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Research Paper / Makale

Testing of System Performance for Different Aerator Configuration Using Venturi

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Abstract: A venturi tube or pipe part or device allows air bubbles to be inserted into flowing water from air inlet holes and so increases dissolved oxygen (DO) levels in water. Therefore, the aim of this paper is to evaluate system design and experimental results related to configuration of venturi tube in air vacuum and aeration process. Different aerator modules constructed using venturi tubes connected in either single or double in parallel (with single or double outlet pipe line) were evaluated and compared for their air flowrate, vacuum capacity, oxygen transfer coefficients (OTC), standard oxygen transfer rate (SOTR), and standard oxygenation efficiency (SOE) determined by clean water tests. The experimental results indicated that the double parallel design (connected to a single outlet pipe line) generally performed better than the single and double parallel (connected to a double outlet pipe line) design in terms of transferring oxygen into water.

Keywords : System performance, air-water, two phase flow, Venturi, Oxygen transfer

Venturi Havalandırıcı Konfigrasyonu İçin Sistem Performansının Test Edilmesi

Öz : Bir venturi tüpü veya boru parçası veya aygıtı, atmosferdeki havanın venturi hava girişi deliklerinden boru akımına geçişini sağlar ve böylece sudaki çözünmüş oksijen (ÇO) seviyelerini arttırır. Bu deneysel çalışmanın amacı venturi ile havalandırma sisteminde venturi boru parçasının konfigürasyonu ile ilgili en verimli sistem tasarımını yapmak ve elde edilen deney sonuçları değerlendirmektir. Tekli veya çiftli paralel (tekli veya çift çıkış boru hattı ile) bağlanan venturi tüpleri kullanılarak sistemi kurulan farklı havalandırma modülleri; hava akış hızı, vakum kapasitesi, oksijen transfer katsayıları (OTK), standart oksijen transfer hızı (SOTH) ve standart oksijenleme etkinliği (SOE) temiz su testleri ile belirlendi. Elde edilen deneysel sonuçlar göre, çiftli paralel tasarımın (tek bir çıkış borusuna bağlı olarak) genel olarak çözünmüş oksijenin suya aktarımı açısından tek ve çiftli paralelden (çift çıkışlı boru hattına bağlı) daha iyi performans gösterdiği gözlemlendi.

Anahtar kelimeler: Sistem performansı, hava-su, iki fazlı akım, Venturi, Oksijen transferi

1. Introduction

Venturi is a viable, economic alternative device for gas-liquid transfer. Air vacuum process with venturi tube, simple in design and easy to operate, have been used in a wide variety of industrial, agricultural and water purification process (e.g., ozone and chlorine injecting/contacting for drinking water, chemical injection such as liquid fertilizers in the sprinkler irrigation system and aeration/dissolved oxygen transfer in the drinking and waste water treatment).

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Main engineering advantages of using a venturi device can be ranged the following ones:

i. It is a cheap system
ii. It is a robust system without mobile pieces
iii. It doesn’t require any type of external energy for their operation.
iv. Low system maintenance costs–no fouling
v. Low operating and installation costs
vi. Easily adaptable for many applications

Bagatur summarized engineering application fields of venture tube or pipe part and concentrated on minimal conditions for venturi aeration of water flows [1, 2]. Venturi tubes can be used to solve the following problems for water/wastewater treatment and irrigation water:

1. Excessive biochemical oxygen demand problem in waste water treatment
2. Excessive chemical oxygen demand problem
3. Lack of dissolved oxygen problem
4. Noise problem for packaged waste water treatment plant
5. Odor problem in waste water evaporation
6. Sour drinking water problem due to containing hydrogen sulfide
7. Excessive organic matter, nutrient, and nitrogen problem
8. Select of efficient aeration system problem
9. Disinfection problem in drinking water treatment
10. Flotation process in waste water treatment
11. Improve soil aeration by entraining air
12. Inject soluble or liquid fertilizer for irrigation

Baylar and Emiroglu investigated air entrainment and oxygen transfer efficiency for a venture nozzle in plunging water jet system [3]. Emiroglu and Baylar studied the influence of air holes on suction port of venturi for aeration performance [4]. Baylar et al. experimentally investigated influence of venturi cone angles on plunging water jet aeration [5]. Ozkan et al. carried out experimental investigations related to air and liquid injection by venturi tubes [6]. Baylar and Ozkan summarized engineering applications of venturi principle for water aeration systems [7, 8]. Baylar et al. determined the optimal location of the air holes on venture tubes [9]. Also, Baylar et al. investigated effect of air hole diameter on suction port of venturi tube on air injection rates [10].

