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Influence of the Flow Rate Ratio in a Jet Pump on the Size of Air Bubbles

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Abstract**—**In wastewater treatment processes, aeration introduces air into a liquid. In these systems, air is introduced by different devices submerged in the wastewater. Smaller bubbles result in more bubble surface area per unit of volume and higher oxygen transfer efficiency. Jet pumps are devices that use air bubbles and are widely used in wastewater treatment processes. The principle of jet pumps is their ability to transfer energy of one fluid, called primary or motive, into a secondary fluid or gas. These pumps have no moving parts and are able to work in remote areas under extreme conditions. The objective of this work is to study experimentally the characteristics of the jet pump and the size of air bubbles in the laboratory water tank. The effect of flow rate ratio on pump performance is investigated in order to have a better understanding about pump behavior under various conditions, in order to determine the efficiency of receiving air bubbles different sizes. The experiments show that we should take care when increasing the flow rate ratio while seeking to decrease bubble size in the outlet flow. This study will help improve and extend the use of the jet pump in many practical applications.

Keywords**—**Jet pump, air bubbles size, retention time.

I. INTRODUCTION

THE activated sludge process (ASP) has gained wide-spread acceptance in biological wastewater treatment. Role of aeration is to provide oxygen to microorganisms. The water aeration equipment used in this process consumes as much as 60-80% of total power requirements in modern wastewater treatment plants [1]. For instance, in wastewater facilities, blowers for aeration of activated sludge account for half the electricity, and pumping accounts for another 15% [2]. Electricity consumption by water and wastewater treatment facilities accounts approximately 3% of total USA electricity consumption. As power costs increase, more energy-efficient systems such as fine-bubble, full-floor coverage systems and jet injectors replace the older and less efficient aeration systems such as coarse-bubble or spiral-roll diffusers.

Many technologies are presently in use for aeration in the ASP. The most commonly employed are coarse- or fine-bubble diffusion, surface aerators, brush aerators (propeller aspirator pumps and paddlewheel aerators), and Venturi aeration systems. A widespread aeration technology is based on oxygen dissolution in wastewater, caused by the action of air bubbles. As the bubbles move through the water, oxygen diffuses into liquid by transfer across the bubble surface. In coarse diffuser systems the air mass pushes out through large orifices because they are less prone to being plugged.

Originally, most diffused air systems used fine bubbles with small diameters created by porous type media, such as ceramic plates. The small bubbles will contain the same volume of air, but in a greater number of bubbles. Fine bubbles are much more efficient at air transfer because they create a larger transfer surface area per unit of added air. The important variable that affects oxygen transfer efficiency is water quality, which includes the presence and concentration of surfactants such as detergents, dissolved solids, and possibly, suspended solids. Changes in bubble shape and size occur when the water is contaminated with surfactants. More effective for the aeration process is the technology that uses Venturi-type jet ejectors connected to various nozzles. Studies conducted by [3], have found that the use of ejector technology in aeration raises its efficiency in wastewater up to three times. Unfortunately, the phenomena underlying aeration processes have not yet been fully understood. The oxygen transfer rate from gas to liquid phases depends on such factors as aeration method, power input intensity, mixing intensity or turbulence, temperature, test facility geometry, and physicochemical properties of the liquid. A small amount of literature [4], [5] focuses on the liquid jet gas pump. Among these works, investigations were focused on bubble size. In the current research project we studied phenomena regarding the influence of the flow rate ratio in the jet pump, on the size of the air bubbles in the water tank. In this study experiments were based on an improved construction of the jet pump. The experimental setup was built in the hydraulics laboratory of SCE - Shamoon College of Engineering, in Israel. The objectives of the present study were to construct a jet pump and device for receiving different sizes of air bubbles, and to study the behavior of multiphase water flow with inclusion of air for different flow ratios. The present study continues to develop our previous investigations [2].

II. EXPERIMENTAL APPARATUS

A schematic description of the experimental setup is presented in Fig. 1. The system consists of the following components: laboratory tank (1), centrifugal pump (2), throttle valve (3), flow meter (4), manometer (5), jet pump (6), throttle valve (7), thermo-anemometer (8), vacuum gauge (9), pitot tube (10), pressure sensor (11) and digital camera (12). The fluid (in our case water) is circulated from the tank (1) through the nozzle of the jet pump (6) by the centrifugal pump (2). The flow rate was controlled by the throttle valve (3) and measured by the flow meter (4). The mixing chamber of the jet pump

