Environmental Engineering and Management Journal February 2015, Vol.14, No. 2, 497-501
http://omicron.ch.tuiasi.ro/EEMJ/

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EXPERIMENTAL STUDY ON THE AERATION OXYGENATION INTO PRINTING AND DYEING WASTEWATER USING JET AERATOR

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Abstract

This study focused on the use of jet aeration to treat printing and dyeing wastewater. The related environmental factors influencing the dynamical efficiency of a jet aerator were investigated. Results showed that an ideal linear relation existed between dynamical efficiency and working pressure ($R^2 > 0.98$), with dynamical efficiency decreasing gradually as the working pressure increased. When the gas–liquid ratio was approximately 0.6:1 to 1.4:1, more bubbles were formed by the gas–liquid mixture in the jet aerator. Dynamical frequency increased steadily when gas–liquid was mixed uniformly and the injection depth was deeper than 6 m. The treatment performed with the hydraulic retention time (HRT) lasted 3 h, and the dissolved oxygen was maintained above 3 mg/L.

Key words: aeration oxygen-rich, environmental factors, jet aeration, textile wastewater

Received: January, 2013; Revised final: July, 2013; Accepted: August, 2013

1. Introduction

Aeration is an important step in sewage aerobic biochemical treatment. This step provides sufficient dissolved oxygen (DO) for reaction in the reactor, aside from maintaining the organism and the substrate, and keeping the adequate oxygen mixture (Thalasso et al., 1995). The energy consumption of aeration accounts for approximately 60% to 70% of the total consumption in wastewater treatment plants (WWTPs) (Flores-Cotera and García-Salas, 2005). Thus, a high dynamic efficiency of aerating equipment is essential in saving energy.

Conventional aerating equipment requires gas to pass through fixed gas pipelines and diffusion devices. Therefore, nozzles are prone to blocking and are costly to maintain. Mechanical aeration is conducted at the expense of considerable energy consumption. The manufacture of a mechanical aerator is also relatively complicated. Mechanical and conventional aerators have low efficiencies and oxygen utilization rates, long aerating time, difficult maintenance, and high infrastructure costs. By contrast, jet aeration is an advanced aerating technology with advantages such as high oxygen utilization ratio ranging from 15% to 30%, effective gas diffusion, high mass transfer coefficient, uniform DO and bubble mixture (Morchain et al., 2000), simple construction, and convenient maintenance (Havelka et al., 1997, 2000; Zahradník et al., 1997). Moreover, a properly installed jet aerator is suitable for treating highly concentrated industrial wastewater (Chedeville et al., 2007; Petruccioli et al., 2002).

The effects of working pressure, gas–liquid ratio, and working depth of the jet device on improving oxygen transfer power efficiency were comprehensively investigated with textile wastewater as the research object.

Based on the experimental results, a reasonable design and operation parameters were proposed to provide technical support for the engineering and operation of a jet aerator.

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2. Experimental

2.1. Experimental device

Fig. 1 shows the pilot device, which is a 4 m × 15 m × 9 m jet aerator. A small amount of activated sludge is found at the bottom. Synergistic nozzles (DN150×210) are installed based on the experimental requirements. The diameter of the branch tubes attached to the synergistic nozzles is 150 mm. Five branch pipes, arranged in a mutually staggered manner, are connected to each side of the main collection tube. The diameter of the main collection tube is 200 mm. The GW1200 jet aerator model has a flow rate of approximately 140 m^3/h to 480 m^3/h, inlet pressure of approximately 0.034 MPa to 0.482 MPa, and maximal inspiratory capacity of 1556 m^3/h under 0.016 MPa. The inlet is connected to the air-compressed pipe, and the tail pipe is connected to the gas–liquid mixing main tube. The working pump is a self-suction pump with a flow rate of 210 m^3/h. The pump head is 11 m with an 18.5 kW of power. A regulator, a pressure reducing valve, and a flow gauge are installed in the pump flow and air-compressed pipes. Pressure gauges are installed at both ends of the jet aerator.

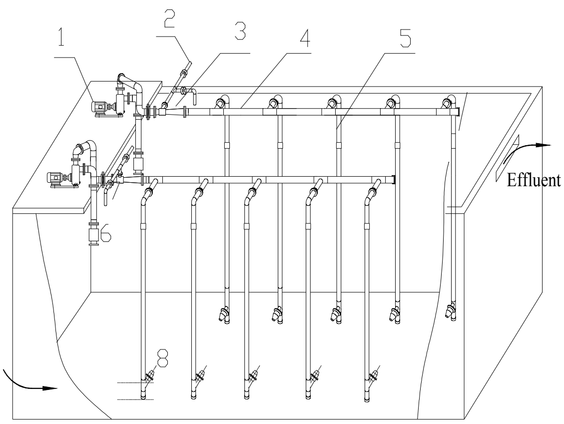

Fig. 1. Jet aeration oxygen-rich pilot test device for printing and dyeing wastewater treatment (1: self-suction pump; 2: air-compressed pipe; 3: jet aerator; 4: gas–liquid mixing main tube; 5: gas–liquid mixing branch tubes; 6: wastewater absorption mouth; 7: pressure reducing valve; and 8: efficient nozzle)