Zhu et al. studied on aerator module development using venturi air injectors to improve aeration efficiency [11]. They present information on how to improve aeration efficiency without effecting additional capital and operating costs. Two different configurations of aerator modules were studied using water test. The aerator modules consisted of a number of venturi air injectors connected either in series or in parallel aimed at achieving better aeration efficiencies. The results obtained indicated that the parallel design generally performed better than the series design in terms of transferring dissolved oxygen into water tank.

Dong et al. evaluated of six aerator modules built on venturi air injectors using clean water test [12]. They suggest that it is possible to improve the aeration performance of a venturi aerator by module design. Thus, effective odor control for liquid swine manure lagoons can be done at an affordable cost. Also, Dong et al. indicated that better aeration efficiency could be achieved by simply changing of venturi arrangement [13].

The aim of this paper is to investigate system design and experimental results related to configuration of venturi tube in air vacuum and aeration process. Different aerator modules constructed using venturi tubes connected in either single or double in parallel (with single double outlet pipe line) were evaluated and compared for their air flowrate, vacuum capacity, oxygen transfer coefficients (OTC), standard oxygen transfer rate (SOTR), and standard oxygenation efficiency (SOE) determined by clean water tests.

2. Background

2.1 Venturi tube

In reality, the venture pipe part is a device which has been used over many years for measuring the discharge along a water pipe in water/hydraulic engineering [14].
Nowadays, the venturi or two phase (air-water) injectors-ejectors have been designed for vacuuming of gas and liquid. Fig. 1 shows an air vacuum process from atmosphere with venturi tube.

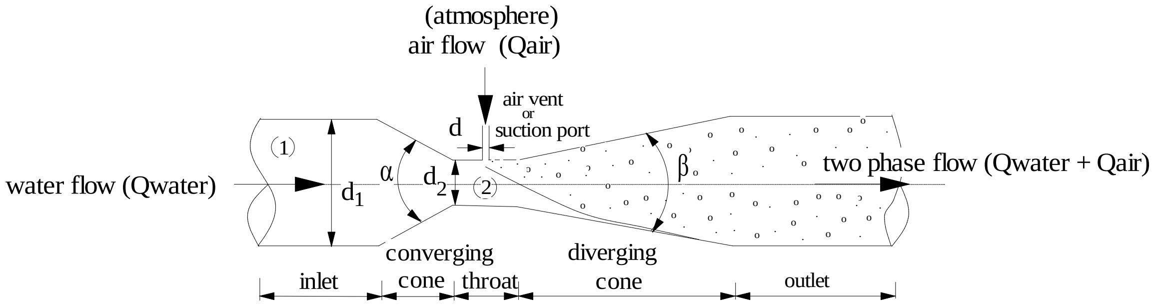

Fig. 1 Air vacuum process from atmosphere with venturi tube

The water flowing in the pipe is led through a contraction section to a throat, which has a smaller cross-sectional area than the pipe, so that the velocity of the water through the throat is higher than that in the pipe. This increase of velocity is accompanied by a fall pressure. Beyond the throat the water is decelerated in a pipe of slowly diverging section, the pressure increasing as the velocity falls. In entry of venturi device or tube, water flow has pressure energy. This pressure energy converted to velocity in converging cone. Water flow changes into a high velocity jet stream. The increase in velocity through the venturi converging cone, as a result of the differential pressure, results in a decrease in pressure. Thus, a vacuum is created at the suction port. Water mixes with air. Two phase flow (the bubbly flow) occurs. This is accomplished when a minimal amount of differential pressure exist between the entry and exit regions of venturi tube. In exit of venturi, pressure energy is regained for mass transfer of air.

