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Influence of Throat Length and Flow Parameters on a Venturi as an Aerator

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ABSTRACT

Venturi system helps to air drawn into a flowing stream of water transferring the oxygen from air to water till they reach the water surface and burst due to Bernoulli's principle in form of bubbles. The efficacy of venturi as an aeration device is primarily dependent on the geometry and the flow conditions prevailing inside. Presently, the diameter and placement of holes in a venturi under different flow conditions was studied to determine the performance of the venturi as an aerator. To evaluate the results, SOTR and SAE were calculated and compared for analyse their performance. The study involved selecting 5 different throat lengths each having multiple hole of 1 mm diameter. The hole distance from the start of the throat section, which has been characterised as the effective distance (ED) has been so selected that all the ED's are different. The ED's selected for study varied from 2 mm to 46 mm under three different discharges of 1.72 m^3/h, 2.02 m^3/h and 2.38 m^3/h. Firstly, it was observed from the experiments that the venturi performs best when the ED is less. Secondly, it was also observed that both SOTR and SAE are more for higher discharge. Next, it was also found that increasing the throat length beyond a certain value has a negative effect on the SOTR and SAE. It was also observed that among all the possible combinations the best was for the 10 mm throat section with the hole situated just adjacent to the start of the throat section and performing at a high discharge.

Highlights

- Venturi aeration is a novel scheme of air water mixing at throat section. Other than the position of throat hole was foundthat the chief factor influencing the air entrainment rate and the oxygen transfer efficiency.

Keywords: Aerator, Venturi, Dissolved Oxygen, SOTR, SAE

With the increasing demand for water use, aeration is helpful to enhance the quality of water by introducing natural air into the water bodies for human consumption as well as for the aquatic fauna and flora (Baylar *et al.* 2009). In other words, it can be precisely said that water quality is vital to the financial health and productivity of the aqua farming operation (Bagatur and Baylar 2006). Oxygen transfer from air to liquid by diffusion has a source of aquatic production which is required for a sustainable environment friendly system of mass production. The satisfactory supplementation of oxygen helpful for increment to various physico-chemical processes occurring in the aquatic biota and provide a healthy environment. Physically, the oxygen transfer or by absorption from the atmosphere to water gives a significant effect on the pond ecosystem (Baylar and Emiroglu, 2003). Promiscuous information has already been acquired on aeration with advanced flow measuring structures and other methods. Venturi aeration has an effective method of aeration, highly efficient, inexpensive cost effective and requiring less than 20% pressure difference to initiate suction (Baylar *et al.* 2005; Rathinakumar *et al.* 2014; Ghomi *et al.* 2009; Kandakure *et al.* 2005; Havelka *et al.* 1997).

A venturi allows air bubbles into the flowing water from air in let holes due to the pressure difference occurs at constricted portion of venturi according to Bernoulli's Theorem, so as to increase oxygen levels in the water. The mechanisms by which the air entrained and transferred into flowing water through differential pressure, which varies with the throat hole, throat length and flow velocity. Flow through a venture represents a state where permanent pressure losses are a minimum; for this reason, the venture uses as a flow-measuring device.

Moreover, high pressure in the venturi also facilitated the entrainment of air into water. Many factors affect the air entrainment and oxygen transfer in venturi aeration systems; the four operating variables adopted by earlier researchers include throat length, throat hole diameter, air hole diameter, water velocity, and converging and diverging angle. Emiroglu and Baylar (2003) studied the effect of varying numbers, positions, and the open/closed status of the air holes at the throat portion of a venturi nozzle on air entrainment rate and oxygen transfer efficiency. Emiroglu and Baylar (2003) investigated the air entrainment rate and oxygen transfer efficiency of a venturi nozzle with air holes along the length of the convergent divergent passage, and in particular, the effect of varying numbers, positions, and open/close status of the air holes. Baylar and Emiroglu (2004) conducted an experimental study on circular nozzles with and without air holes and studied the effect of varying the number, positions, and open/close status of the air holes of circular nozzles on air entrainment rate and oxygen transfer efficiency. Bagatur *et al.* (2002) has acquitted a series of laboratory experiments on inclined plunging water jets and investigated the effect of nozzle shapes on air entrainment rate and oxygen transfer efficiency.