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connected with atmosphere through the throttle valve (7), thermo-anemometer (8), and vacuum gauge (9). The flow rate of air was controlled by the throttle valve (7) and measured by the thermo-anemometer (8). The air entered the jet pump through the throttle valve (3) and the throat of the jet pump (6). There was a two phase flow outlet from the diffuser of the jet pump. The velocity measurements were done using a pitot tube, and for pressure measurement, an Endevco 8507-50 type transducer and an Endevco 136 type amplifier. Registration of values of measurement parameters was conducted by a type DS1052E oscilloscope. An experimental apparatus was constructed where the jet pump is situated inside a water. Bubble size was measured by taking photographs [6] with a digital camera (12) and thereafter processed further by special computer program. The bubble size was analyzed in three horizontal planes. One plane was situated 10 mm above the bottom of the tank, the second one 200 mm above the bottom of the tank and the third plane 10 mm below the water surface (400 mm above the tank bottom). The bubble size is represented as the bubble diameter that was measured at the planes. The average of the three measurements is reported here as the bubble diameter.

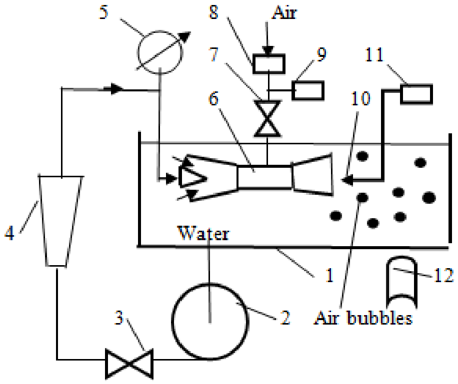


Fig. 1 Experimental setup

Experiments were performed in a 1m long laboratory tank with a 0.4m x 0.5m rectangular cross section. The model of the laboratory rig, constructed with a transparent material, is presented in Fig. 2.

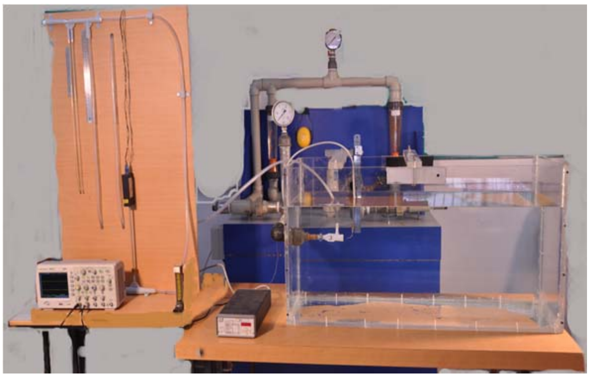
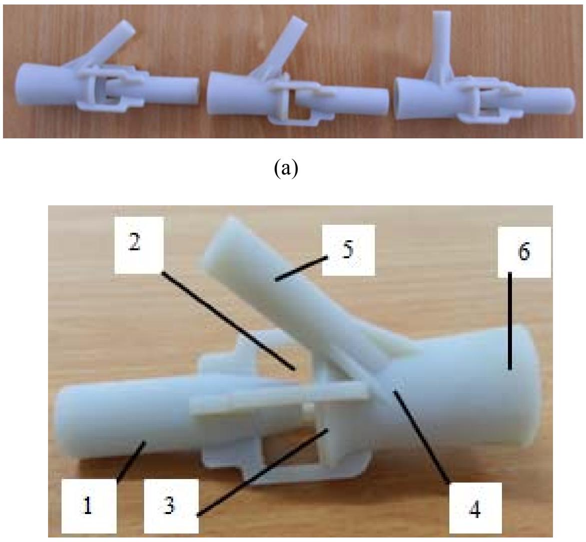


Fig. 2 Model of a laboratory rig

The series of jet pumps with different slope angles of the air suction nozzle Fig. 3 (a) were produced using 3D printing technology. A photograph of a representative jet pump is presented in Fig. 3 (b). This jet pump is composed of the following components: driving nozzle (1), water suction nozzle (2), suction chamber (3), mixing chamber or throat (4), air suction nozzle (5) and diffuser (6). The flow conditions through the jet pumps were considered for all the experiments; this condition being common in those pumps. A pressure gauge was used at the inlet of the pump to measure the pressure head of water. The inlet flow rate of water was variable but did not exceed 0.0004 m^3/s. A vacuum gauge was used at the air suction (5) entrance to measure the suction pressure created in the throat of the jet pump. The flow rate of the air was measured by a thermo–anemometer and did not exceed 0.0002 m^3/s.



(a)

(b)

Fig. 3 Photographs of jet pumps

For measuring bubble sizes, we used photographs of bubbly flow zones that were obtained by the digital camera. Fig. 4 indicates the distribution of the bubbles in different liquid-gas flow rate ratios.

