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Research Article

The Effect of The Throat Length and The Hole Diameter in Throat Portion of The Venturi Nozzle on Aeration Efficiency

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Abstract: Aeration is a procedure carried out to enhance water quality. Various hydraulic structures and devices for water aeration have been utilized in the literature. The venturi nozzle plays a significant role in water jet aeration. The aeration efficiency achieved with the venturi nozzle is seven times higher than that of the classic circular nozzle. In this experimental study, various holes of different sizes were created in the throat portion of the venturi nozzle; thus, air was drawn into the flow by creating negative pressure. The study examined the impact of the venturi nozzle on aeration efficiency by varying the length of the throat portion. The findings revealed that making a hole in the throat portion significantly improved aeration efficiency increasing the size of the throat portion had a detrimental effect.

Keywords: Drinking and domestic water; aeration; oxygen transfer; water jet; venturi nozzle

Venturi Ağızlığın Boğaz Bölgesindeki Delik Çapının ve Boğaz Uzunluğunun Havalandırma Verimine Etkisi

Özet: Havalandırma, suların kalitesini artırmak için yapılan bir işlemdir. Suların havalandırılmasında farklı hidrolik yapılar ve aygıtlar literatürde kullanılmaktadır. Su jetleri ile havalandırmada venturi ağızlığın önemli bir yeri vardır. Venturi ağızlık ile elde edilen havalandırma verimi, klasik dairesel ağızlığa göre yedi kat daha fazladır. Bu deneysel çalışmada venturi ağızlığın boğaz bölgesinde farklı çaplarda delikler açılmış ve negatif basınç oluşturularak akım içerisine hava girişi sağlanmıştır. Ayrıca venturi ağızlığının boğaz bölgesi uzunluğu değiştirilerek havalandırma verimine etkisi araştırılmıştır. Elde edilen bulgulara göre boğaz bölgesinde delik açılmasının havalandırma veriminin arttırılmasına önemli bir katkı sağladığı ve boğaz bölgesinin uzunluğunun arttırılmasının ise olumsuz yönde etki ettiği sonucuna varılmıştır.

Anahtar Kelimeler: İçme ve kullanma suyu; havalandırma; oksijen transferi; su jeti; venturi ağızlık

1. Introduction

Water is the most essential substance for life of all creatures. Freshwater resources are limited in the world. Studies on the preservation and enhancement of the quality of limited waters have always attracted researchers' attention. The concentration of dissolved oxygen in water decreases with the pollution of water. It is crucial to replace the decreasing oxygen concentration in water. In some types of water, removing gases such as carbon dioxide, methane, and hydrogen sulfide may be necessary. In this case, the process of water aeration comes forward. Water aeration is necessary to increase the decreasing dissolved oxygen value in the waters and remove the volatile gases in the waters [1, 2].

Many different hydraulic structures have been used in water aeration. Waters in the streams can be aerated, and dissolved oxygen concentration can be increased by passing through the stepped spillways, cascades, weirs, and levees. For example, if the dissolved oxygen concentration value in a stream has decreased to 3-4 mg/L, this value can be increased to 8-9 mg/L using the cascade structure. The water collected from dam reservoirs is subject to treatment in the treatment facility before being supplied to the network as drinking and domestic water. Water can be aerated by flowing water through cascades built around the four sides of a pool. This method is frequently used in practice. Besides the above-mentioned hydraulic structures, using water jets in the aeration process is also very common. Differently from the hydraulic structures such as stepped spillways, cascades, and weirs, the water jets require energy. Water jets are a device frequently used for different purposes in civil engineering, environmental engineering, and chemical engineering.