2.2 Dissolved oxygen (DO) transfer

In atmosphere, the air contains 20.95% oxygen gas. At standard barometric pressure (760 mm Hg or 1 atmosphere), the pressure of oxygen gas in air is 159 mm Hg (760x0.2095). It drives oxygen into water until the pressure in water is equal to the pressure in the atmosphere. When pressures in water and atmosphere are equal, net movement of oxygen molecules from atmosphere to water ceases. Dissolved oxygen (DO) is a measure of the free oxygen dissolved in water. The dissolved oxygen concentration in water at saturation varies with temperature, salinity and barometric pressure or elevation of study area.

The rate of mass transfer of oxygen from the atmosphere to the body of the turbulent liquid generally is proportional to the difference between the existing dissolved oxygen concentration (C) and the equilibrium or saturation concentration (C_S) of oxygen in the liquid.

The rate of oxygen transfer is given by Fick’s diffusion equation applied across the liquid film [15]:

$$OC = \frac{dC}{dt} = K_L a\,(C_S - C) \qquad (1)$$

Where OC is oxygenation capacity of water (mg O_2/ liter hour). In the determination of the oxygen-transfer coefficient (K_L), the overall coefficient K_La is obtained without attempting to separate the factors K_L and a. The difference (C_S-C) between dissolved oxygen saturation value at the liquid film interface and measured concentration of oxygen in the bulk of the liquid phase is called oxygen deficit.

For simply, it is assumed that the product K_La remains constant in venturi pipe part. K_La may also be a function of time or distance along the pipe line without the resulting indexing relationship.

Integrating the equation between the limits C=C_0 at time t=0 and C=C_t at t=t, one obtains

$$K_L a_{(T)} = Ln\left[\frac{(C_S - C_O)}{(C_S - C_t)}\right]/t \qquad (2)$$

where Ln represents natural logarithm of the given variables and the concentrations Cs, C_0, and C_t are usually expressed in parts per million (mg/L).

The overall oxygen transfer coefficient is adjusted to 20^{o}C with the following equation:

$$K_L a_{(20)} = \frac{K_L a_{(T)}}{1.024^{(T-20)}} \qquad (3)$$

where $(K_La)_{20}$ is overall oxygen transfer coefficient at 20°C (1/hr) and T is water temperature (°C).

$$SOTR = K_L a_{(20)}\, C_{S(20)}\, V\, 10^{-3} \qquad (4)$$

where SOTR is standard oxygen transfer rate (kgO_2/h), $C_{S(20)}$is saturated DO at 20^{o}C and standard atmospheric pressure (mg/L), V is aeration tank volume (m^3), and 10^{-3} is factor for converting gram to kilogram.

The SOTR value may be divided by pump power applied to obtain the standard oxygen transfer efficiency (SOE):

$$SOE = \frac{SOTR}{Pump\,power} \qquad (5)$$

where SOE is oxygen transfer efficiency (kgO_2 /kWh) and the power consumption is determined by pump size (kW).

Table1 indicates saturation values (C_S) based on location elevation of measurement point and water temperature [16]. Salinity concentration value is the total amount of dissolved salts in water; grams of salts per kilogram of water (g/kg) or as parts per thousand (ppt). Also, Table 2 shows the solubility values based on temperature and salinity at standard barometric pressure. Benson and Krause investigated the concentration of dissolved oxygen in freshwater and seawater [17].

The saturation of DO concentration for a particular water temperature and barometric pressure may be calculated as follows [18]:

$$C_S = C_{tab}\left(\frac{BP - P_{H_2O}}{760 - P_{H_2O}}\right) \qquad (6)$$

Where, C_S is DO saturation concentration (mg/l). C_{tab} is DO concentration at the existing temperature and standard barometric pressure (mg/l) (Table 2). BP is barometric pressure at measurement field (mmHg). P_{H_2O} is vapor pressure of water (mmHg).