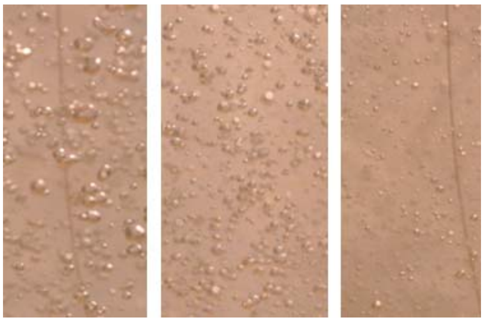


Fig. 4 Photographs for typical images of bubbles in the water for different gas- liquid flow rate ratios

III. EXPERIMENTAL RESULTS

The experimental apparatus allows us to explore different conditions of the liquid-gas flow through the system. Our goal was to use different conditions of the system to determine the size of the mean diameter of gas bubbles in the water. We studied the jet pump, focusing on different slope angles of the air suction nozzle, which is situated in the mixing chamber (Fig. 3). The design utilized a water flow rate through the water nozzle that would not exceed 0.0004 m^3/s. We tested that water flow rate through the water nozzle, as well as a flow rate through the water suction nozzle, to verify compliance with established flow rate parameters. The results of the measurements of the relation between the water flow rate entering through the suction chamber and water jet flow rate, are presented in Fig. 5.

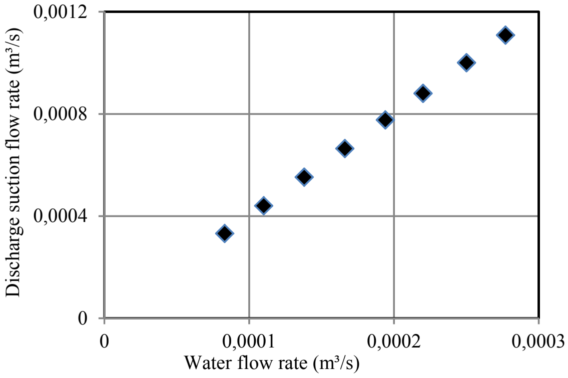


Fig. 5 Relation between water flow rate entering through suction chamber, and the water jet flow rate

Fig. 6 represents the results of the measurements of the flow rate of air through the suction nozzle and the water flow rate, entering through the driving nozzle.

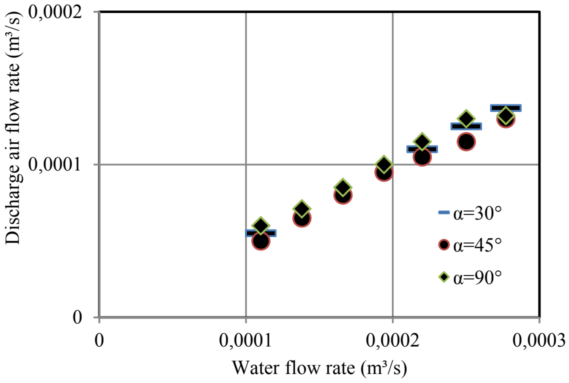


Fig. 6 Relation between flow rate of air through the suction nozzle, and water flow rate entering through the driving nozzle, for different slope angles of the air suction nozzle

Fig. 7 shows the relation between air to water flow rates and water pressure of the driving nozzle.

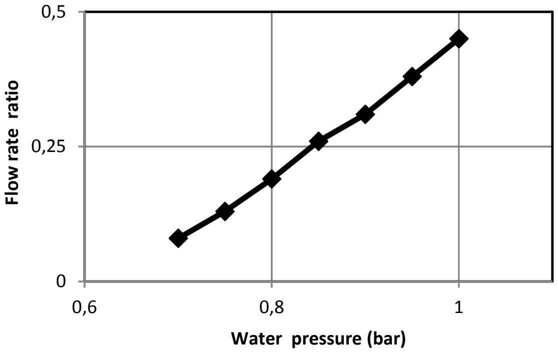


Fig. 7 Relation between air to water flow rates and water pressure

Prior to obtaining a quantitative answer for the influence of different parameters on the mean diameter of the bubbles, we used dimensional analysis to reduce these complex physical problems to their simplest forms. We used the main geometric and dynamic parameters that are representative of our system. The relationships between the dimensions and hydraulic characteristics are as shown in Table I.