Bin [3] conducted a very comprehensive review of water jets. The studies published until the publication date of the review article were collected in that article. In that article, it was reported that water jets are used for different purposes in different engineering fields. Bağatur [1] examined different types of nozzles in water jets in his doctoral thesis. He changed the outlet sections of the nozzles and investigated the effect of this change on the aeration efficiency. Bağatur [1] found that the change of nozzle outlet section has a significant impactsignificantly affected aeration efficiency. Emiroglu and Baylar [4] created holes near the outlet point of a circular nozzle and investigated the effect of these holes on aeration efficiency. They found that the air holes changed the shape of the water jet, and the expansion of the water jet was increased at the point of impact with the water and thus the aeration efficiency can be increased. Bağatur and Onen [5] used Gene Expression Programming (GEP) and Artificial Neural Network (ANN) models to determine the aeration efficiency of water jets. They stated that these models were a very successful technique for determining the aeration efficiency. Bağatur and Onen [6] used water jets to improve oxygen transfer efficiency. The authors used the GEP model to determine the oxygen transfer efficiency. Onen [7] used artificial intelligence techniques to determine the penetration depth of water jets and stated that artificial intelligence techniques successfully determined penetration depths. Puri et al. [8] prepared a review article on increasing oxygen yield in water. The authors reviewed and summarized the relevant studies up to the article's publication date. They stated that different hydraulic structures would be used to increase the oxygen transfer efficiency of water. Can et al., [9] numerically analyzed the aeration performance of turbulent water jets and compared it with experimental data. The authors used

ANSY-CFX commercial software for numerical analysis. They stated that the numerical and experimental results were very compatible.

Many studies have been carried out in the literature to increase aeration and oxygen transfer efficiency using water jets. A Venturi device has also been used as a nozzle. The present study focused on the effect of the diameter of the hole created in the throat portion of the venturi nozzle on aeration. Within the scope of the current studyit is aimed to experimentally investigate the effect of changing the length of the throat portion of the venturi nozzle and the diameter of the hole created in the throat portion on air entrainment rate and oxygen transfer efficiency.

2. Materials and Methods

2.1. Basic Theory

Equation (2.1) calculates the oxygen transfer efficiency in the literature [1, 2, 4].

$$\frac{dC}{dt} = K_L \frac{A}{\forall_w}(C_s - C) \tag{2.1}$$

where, C_s expresses the saturation concentration of oxygen in the water. Instead of the $A/\forall_w$ expression in Eq. (2.1), "a" showing the specific intersection surface is used in the literature.
In Eq. (2.1), if integral for $C=C_o$ and $C=C$, $t=0$ and $t=t$ is taken, it becomes as

$$\int_{C_o}^{C} \frac{dC}{C_s - C} = (K_L a)\int_{o}^{t} dt \tag{2.2}$$

From the solution of Eq. (2.2);

$$\ell n\left(\frac{C_s - C_t}{C_s - C_o}\right) = -(K_L a)t \tag{2.3}$$

Equation (2.3) is obtained. Where, C_o and C_t are water oxygen concentrations at baseline and at time t, K_La is the mass transfer coefficient. According to Eq. (3), the values of K_La are obtained by using against time t on a semi-logarithmic paper. K_La was normalized at 20 ºC by using Eq. (2.4) to make a comparison in different systems.

$$(K_L a)_{20} = (K_L a)_T (1.024)^{(20-T)} \tag{2.4}$$

Oxygen transfer efficiency (OE) was calculated by Eq. (2.5).

$$\text{OE} = \frac{(K_L a)_{20} C_s^* \forall_w}{0.5\rho Q_w V_j^2} \tag{2.5}$$

In Eq. (2.5), OE indicates the oxygen transfer efficiency (kgO$_2$/kW-hr), C_s^* indicates the saturation concentration of dissolved oxygen (mg/ℓ), $\forall_w$ indicates the volume of the water (m^3), ρ indicates the mass density of water (kg/m^3), Q_w indicates the discharge of water (m^3/s), and V_j indicates the velocity of the water jet (m/s).

3. Experimental setup and Method

The experimental study was conducted in the Hydraulic Laboratory of Fırat University, Faculty of Engineering, Department of Civil Engineering. Within the scope of the study, a tank with a volume of 1.80 m^3 was manufactured (Fig. 1). The front side of the tank was made of glass material. Thus, the movement and scattering of air bubbles in the tank could be monitored. The tank was filled with tap water. The water in the tank was circulated with the help of a water pump. After the pump drew water from the tank, it was fed into a supply pipe. A venturi nozzle was placed at the end of the supply line. Thus, the water coming out of the nozzle impacted the water in the tank from a certain distance (L_j=0.30 m). The impact angle of the water jet was taken as θ=45°. Air holes were created in the throat portion and the venturi nozzle's center. The diameters of the air holes were taken as 1.4, 1.7, 2.0, 2.8, 3.4, 4.0, 4.2, 5.1 and 6.0 in mm. The angle α_1 was chosen as 21° in the converging cone region of the venturi nozzle, and the angle α_2 was chosen as 7° in the diverging cone region (Fig. 2). These angles are both accepted in practice and in the literature [4]. The outlet diameters of the circular nozzles were taken in the same way as the venturi nozzles. Thus, comparisons were significant. The outlet diameters were D=18.67, 22.67, 26.67, 28.00, 34.00, and 40.00 mm. L/D=1 and L/D=2 ratios were used in all experiments for venturi and circular nozzles (Fig. 3). The throat diameters of venturi nozzles were taken as d=14, d=17, and d=20 mm. The ratio of throat portion diameter to nozzle diameter was taken as d/D=0.50 and d/D=0.75. The ratio of the diameter of the air holes to the diameter of the throat portion was selected as hd/d=0.1, hd/d=0.2 and hd/d=0.3. The ℓ/d=0.50 and ℓ/d=1.00 ratios were used to manufacture venturi nozzles.