Bagatur and Sekerdag (2003) investigated the air entrainment rate of circular nozzles with and without air holes, and in particular, the effect of varying numbers and positions of the air holes and distance between the location of the air holes and the nozzle exit. Zhu *et al.* (2007) studied air entrainment characteristics in a plunging water jet system using rectangular nozzles with rounded ends. Baylar and Ozkan (2005) conducted an experimental study on the use of a venturi nozzle in a plunging water jet aeration system and investigated the effect of varying angle of diverging cone and out let length of a venturi tube on the air entrainment rate. Most of the experimental studies have been concluded on various designed venturi under different operation conditions. Parallel modules of two and three-aerators were observed to perform better than the series design with the oxygen transfer coefficients of 9.67 h^{-1} and 5.93 h^{-1}, respectively (Zhu *et al.* 2007). Furthermore, the two modules under parallel design, the aeration efficiencies were also observed to be higher as compared to the series module. Laksitanonta and Singh (2003) observed that the dissolved oxygen increased with the volume flow rate of water, contributed by the velocity of water flow and size of nozzle. The velocity of water flow was found to be 0.59 m/s. The present excogitation is addressed to describe a performance of venturi aeration system on different throat length and flow parameters.

THEORETICAL CONSIDERATION

Oxygen Transfer into Water

The effectiveness of oxygen transfer is a critical factor for determining the successful application of venturi for dissolving oxygen concentration. Two-film theory (Lewis and Whitman 1924) has been used to estimate the oxygen transfer rate. The rate of mass transfer of oxygen from the atmosphere to the body of the turbulent water generally is proportional to the difference between the existing concentration and the equilibrium or saturation concentration of oxygen in the water. According to two-film theory, the oxygen transfer coefficient at T°C, $K_L a_T$ may be expressed as follows:

$$K_L a_T = \frac{1n\left(C_s - C_0\right) - 1n\left(C_s - C_t\right)}{t} \quad \ldots(1)$$

where, ln represents natural logarithm and C_s, C_0 and C_t are dissolved oxygen concentrations in parts per million (ppm). C_s is the saturation DO at time tending to very large values, C_0 is at the beginning of time t=0 and C_t is at time t=t. The value of $K_L a_T$ can be obtained as slope of the linear plot between $ln(C_s – C_t)$ and time t. Similarly, other theories such as (Higbie 1935, Danckwerst 1951, Dobbins 1956) offered alternative models to the two-film theory.

Oxygen Transfer Cause to act by Venturi Principle

The venturi effect is the increase in the velocity of a fluid stream as it passes through a narrower section in a channel, pipe or duct. The discharge through the venturi section can be described by the Bernoulli equation similar to the evaluation of flow through a closed conduit venturi (Baylar and F. Ozkan 2005) Writing the Bernoulli equation between section 1 and section 2 shown in Fig. 2.

$$\frac{P_1}{\gamma}+Z_1+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+Z_2+\frac{V_2^2}{2g} \qquad \ldots(2)$$

where, 1 and 2 are subscripts indicating points (1) and (2); P_1 and P_2 are pressures; γ is specific weight; Z_1 and Z_2 are elevations; V_1 and V_2 are velocities and g is gravitational acceleration.

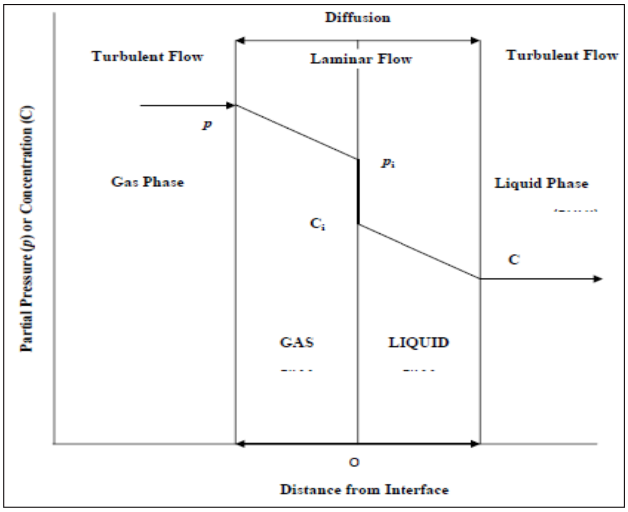

Fig. 1: Definition sketch of the gas transfer process (Treybal 1985)