Table 1. Oxygen saturation values (C_S) depend on elevation and temperature

Elevation, m	**Water Temperature, °C**								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
	Dissolved Oxygen (DO) Saturation, mg/L								
0 (sea level)	14.6	12.8	11.3	10.1	9.1	8.3	7.6	7.0	6.4
300	14.2	12.3	10.9	9.7	8.7	8.0	7.3	6.8	6.2
600	13.7	11.9	10.6	9.4	8.5	7.7	7.0	6.7	6.0
900	13.3	11.5	10.2	9.1	8.2	7.6	6.8	6.3	5.8
1200	12.7	11.1	9.8	8.8	7.9	7.1	6.5	6.1	5.6

Table 2. The solubility of oxygen depend on temperature and salinity at standard pressure

Temperature, °C	Salinity, ppt							
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**
	Dissolved Oxygen (DO) Saturation, mg/L							
0	14.62	14.12	13.64	13.17	12.71	12.28	11.85	11.45
5	12.77	12.35	11.95	11.55	11.18	10.81	10.45	10.11
10	11.29	10.93	10.59	10.26	9.93	9.62	9.32	9.02
15	10.08	9.78	9.49	9.20	8.92	8.65	8.39	8.14
20	9.09	8.83	8.57	8.32	8.08	7.85	7.62	7.40
25	8.26	8.03	7.81	7.59	7.38	7.17	6.97	6.77
30	7.56	7.35	7.16	6.96	6.77	6.59	6.41	6.24
35	6.95	6.77	6.59	6.42	6.25	6.08	5.92	5.77
40	6.41	6.25	6.09	5.94	5.78	5.64	5.49	5.35

However, for practical purposes, the contribution of vapor pressure can be ignored and eq. (6) can be written as:

$$C_S = C_{tab}\left(\frac{BP}{760}\right) \qquad (7)$$

The saturation of DO concentration for a particular water temperature and elevation may be calculated as follows:

$$C_S = C_{tab}\left[1 - \frac{(0.0065\,EL)}{298}\right]^{5.25} \qquad (8)$$

Where, C_S is DO saturation concentration (mg/l). C_{tab} is DO concentration at the existing temperature and standard barometric pressure (mg/l) (Table 2). EL is the location elevation at measurement field (m).

3. Material and Methods

Aeration experiments with venturi were performed using an experimental apparatus in the Hydraulic and Environmental Laboratory at the Engineering Faculty of Dicle University. A schematic flow diagram of the experimental arrangement used in the study shown in Fig. 2.

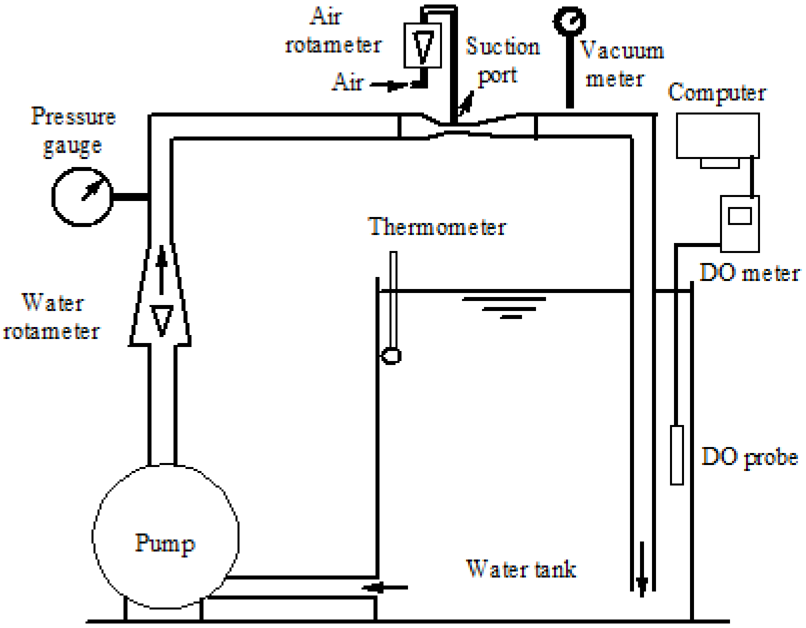

Fig. 2. Experimental setup

The experimental apparatus consists of a recirculation pump (0.37 kW) and a water tank (0.50 m diameter). The total water volume was held constant at 45 liter. Tap water was used throughout the experiments. The water tank was deoxygenated by the sodium sulfite technique. Theoretically, 7.9 mg/L of sodium sulfite is required to remove 1 mg/L o DO. Based on the DO of the test water, the approximate sodium sulfite requirements are estimated (with 10-20% excess). Also, addition of cobalt II chloride is required at a dosage of 3.3 mg/L as a catalyst for the deoxygenation reaction in tank. In this experimental study, 75 mg/L of sodium sulfite and 3.3 mg/L of cobalt II chloride were added.