2.2. Experimental method

The experiment was conducted in a continuous feed mode. Effluent from the working pump passed through the nozzles of the jet device. The decreased diameter of the branch pipes resulted in high flow velocity. The high-speed flow passed through the inspiratory room into the throat pipes, forming a partial vacuum. After a large amount of air was drawn into the throat pipes using an air-compressed pipe (the pressure of the supplied gas was 0.016 MPa), the pressure from the water jet generated many small bubbles while the activated sludge was cut into tiny particles with full contact with air bubbles and with a large specific surface area. A mist-shaped gas–liquid mixture was released from the synergistic jet nozzle because of the second jet. The experiment was conducted in a textile WWTP in Nantong City, Jiangsu Province, China. Wastewater was first hydrolyzed, acidified, and stored in the jet aeration tank. The necessary parameter (i.e., DO) was recorded before measuring the oxygen transfer power efficiency of the jet device. Air jet aeration was compared with pure oxygen jet aeration.

2.3. Measurement

The measurements used were regular indices and bubble photographs with different gas–liquid ratios. The regular indices were pH and DO. DO was measured using a DO meter (YSI Pro20), and pH was determined using a pH Meter (-2 to 18 measurement range with uncertainty of less than 1%). Bubble photographs were scanned with an electron microscope (JSM 6390).

3. Results and discussion

3.1. Effect of working pressure on oxygen transfer power efficiency

Jet aerators are classified as either high-pressure or low-voltage types based on the pressure of the working medium. The working pressure and nozzle flow velocity of high-pressure and low-pressure jets are 0.2 MPa, 20 m/s and 0.07 MPa, 12 m/s, respectively. Energy consumption of the low-pressure type is one-third higher than the high-pressure type in theory. However, the actual energy consumption is less than the energy consumption in theory. The low-pressure jet was chosen in this experiment because of the abovementioned characteristics. A large working pressure means more water passed through the jet and more gas was inhaled. Considering the specific amount of oxygen demanded, the number of jets required was relatively few, and the cost of the equipment was low.

The effects of the working pressure at different depths on the oxygen transfer coefficient are shown in Fig. 2. The pressure of the supplied gas was 0.016 MPa, and the gas–liquid ratio was 0.6. Although the power of the pump increased as the working pressure increased, the dynamical efficiency decreased based on a linear relation. Correlations (R^2) with different water depths were 0.9971, 0.9903, and 0.9850. Increasing water depth under the same pump power increased the dynamical efficiency. At water depths of 3 m and 5 m, the down-slope trend of the dynamical efficiency was almost consistent. At a water depth of 7 m, the dynamical efficiency slightly increased by 0.3719 kgO_2/kWh compared with the measured value at 5 m depth. When the working pressure was 0.07 MPa and depth was 7 m, the oxygen transfer dynamical efficiency was 2.44 kgO_2/kWh.

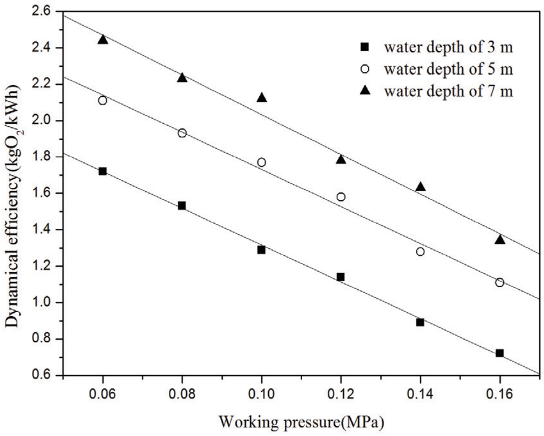

Fig. 2. Effect of the working pressure of the jet device on dynamical efficiency

3.2. Effect of the gas–liquid ratio on oxygen transfer dynamical efficiency

The use of bubble diffusion and hydraulic shear to achieve aeration and mixture differentiates a jet aeration device from mechanical aeration and bubble diffusion devices. The interaction between gas and liquid facilitates ejection, which forms a pulsed surface wave and causes the flow to drip liquid into the device interior (Gamisans et al., 2004; Kandakure et al., 2005; Little, 1995). This process facilitates the collision of compressed air and the formation of small bubbles (Fig. 3). Smaller bubbles mix more easily with liquid droplets to form a creamy mixture. Bubbles are compressed in the water after entering the diffusion tube.

The effects of different gas–liquid ratios on the dynamical efficiency of air jet aeration and pure oxygen aeration are shown in Figs. 4 and 5.