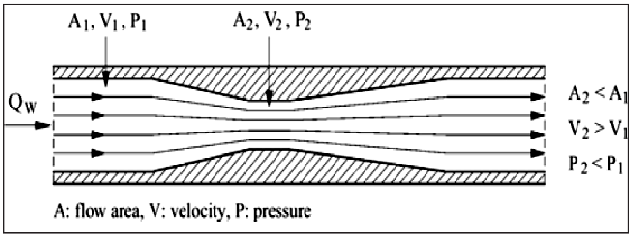

Fig. 2: Variations in Piezometric Head through Venturi (Baylar *et al.* 2010)

When a fluid is passed through the venturi, the fluid velocity of the flow is caused to increase, where as the pressure is correspondingly caused to decrease. This pressure difference at the constricted portion of the venturi is relevant to the air entrainment through the air holes and vigorously ascends into the operating section (Baylar *et al.* 2009); the greater the difference between the pressure of the oxygen in the water and atmosphere, the larger them movement of oxygen molecules from the atmosphere to the water.

Analysis of Oxygen Transfer Efficiency

In an aeration assessment, water is deoxygenated with cobalt chloride and sodium sulphite (1:100). Cobalt catalyzes the following reaction between molecular oxygen and sodium sulphite:

$$Na_2SO_3 + 1/2O_2 \rightarrow Na_2SO_4 \qquad \ldots(3)$$

Then, DO concentrations are measured with a DO meter at time t intervals while DO increases from 0% saturation to at least 80% saturation. The DO deficit is computed for each times that DO was measured during re-aeration:

$$\text{DO deficit} = C_s - C_t \qquad \ldots(4)$$

where, C_s is the DO concentration at saturation (mg/L) and C_t is the measured DO concentration (mg/L). The aeration performance of venturi oxygen transfer efficiency as defined the following equation:

$$K_L\alpha_{20} = K_L\alpha_T \times \theta^{(20-T)} \qquad \ldots(5)$$

where, $K_L\alpha_{20}$ = Standard oxygen transfer coefficient at temperature 20°C (h^{-1}), $K_L\alpha_T$ = oxygen transfer coefficient at temperature (°C), and θ = 1.024.

Ability of aerator to transfer the oxygen from atmosphere expressed in terms of SOTR and SAE calculated as follows:

$$SOTR = K_L\alpha_{20} \times (C_s - C_o) \times V \times 10^{-3} \qquad \ldots(6)$$

where, C_s = the DO saturation concentration at 20°C, V = Aeration water volume (m^3), $SOTR$ = Standard oxygen transfer rate (kgO_2/h)

$$SAE = \frac{SOTR}{P} = \frac{K_L\alpha_{20} \times (C_s - C_0) \times V \times 10^{-3}}{P} \qquad \ldots(7)$$

where, SAE = Standard aeration efficiency (kgO$_2$/kWh) and P = Power input (kW).

MATERIALS AND METHODS

The detailed design of the experimental set-up and the method employed to fulfil the requirement of the study was conducted using the experimental setup in the Laboratory of the Department of Agricultural Engineering, Assam University, Silchar, Assam. The detailed study and procedure is given below.

Experimental Setup

The setup consisted of a DC electric motor coupled with a centrifugal pump, storage tank, collecting tank and pipe fittings for closed loop water circulation, water meter and pressure gauge, as shown in Fig. 3. The setup consists of a storage tank of dimension 90cm × 55cm × 45cm (220l) and a collecting tank with 60cm × 35cm × 45cm (94l) connected through pipes. Before running the experimentation, initially fetch down the DO concentration up to 0 mg/l by mixing chemicals sodium sulphite (Na_2SO_3) and cobalt chloride ($CoCl_2$) @10 mg/l and 0.1 mg/l, respectively, with tap water, after that the experimentation started through supplying water in closed loop system (Figure 3).With this experiment deoxygenized water was continuously supplied from the bottom tank to the top tank where that passes through the venturi also. The DO concentration at room temperature is measured using a calibrated portable YSI Pro ODO DO meter (Yadav *et al.* 2016). DO readings are taken at regular intervals when DO concentration reaches 80% saturation.