DO concentration of receiving water tank was analyzed at constant intervals (1 min) with HACH HQd Portable Meter. The portable DO meter was calibrated daily prior to use by the humid calibration technique.

The location elevation of Dicle University is 660-680 m. In the university campus region, the barometric pressure and relative humidity are 702 mmHg and % 60, respectively. Using eq. (7) or eq. (8), table 1 and table 2 for 702 mmHg (barometric pressure) and 20 ^{o}C (water temperature), the dissolved oxygen saturation of aerated water is determined as 8.40 mg/L. Thus, the dissolved oxygen concentration of aerated water is taken into account as 8.40 mg/L in this study.

A water rotameter was used to measure water discharge recirculated by the water pump. Also, an air rotameter was installed on the suction port of the venturi device to measure the values of volumetric air flowrate resulting from air vacuum process. Additionally, obtained vacuum values were measured with connecting to suction port of vacuum meter.

All venturi tubes (aerators) were purchased from the Guangzhou Quanju Ozone Technology Corporation (Model I: 25152; inlet and outlet diameter: 1/2 inch, length: 95 mm and Model II: 25100; inlet and outlet diameter: 3/4 inch, length: 152 mm). All venturi injectors were made of glass reinforced polypropylene. The ratio of the throat diameter of venturi tube to the inlet diameter of venturi pipe part equal to 0.5.

Using the ASCE standard method [19], different aerator modules constructed using venturi tubes connected in either single or double in parallel (with single and double outlet pipe line) are considered for evaluating of their air flowrate, vacuum capacity, oxygen transfer coefficients (OTC), standard oxygen transfer rate (SOTR), and standard oxygenation efficiency (SOE) determined by clean water tests (Fig. 3). The injectors in the parallel design were placed 30 cm apart from each other (Fig.4).

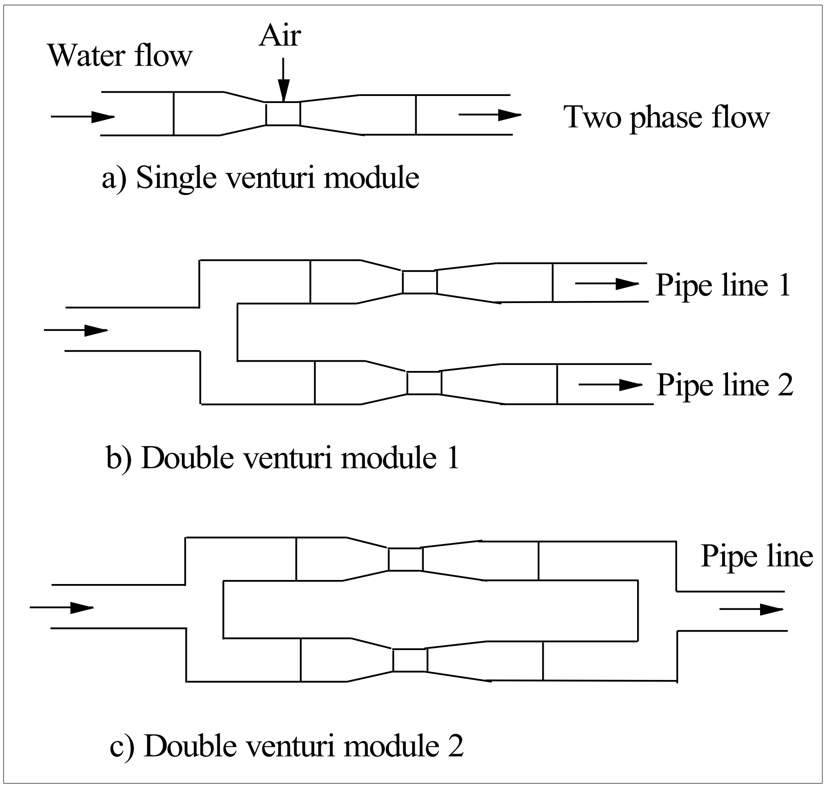

Fig. 3 Different configuration of venturi module for aeration process.