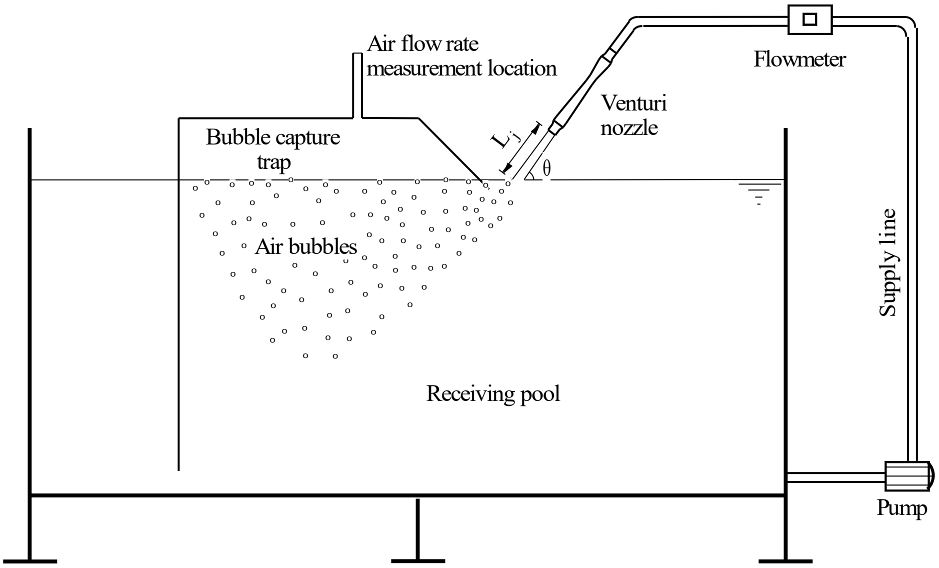


Fig. 1. Experimental set-up

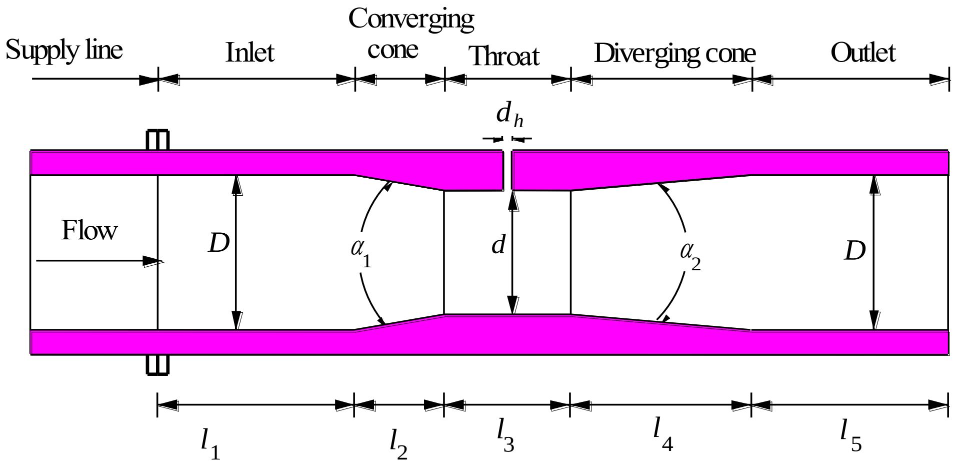


Fig. 2. Venturi nozzle and its geometric details

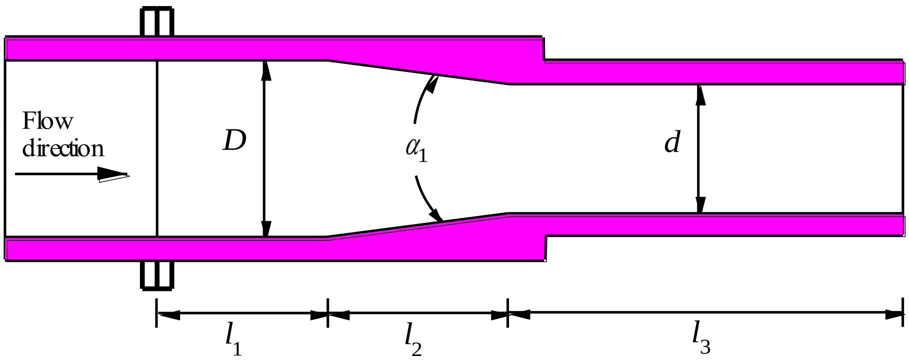


Fig. 3. Circular nozzle and its geometric details

After the tank was filled with tap water, the dissolved oxygen (DO) concentration in the water was decreased before each experiment was conducted for oxygen transfer. Sodium sulfite (Na_2SO_3) and cobalt chloride ($CoCl_2$) were used for this purpose. The experiments used these chemicals to reduce the DO concentration to 0 mg/L. After these chemicals are added to the water, it is necessary to mix them thoroughly. After the mixing process was completed, measurement was taken with the HANNA Model HI9142 dissolved oxygen meter. Then, the pump was started and the water coming out of the venturi nozzle was impacted into the impact pool. At this phase, the DO value of the water in the tank was measured continuously. When the DO value reached saturation, the time was determined. The air entrainment rate (Q_A) was measured using a Testo 435 anemometer. In the current study, each nozzle was tested for jet velocities (V_J) ranging from 2.50 m/s to 15.00 m/s. Reynolds number was calculated from the equation $\left(\mathrm{Re} = (V_j \times D)/\nu\right)$. Where V_j= jet impact velocity (m/s), D= diameter of nozzle (m), and ν= kinematic viscosity of water (m^2/s). To determine the K_La values, t expression in x-axis and $-\ell n\left((C_s - C_t)/(C_s - C_o)\right)$ expression in y-axis were considered. The scatter diagram for these two parameters was plotted and the line was fitted. The (K_La) values were found (Fig. 4) from the fitted line. Then, the values of OE were obtained using Eq. (2.5).