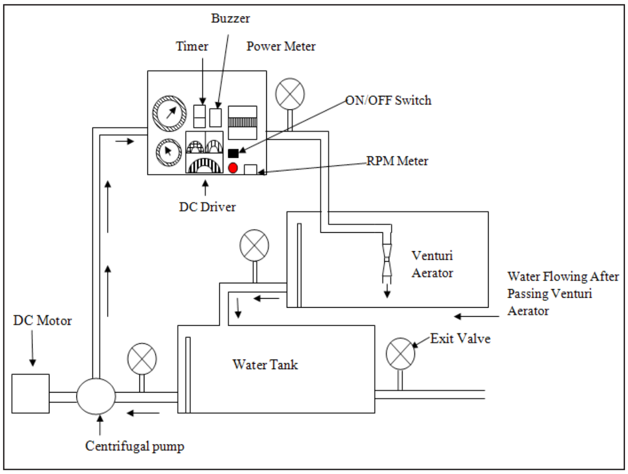

Fig. 3: Experimental Setup

Fabricated Venturi

The specific view of the fabricated venturi is given in Fig. 4, having three different parts, which are the converging section, throat section and diverging section, with all sections able to be dismantled from each other. The converging and diverging sections of the aerator are made the same length i.e. 100 mm and were connected with a throat portion of 5 numbers of sets of various lengths of 10 mm, 20 mm, 30 mm, 40 mm and 50 mm. The venturi fabricated using aluminium of 5 mm thickness and holes of 1 mm were drilled in the throat is presented in the section below:

Table 1: Details of the throat section of the venturi

Throat Length	Hole Diameter	Number of Holes	Effective Distance, ED(mm)
10mm	1mm	2	13,17
20mm	1mm	7	13,15,17,19,21,23,25
30mm	1mm	9	12, 15, 18, 21, 24, 27, 30, 33, 36
40mm	1mm	9	12, 16, 20, 24, 28, 32, 36, 40, 44
50mm	1mm	9	16, 21, 26, 31, 36, 41, 46, 51, 56

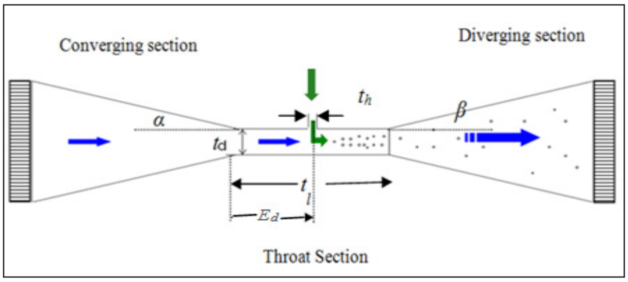

Fig. 4: Geometric view of Venturi Section; t_d, throat diameter; t_h, throat hole; t_l, throat length; E_d, effective distance; α, converging angle; β, diverging angle

RESULTS AND DISCUSSION

Effect of Discharge on DO Diffusion

In order to study the effect of throat length at increasing discharge rate on DO diffusion the effective length of throat hole was varied as mentioned earlier. It was seen from the study that the DO diffusion rate increases with increasing discharge and time. The experimental details along with the results are presented in Figs. 5 and 6. The value of DO was found maximum 7.34 mg/l at higher discharge 2.38 m^3/h by 10 mm throat length, as compared with 20 mm, 30 mm, 40 mm, and 50 mm throat length. It can be said that as the DO values of water moves towards saturation, the rates of diffusion decreases considerably in the case of lower discharge than that of higher discharge.

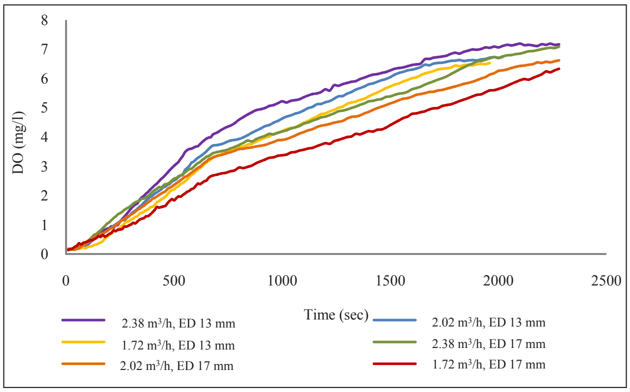

Fig. 5: Variation of DO with time for hole 1and hole 2 of 10 mm throat length at different discharge rate

Fig. 6 shows that the maximum DO concentration obtained at the maximum discharge rate of 2.38 m^3/h for all 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm throat lengths were 7.34 mg/l, 7.11 mg/l, 7.13 mg/l, 7.12 mg/l, and 7.12 mg/l, respectively.