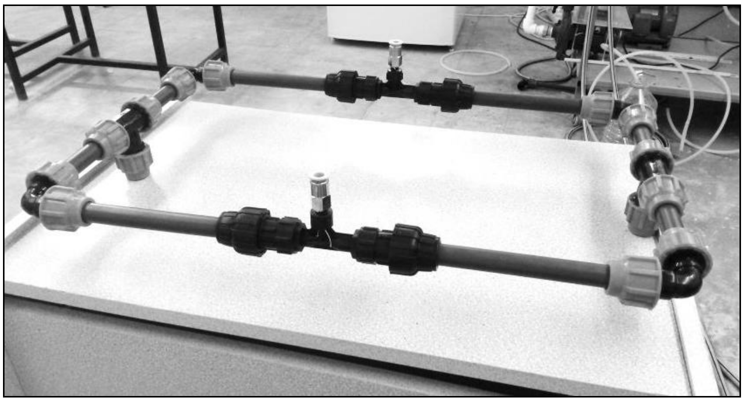

Fig. 4 Configuration of venturi aerator in parallel set up.

4. Results and discussion

In this study, a series of laboratory experiments were carried out to investigate water aeration by two phase flow systems using venturi tubes. The changes in DO concentration during aeration are given both venturi model I and model II in fig. 5 and 6, respectively.

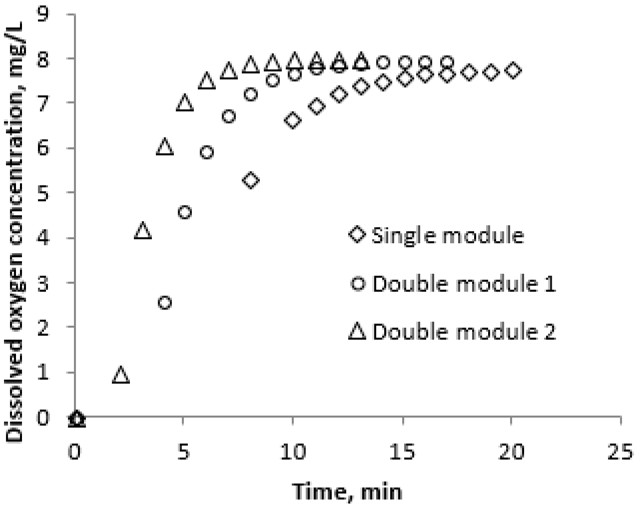

Fig.5 Measured mean dissolved oxygen (DO) concentration values for Model I.

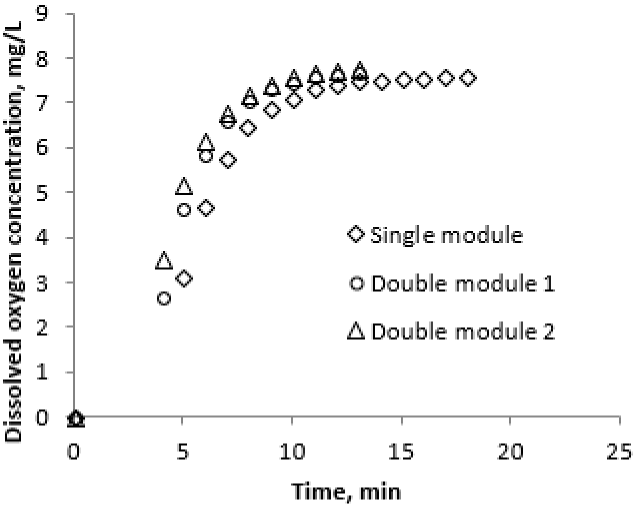

Fig.6 Measured mean dissolved oxygen (DO) concentration values for Model II.

