy and pressure (Equation 1)). The research conducted [32] also states the performance of the diffuser in terms of pressure recovery coefficient, C_p (Equations 2) and 3)). The performance of the ejector can be obtained from efficiency; research conducted by Cunningham [33] to determine efficiency can use equation 4).

$$C_p = \frac{(\dot{m}_s+\dot{m}_1)(P_2-P_1)}{\dot{m}_1\frac{1}{2}\rho U_1^2+\dot{m}_s\frac{1}{2}\rho U_s^2} \qquad 1)$$

$$C_p = \frac{\Delta P}{\frac{1}{2}\rho_m V^2} \qquad 2)$$

$$\rho_m = \rho_g \varepsilon + (1-\varepsilon)\rho_l \qquad 3)$$

$$\eta = \frac{P_e\, \phi_1\, Ln\, (P_d/P_s)}{(P_m - P_d)} \qquad 4)$$

3. RESULTS AND DISCUSSION

From the results of the tests that have been carried out, data on main flow (Q_m), suction discharge (Q_s), main flow pressure (P_m), suction pressure (P_s), discharge pressure (P_d), and time (t). In collecting this data, the pressure of the main flow is a reference for obtaining other data results by adjusting the valve at the pump bypass opening; besides that, the suction pressure can also be adjusted manually by changing the valve at the suction discharge opening. However, the main flow pressure must still be considered as a reference. This research was conducted to determine the effect of the divergence angles of 2β 7° and 2β tiered at the diffuser on the performance of the gas-liquid ejector. The following is the result of the discussion.

3.1. Performance of the liquid-gas ejector

Figure 5 shows the performance of the liquid-gas ejector in terms of the efficiency of the diffuser with a divergence angle of 2β 7° and the diffuser with a tiered divergence angle of 2β. The diffuser with a tiered 2β divergence angle shows that the efficiency value is higher than the diffuser with a 2β 7° divergence angle. The flow ratio (φ_s) is obtained from q_s/q_m, while the efficiency formula uses equation (4). High discharge main flow (qm) tends to provide better efficiency values at all levels of flow ratios. Efficiency decreases in all variations of discharge motive flow towards a decrease in flow ratio. The maximum efficiency of the diffuser with a tiered 2β divergence angle is 14.97 %, and the maximum efficiency of the diffuser with a divergence angle of 2β 7 ° is 14.78%.

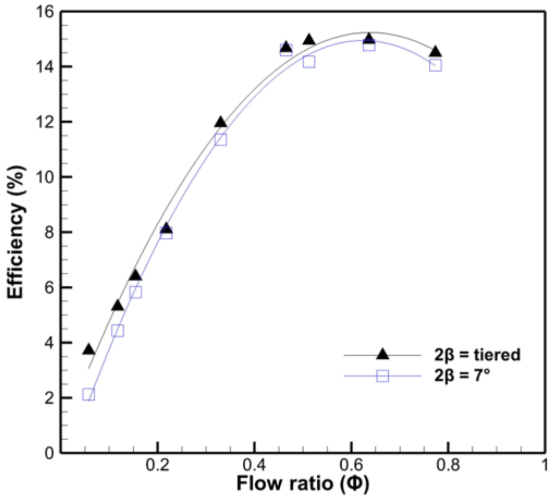

Figure 5. The efficiency of ejectors for two different divergence angles.

The c_p diffuser is shown in Figure 6. It can be seen that the c_p on the diffuser with a tiered 2β divergence angle is higher than the c_p value on the diffuser with a 2β divergence angle of 7 °. The cp value on the diffuser with a tiered 2β divergence angle decreased from 0.754 to 0.65 on the diffuser with a 2β 7° divergence angle; the greater the void fraction value, the lower the c_p value. This proves that the length of the diffuser increases flow resistance.

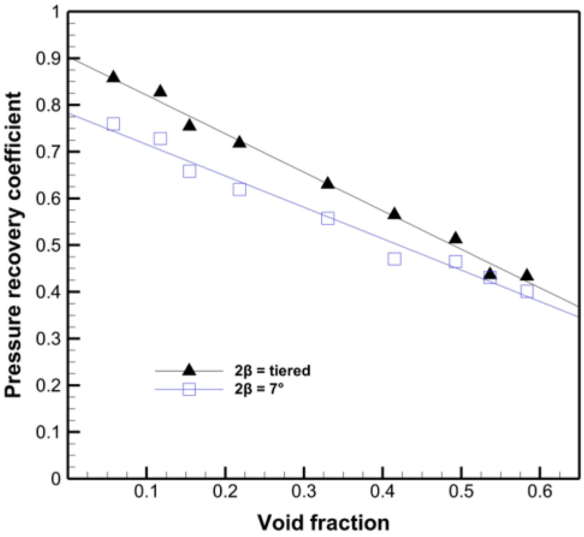

Figure 6. The effects of void fraction on pressure recovery coefficient (C_p) for two different divergence angles.

3.2. Pressure Profile on Throat and Diffuser

Figure 7 shows the pressure profile on the throat of the diffuser with a divergence angle of 2β 7° at a main flow pressure of 201.32 kPa. The research [28] found that the pressure profile affects the flow rate retained in the throat; the higher the entrained flow rate, the higher the pressure, and the lower the entrained flow rate, which affects the starting point of the maximum pressure upstream of the throat. Coaxial flow is seen before the pressure jump due to entrained gas, and bubbly flow is seen after the pressure jump to the end of the throat.