It was also observed that the rate of diffusion is more in the throat hole near the converging part than that of the other holes near the diverging part of the venturi. It was also observed that in order to reach the final value of DO, the time taken with a lower discharge rate 1.72 m^3/h is almost three times that of the higher discharge of 2.38 m^3/h. It can be said that the rate of aeration is more at maximum discharge than that of minimum discharge.

Fig. 7 and 8 shows the effect of SOTR and SAE for the effective distance of the throat hole at different discharge rates. It can be also observed

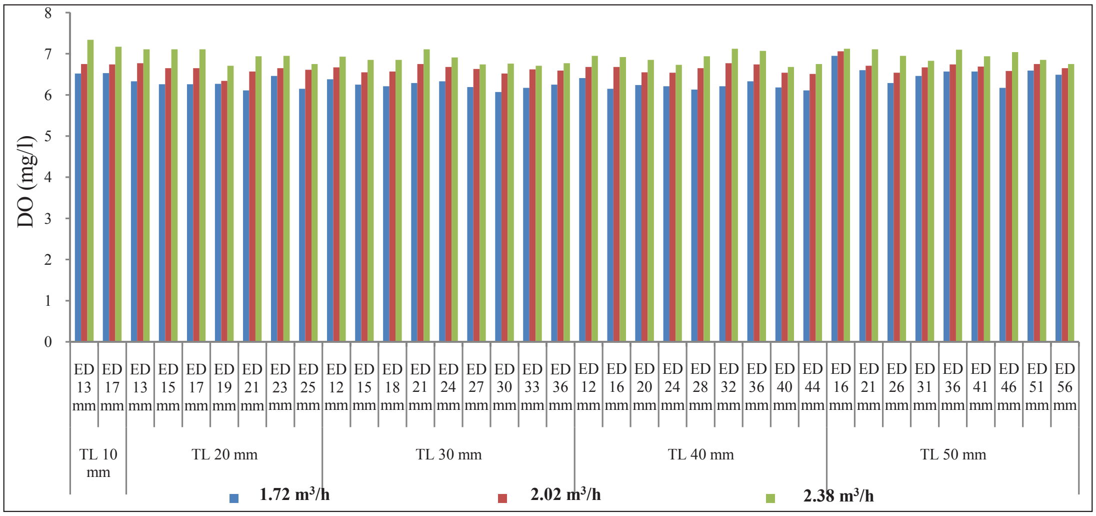

Fig. 6: Comparison of DO diffusion for different throat length at increasing discharge