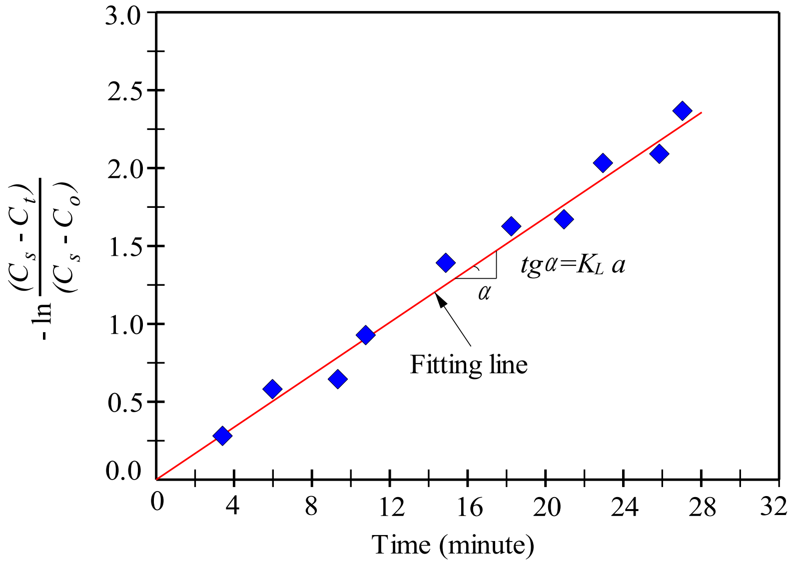


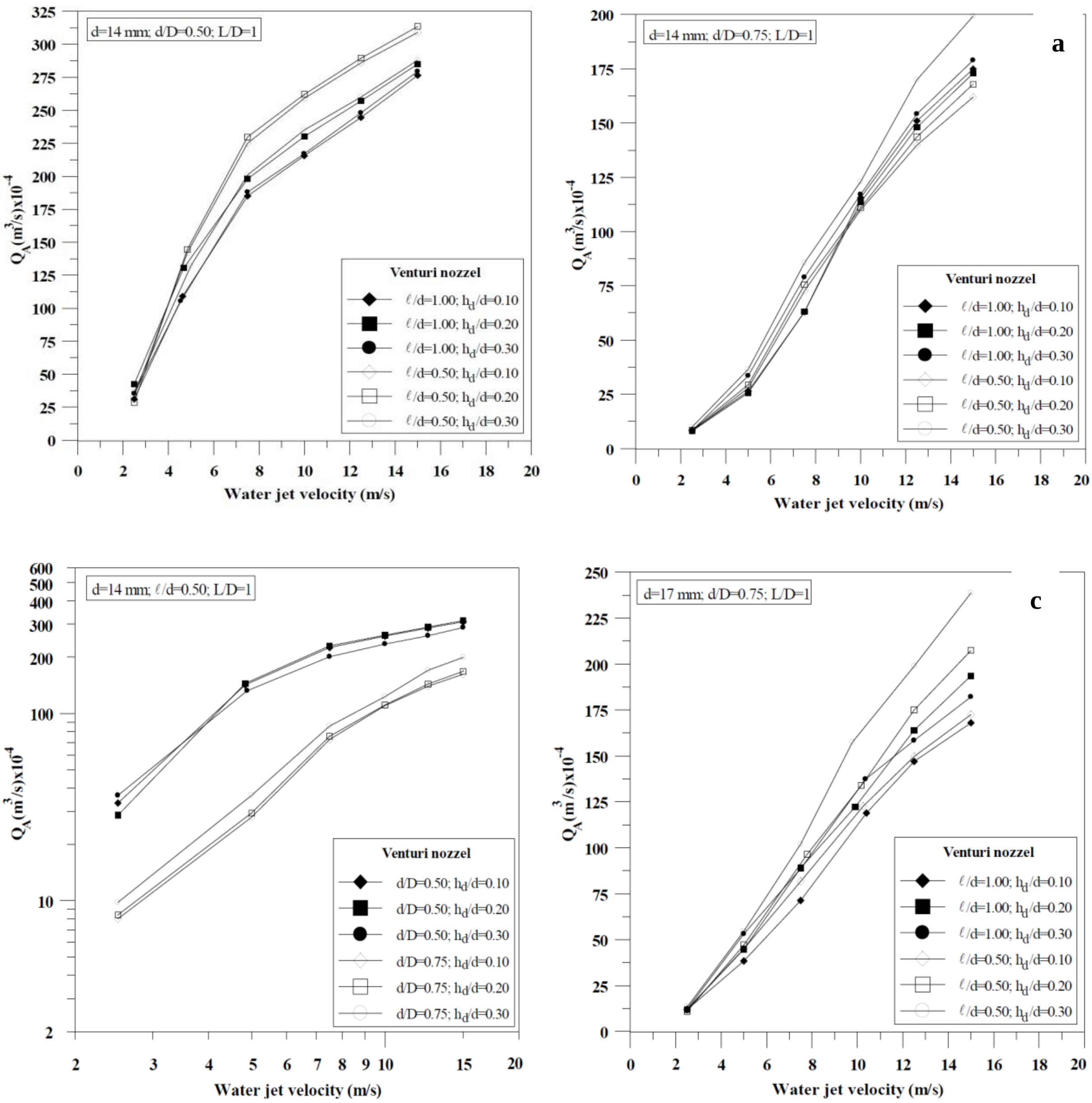
Fig. 4. Determination of K_La values

4. Results and Discussion

4.1. The Effect of Variation of Throat Portion Length and Hole Diameter on Air Entrainment Velocity

Figures 5(a-e) show the effect of both the change in the length of the throat portion of the venturi nozzle and the change in the diameter of the hole created in the throat portion on the air entrainment velocity. In Figs. 5(a-c), the throat diameter of the venturi nozzle is 14 mm. In Fig. 5(a), the ratio of the throat portion to the nozzle outlet diameter is 0.50, and the ratio of the nozzle outlet length to the outlet diameter is 1. As can be seen from Fig. 5(a), the increase in the length of the throat portion caused a decrease in the air entrainment rate values. The most important reason for this is the negative effect of the air drawn into the flow due to the negative pressure in the throat portion on the change in the shape of the jet with the increase in the length of the throat portion. In other words, when the length of the throat