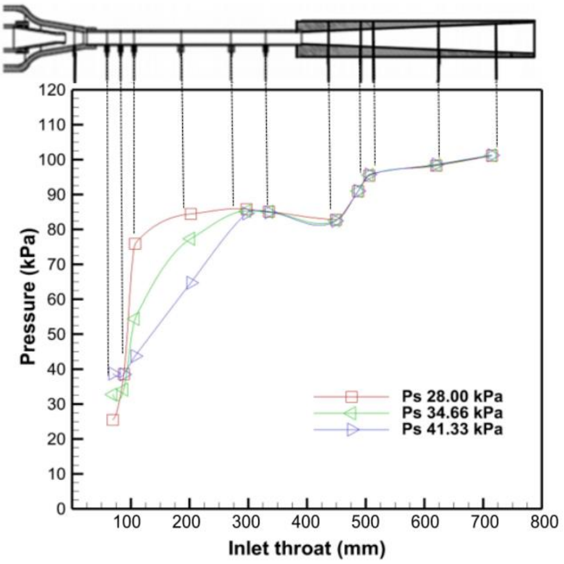

Figure 7. Pressure profile on various vacuum pressures for ejector with a diffuser divergence angle of 7°.

The distribution of the suction pressure profile of 28.00 kpa resulted in the highest peak pressure compared to the suction pressure profile of 34.66 kPa and the suction pressure profile of 41.33 kPa. In the pressure profile, there is a pressure drop at the inlet of the diffuser. Then, tests were carried out using a diffuser with tiered divergence angles at the same motive flow pressure of 201.32 kPa and different diffuser lengths.

Figure 8 shows the pressure profile on the throat of the diffuser with tiered divergence angles. It can be seen that the pressure profile on the throat and the diffuser has changed, and the pressure profile has experienced a steady increase in pressure. The distribution of the suction pressure profile of 28.00 kPa resulted in the highest peak pressure compared to the suction pressure profile of 34.66 kPa and the suction pressure profile of 41.33 kPa. There is no pressure drop at the inlet diffuser either.

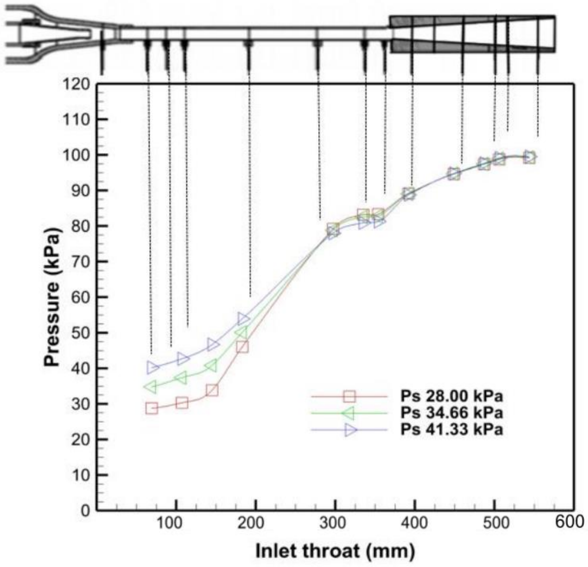

Figure 8. Pressure profile on various vacuum pressures for ejector with diffuser tiered divergence angle.

From a comparison of the two diffusers with the same main flow pressure of 201.32 kPa and at a suction pressure of 28.00 kPa, as shown in Figure 9, in a diffuser with a divergence angle of 2β 7 ° with length x dt (mm) = 700 mm, the pressure profile from the inlet throat to the outlet throat experiences a steady increase in pressure. However, when entering the inlet diffuser, the pressure drops. Then, the pressure rises again after entering the diffuser, which means the separation occurs at the inlet point with a divergence angle of 2β 7°, resulting in a pressure drop. In the diffuser with a tiered 2β divergence angle with a length of x dt (mm) = 497 mm, the pressure profile from the inlet throat to the outlet throat experiences a steady increase in pressure. The pressure does not go down at the inlet diffuser, indicating no separation at the inlet point. These results mean that the diffuser can be made shorter with tiered divergence angles to improve the performance of the gas-liquid ejector.

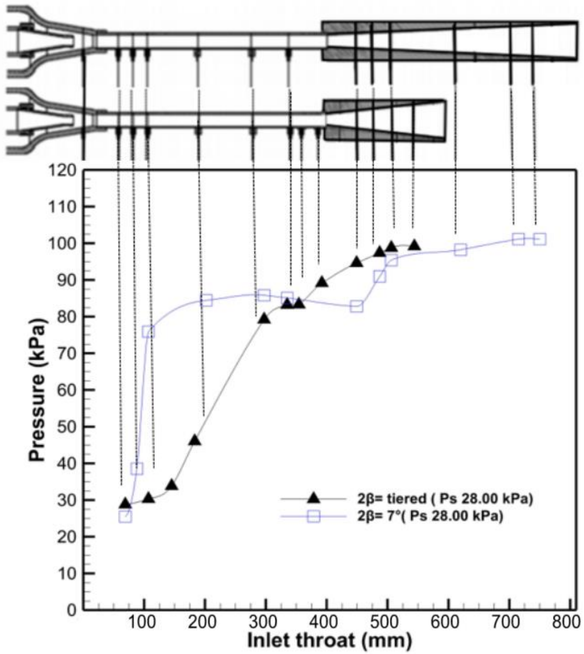

Figure 9. Pressure profile on two different diffusers.

4. CONCLUSION

In a diffuser with a divergence angle of 2β 7° and a diffuser with a tiered divergence angle of 2β, there is a difference in the efficiency, the C_p value, and the pressure profile. The angle of divergence on the diffuser is very influential on the pressure that occurs at the diffuser inlet and outlet throat. Diffusers with tiered 2β divergence angles can reduce the degree of separation at the diffuser inlet. Changes in the length and divergence angle of the diffuser also affect C_p and efficiency.

CONFLICTS OF INTEREST

The author declares that no competing financial interests could have appeared to impact the work.

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