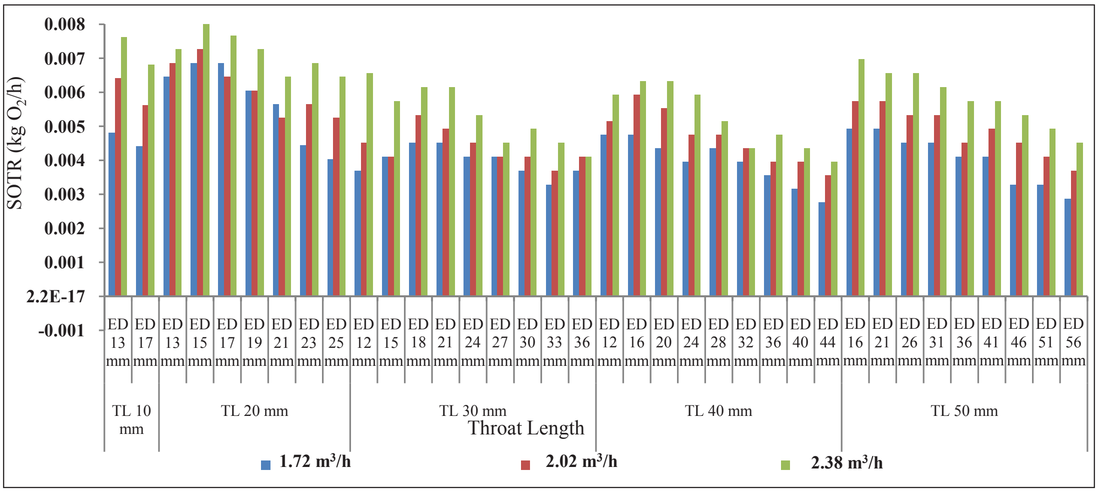

Fig. 7: Effect of SOTR at different discharge for different throat length

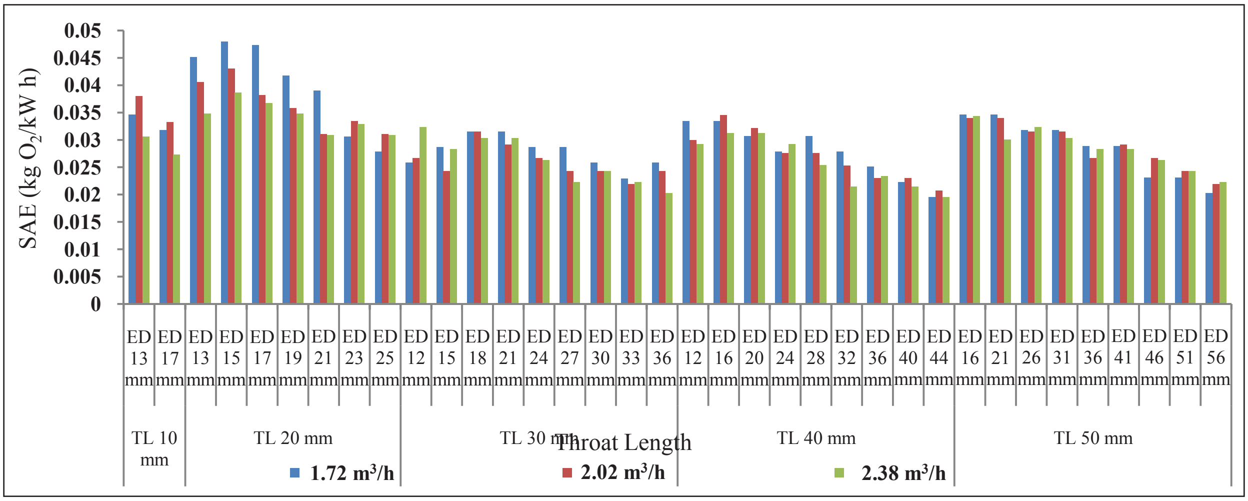

Fig. 8: Effect of SAE at different discharge for different throat lengths

from the graphs that SOTR is linearly increasing with the increase in discharge and it is found maximum at maximum discharge. This shows that due to increase in molecular turbulence, the rate of exchange of gas between liquid film and gas increases. The maximum SOTR found was 7.62×10^{-3} kgO_2/h at ED 13mm, 8.08×10^{-3} kgO_2/h at ED 15 mm, 6.56×10^{-3} kgO_2/h at ED 12 mm, 6.32×10^{-3} kgO_2/h at ED 16 mm and 6.97×10^{-3} kgO_2/h at ED 16 mm for 10 mm, 20 mm, 30 mm, 40 mm and 50 mm throat length, respectively, all at higher discharge rates, but maximum SAE was found at lower discharge 47.95×10^{-3} kgO_2/kWh.

CONCLUSION

From the overall experimental study, it can be concluded that the DO diffusion have a significant efficacy on effective throat length and discharge parameter, and further increases with time. The value of DO diffusion was observed to be higher at maximum discharge. It was also found that the maximum DO diffusion rate from the throat hole, which is nearer the converging part than that of the other holes near the diverging part of the venturi. It was also observed that SOTR increases at maximum discharge and SAE increases at lower discharge for a particular throat hole placement. Based on the findings of this study, the position of the throat hole was found to be the most important factor influencing the air entrainment rate and the oxygen transfer efficiency. From the above study it can be said that venturi aeration is one of the ideal forms to increase air entrainment and oxygen contention to water; in addition, the venturi tube can be used as a highly efficient aerator in water aeration systems.

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