portion was shorter, the expansion of the water jet coming out of the nozzle was greater. With the increase in the jet expansion, the water jet impacting the pool carried much more air bubbles to the impact pool. Thus, the air entrainment rate values were higher when the throat portion was shorter. Figures 5(a-e) show the effect of the diameter of the air hole created in the throat portion of the Venturi nozzle on the air entrainment rate. In the throat portion of the Venturi nozzle, the velocity head ($V^2/2g$) increased excessively while the pressure head (P/γ) decreased. Thus, negative pressure was generated in the throat portion from the energy equation. When a hole was created in the throat portion, air was absorbed into the stream due to the negative pressure. The air absorbed into the flow changed the shape of the water jet, caused air to mix into the flow, and led the water jet to take the shape of a crescent at the outlet. Thus, the expansion of the jet increased at the point of impact with the pool. As the jet expansion and impact velocity increased, the values of the air entrainment rate also increased. Although there was no significant change with the change of the hole diameter, larger Q_A values were generally obtained for h_d/d=0.20.

In Fig. 5(d), the diameter of the throat portion of the venturi nozzle was 17 mm. The ratio of the diameter of the throat portion to the nozzle outlet diameter was 0.75. As shown in Fig. 5(d), the highest value was obtained for ℓ/d=0.5. For h_d/d=0.20, higher Q_A values were obtained compared to other hole diameters. This was because d/D=0.75 caused more air intake into the flow for h_d/d=0.20. In Figs. 5(e, f), the throat portion diameter of the venturi nozzle was 20 mm, and similar results were obtained with other diameters. It should also be stated that Q_A values increased with increasing water jet velocity, and the rate of increase was significant. This was due to the increase in the momentum of the jet ($\rho Q V_j$) at the point of impact on the receiving pool.



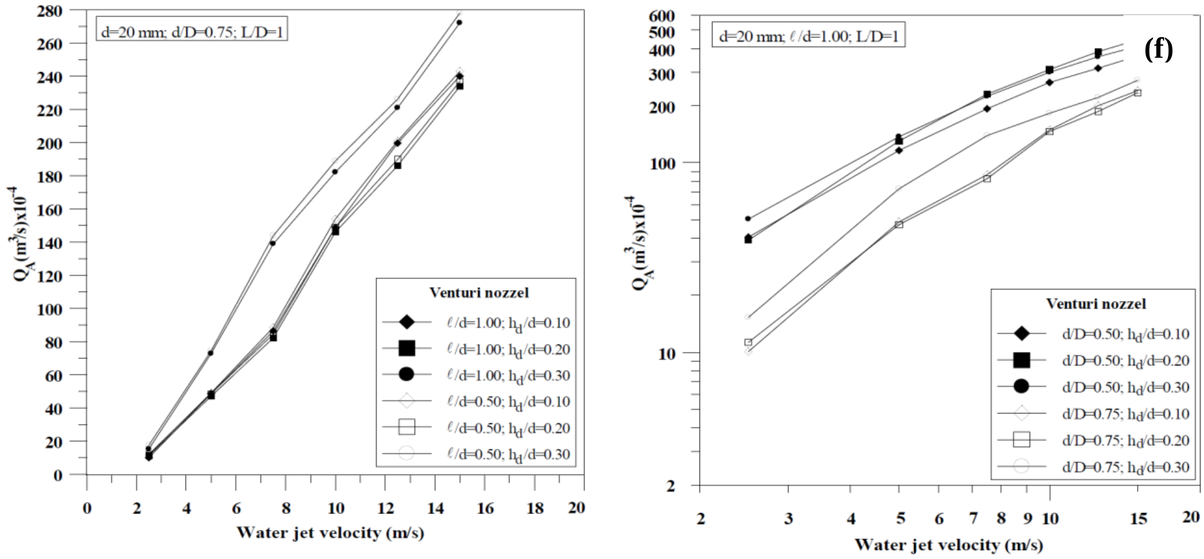


Fig. 5. Effect of changing the length of throat portion and hole diameter on air entrainment rate in a venturi nozzle