TABLE I
DIMENSIONS OF PHYSICAL PARAMETERS

Symbol	Quantity	Dimensions
L	length of the tank	L
B	width of the tank	L
H	height of the tank	L
h	submergence of jet pump	L
q_a	discharge air	L^3T^{-1}
Q_W	discharge water	L^3T^{-1}
ρ	density of water	ML^{-3}
μ	viscosity of water	$ML^{-1}T^{-1}$
g	gravity	LT^{-2}
d_b	mean diameter of bubbles	L
K_La	mass transfer coefficient	T^{-1}
D_a	coefficient of molecular diffusion	L^2T^{-1}

Assuming that the mean diameter of bubbles depends on these geometric and dynamic parameters, the following expression can be written:

$$d_b = f(L, B, H, h, q_a, Q_W, \rho, \mu, g, K_La, D_a) \qquad (1)$$

We applied dimensional analysis to these variables to find a set of π- parameters. The following dimensionless complexes will be achieved:

$$\frac{d_b}{h} = R_e \cdot F_r \cdot Sh \cdot \left(\frac{q_a}{Q_W}\right) \cdot \left(\frac{B \cdot H}{L^2}\right) \qquad (2)$$

where: $R_e = \frac{Q \cdot \rho}{\mu \cdot L}$ - Reynolds number, $Fr = \frac{Q}{\sqrt{g \cdot L^5}}$ - Froude number, $Sh = \frac{K_La \cdot L^2}{D_a}$ - Sherwood number.

The (d_b/h) ratio in (2) represents the effect of the jet pump location in the tank as related to the bubble size. The ratio of (BH/L^2) represents the effect of shape and the tank geometry. The ratio of (q_a/Q_W) represents the flow rate gas – liquid ratio in the jet pump. Solutions of expression (2) show good agreement with the experimental results [7].

Fig. 8 demonstrates the effect of the flow rate ratio upon mean bubble diameter. The flow rate ratio is defined as the ratio of the flow rate of the air to the flow rate of the water. In this experiment we changed the flow rate of the air and maintained a constant flow rate of the water. We found that decreasing the flow rate ratio results in a decrease in the mean diameter of the air bubbles. The mean bubble diameter can be expressed as shown [8]:

$$d_{32} = \frac{\sum_{i=1}^{N} (N_i d_b^3)}{\sum_{i=1}^{N} (N_i d_b^2)} \tag{3}$$

where d_{32} is the mean bubble diameter, Ni is the number of bubbles of diameter d_b.

The flow rate ratio was changed by increasing the area of the throttle valve (7). Discharge of water in the jet pump was constant for each experiment. It can be seen from Fig. 8 that the bubble diameter is mainly concentrate in the 0.2 - 2.5 mm range.

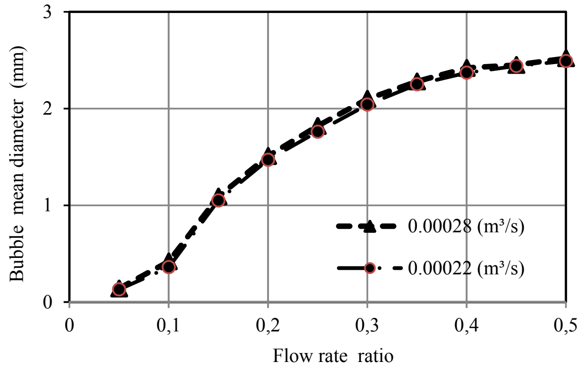


Fig. 8 Effect of change in flow rate ratio upon the mean bubble diameter

The bubble size has a significant changing trend based on the different gas-liquid flow rate ratios. The comparisons of the experimental data for different values of the water flow rate, shown in Fig. 8, illustrate the correlation. Note that only changes in the flow rate ratio were used to exert influence on the bubble size for this jet pump. Bubble size can be controlled by changing the gas discharge range, using the very simple throttle valve. In this study we also investigated the influence of the flow rate ratio on the retention time of bubbles in the water. Fig. 6 represents the flow rate ratio effect upon bubble retention time in the water. The retention time of gas bubbles as well as their size and distribution in the liquid are important parameters for various technological processes that employ aeration.

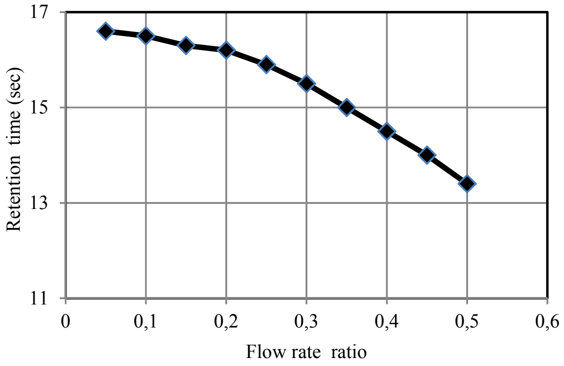


Fig. 9 Flow rate ratio effect upon the bubble retention time in the water

Obviously, smaller and more uniformly distributed bubbles with longer retention time result in oxygenation improvement.

IV. CONCLUSIONS

The results of experimental investigations of jet pumps situated in a tank are presented. The experiments were performed in a laboratory using different jet pumps. The influence of the flow rate ratio in the jet pump on the size of the air bubbles is discussed. This work demonstrates the possibility of using physical models to study very complicated effects in a jet pump, for creation of different sized air bubbles in the water, and their retention time.

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