Different aerator modules constructed using venturi tubes connected in either single or double in parallel (with single and double outlet pipe line) were evaluated and compared for their air flowrate, vacuum capacity, oxygen transfer coefficients (OTC), standard oxygen transfer rate (SOTR), and standard oxygenation efficiency (SOE) determined by clean water tests (Table 3 and Table 4). The experimental results indicated that the double parallel design (connected to a single outlet pipe line) generally performed better than the single and double parallel (connected to a double outlet pipe line) design in terms of transferring oxygen into water.

The venturi configuration has been found to be an important factor influencing air performance and dissolved oxygen transfer. K_La is highest for double in parallel (connected to a single outlet pipe line) and lowest for the single venturi. This may be described by the turbulence intensity, mixing, and small air bubbles.

Table 3.Summary of experimental investigationfor venturi Model I

System Parameter	Single Venturi Module	Double Venturi Module 1	Double Venturi Module 2
Configuration	**Settlement:Single** **Inlet:Single pipe** **Outlet:Single pipe**	**Settlement:Parallel** **Inlet:Single pipe** **Outlet:Double pipe**	**Settlement:Parallel** **Inlet:Single pipe** **Outlet:Single pipe**
Pump Pressure (PP), bar	1.35	0.75	0.75
Pump size (PS), kW	0.37	0.37	0.37
Volumetric air flow rate (entrained air), L/min	9.40	7.55	7.55
Tank volume, L	45	45	45
Tank diameter, m	0.50	0.50	0.50
Vacuum, bar	893	883	763
Water discharge, L/h	1.25	1.90	1.90
Temperature, degree	24.9	23.6	23.8
$k_La(T)$, 1/h	12.78	24.36	39.54
$k_La(20)$, 1/h	11.38	22.26	36.30
SOTR, kg O_2/ h	0.004654	0.009106	0.01485
SOE, kg O_2/ kW h	0.0126	0.0246	0.0401

Table 4.Summary of experimental investigation for venturi Model II

System Parameter	Single Venturi Module	Double Venturi Module 1	Double Venturi Module 2
Configuration	**Settlement:Single** **Inlet:Single pipe** **Outlet:Single pipe**	**Settlement:Parallel** **Inlet:Single pipe** **Outlet: Double pipe**	**Settlement:Parallel** **Inlet:Single pipe** **Outlet:Single pipe**
Pump Pressure (PP), bar	0.50	0.20	0.20
Pump size (PS), kW	0.37	0.37	0.37
Volumetric air flow rate (entrained air), L/min	9.50	4.55	8.45
Tank volume, L	45	45	45
Tank diameter, m	0.50	0.50	0.50
Vacuum, bar	550	830	720
Water discharge, L/h	2.15	2.65	2.65
Temperature, degree	23.6	22.9	23.1
$k_La(T)$, 1/h	10.80	17.70	19.62
$k_La(20)$, 1/h	10.05	16.48	18.27
SOTR, kg O_2/ h	0.004114	0.006743	0.007474
SOE, kg O_2/ kW h	0.0111	0.0182	0.0202

5. Conclusion

The effect of aerator module configuration on aeration performance, vacuum process and oxygen transfer efficiency was examined in an aeration system with venture tubes/injectors using the clean water test. In detail, different aerator modules constructed using venturi tubes connected in either single or double in parallel (with single and double outlet pipe line) were experimentally measured values of air flowrate, vacuum capacity, oxygen transfer coefficients (K_La), standard oxygen transfer rate (SOTR), and standard oxygenation efficiency (SOE).In venturi Model I, standard oxygen transfer rates (SOTR) were obtained to be 0.04654, 0.09106, 0.01485 kgO_2/h. Standard oxygenation efficiencies were observed 0.0126, 0.0246, 0.0401 kgO_2/kWh. In venturi Model II, standard oxygen transfer rates (SOTR) were obtained to be 0.004114, 0.006743, 0.007474 kgO_2/h. Also, standard oxygenation efficiencies were observed 0.0111, 0.0182, 0.0202 kgO_2/kWh. Three venturi aerator modules were evaluated, and the results indicated that better aeration efficiencies could be achieved by simply changing of venturi aerator arrangement. Among all the configurations studied, double aerators connected in parallel (connected to a single outlet pipe line) were able to bring more dissolved oxygen into water than the others.

Acknowledgements

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