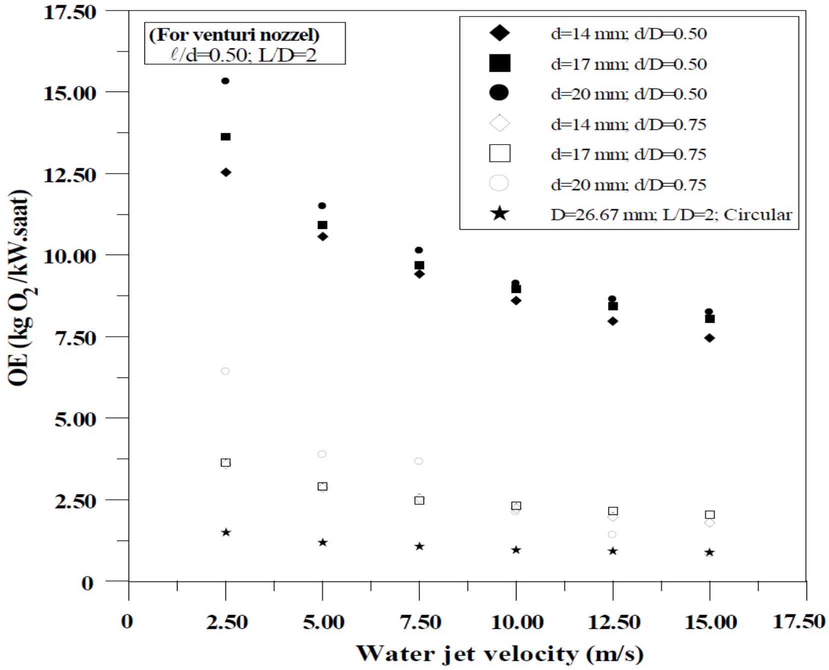
4.2. Effect of Changes in Length of Throat Portion and Hole Diameter on Oxygen Transfer Efficiency

Figure 6(a) shows the change between water jet velocity and OE. The values of OE decreased with increasing water jet velocity. The most important reason for this was the increase in pump power. This is because $N_j = 0.5\rho Q_w V_j^2$ in the denominator of the OE equation given in Eq. (2.5) was equal to power. Oxygen transfer efficiency also increased with the increase in diameter. This was due to the increase in jet momentum ($\rho Q V_j$). The OE values decreased with the increase in the ratio of the diameter of the throat portion to the outlet diameter. With the increase in the diameter of the throat portion, the outlet velocity of the water jet decreased. Thus, OE values decreased. The increase in the velocity of the water jet caused an increase in the momentum, and thus, the OE values increased. Figure 6(a) shows that the oxygen transfer efficiency of the venturi nozzle was considerably higher than that of the circular nozzle.

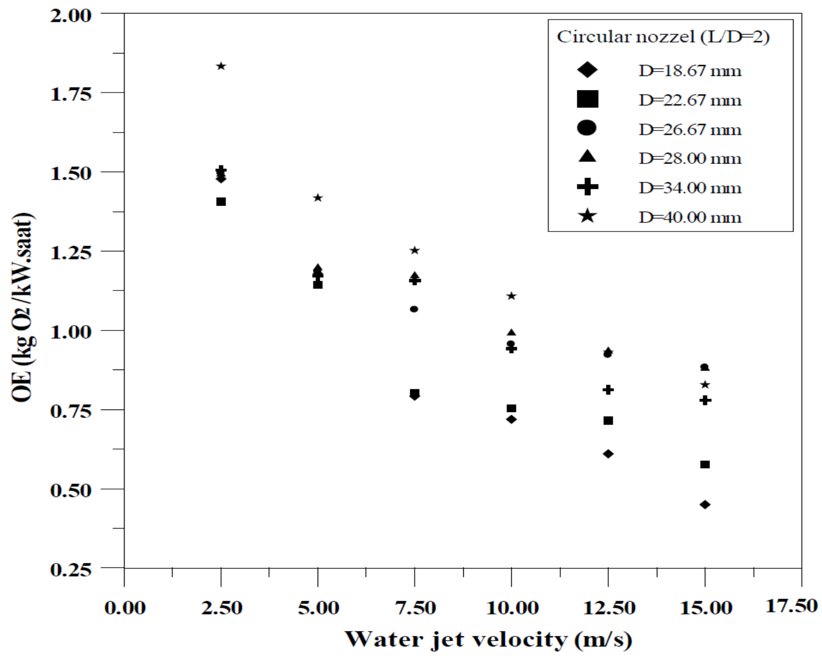
Figure 6(b) shows the change between water jet velocity and OE for circular nozzle. As shown from Fig. 6(b), OE values increased with increasing diameter. The most important reason for this was the increase in the momentum of the water jet.

Figure 6(c) shows the effect of the change in the length of the throat portion on the oxygen transfer efficiency. As can be seen from Fig. 6(c), the most significant OE values were obtained when both the diameter of the throat portion was narrow and the length of the throat portion was small. It is also seen from the figure that the values of non-dimensional throat portion diameter d/D=0.50 were considerably higher than d/D=0.75. In addition, the best OE values were obtained for ℓ/d=0.50. In their study, Van de Sande and Smith [10] indicated the oxygen transfer efficiencies of 3.9, 5.8, 8, 10, and 12 mm circular nozzles. The maximum velocity was taken as 15 m/s. K_La values increased with increasing velocity. The slope of the obtained graph was in agreement with the slopes of the values obtained in the present study.

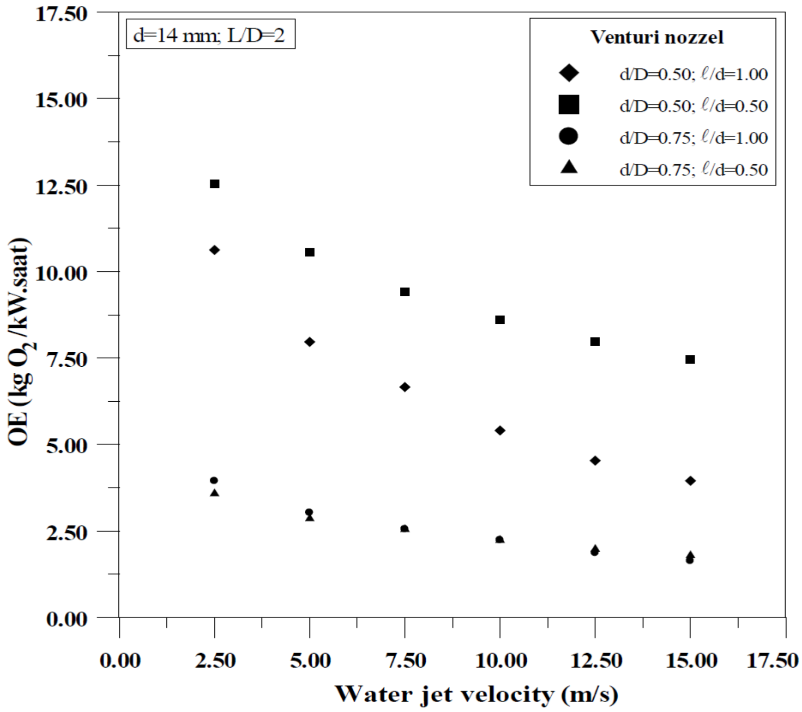
In the study by Van de Sande and Smith [10], a graph was plotted between velocity and OE, and OE values decreased with increasing velocity. The same trend was obtained in the current study.



(a)



(b)



(c)

Fig. 6. Effect of the change in length of throat portion and hole diameter on oxygen transfer efficiency in venturi nozzle

4. Conclusion

The current study investigated the air entrainment rate and oxygen transfer efficiency of circular and venturi nozzles with different diameters. Particular focus was attached to the effect of the length of the throat portion of the venturi nozzle and the effect of the hole made in the throat portion. Varying diameters of the air holes in the throat portion significantly affected the air entrainment rate and oxygen transfer efficiency. No increase in air entrainment rate was observed with increasing h_d/d. In general, higher data were obtained for h_d/d=0.2 and h_d/d=0.3. The ratio of throat portion length to throat portion diameter, ℓ/d was effective on air entrainment rate and oxygen transfer efficiency. ℓ/d=0.50 generally gave better results than ℓ/d=1.00.

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Conflict of Interest

The Author reports no conflict of interest relevant to this article

Research and Publication Ethics Statement

The author declares that this study complies with research and publication ethics.

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