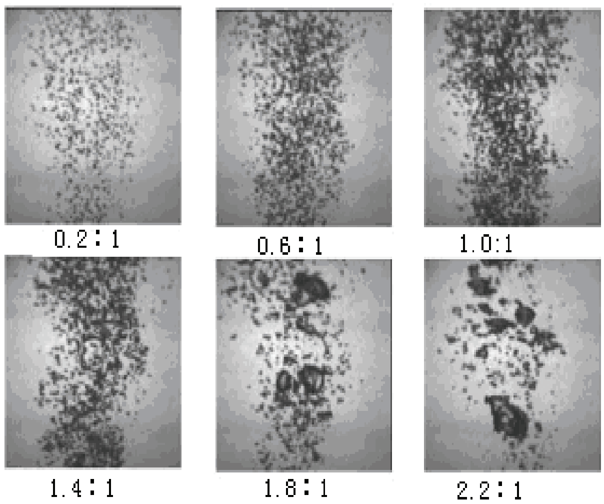

Fig. 3. Images of bubbles at different gas–liquid ratios

As shown in Fig. 3, the size and the degree to which small bubbles are mixed and formed by high-speed fluid droplets varied with different gas–liquid ratios (Qgas/Qliquid). Larger gas–liquid ratios resulted in larger particle sizes.

When the gas–liquid ratio was 0.2:1, particle size was at an extreme value, whereas the amount of bubbles in per unit area was at minimum.

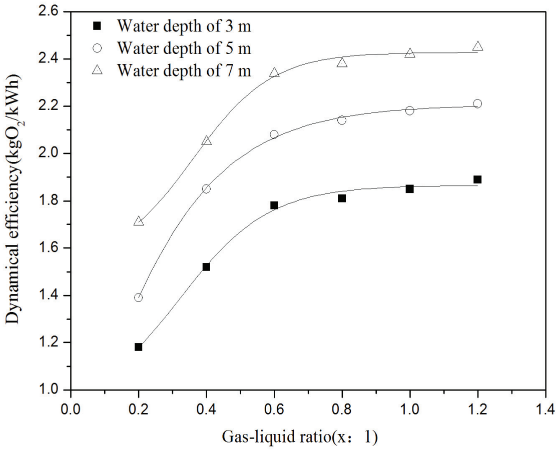

Fig. 4. Effect of different gas–liquid ratios on the dynamical efficiency of air jet aeration

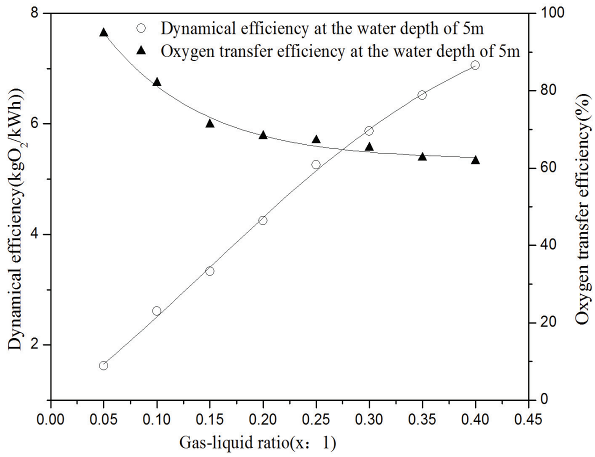

Fig. 5. Effect of different gas–liquid ratios on the dynamical efficiency of pure oxygen jet aeration

When the gas–liquid ratio was 1.8:1, the particle size was large and appeared as a speckle, which was in incomplete contact with the liquid. When the gas–liquid ratio was 1:1, the particle size was smaller, with a maximum number of bubbles in per unit area. When aeration with gas–liquid was 1:1, water, gas, and the organism completely contacted with each other.

Figs. 4 and 5 show that under the same working pressure, a larger gas–liquid ratio resulted in more gas per unit of water inhaled by the jet aerator and an increased dynamical efficiency. However, the oxygen transfer efficiency decreased despite air or pure oxygen aeration. At the water depth of 5 m and a gas–liquid ratio of 0.4:1, the dynamical efficiency of pure oxygen jet aeration was 7.06 kgO_2/kWh, which is far higher than the dynamical efficiency of air jet aeration (1.85 kgO_2/kWh). Dynamical efficiency increased as the ejection depth increased. When the gas–liquid ratio was higher than 0.6:1, the dynamical efficiency increased steadily, as shown in

Fig. 3. When the gas–liquid ratio was between 0.6:1 and 1.4:1, the amount of bubbles per unit area was almost stable.

3.3. Effect of the working depth on oxygen transfer dynamical efficiency

Synergistic nozzles were installed at different depths to examine the dynamical efficiency and the oxygen transfer efficiency at 0.088 MPa working pressure and 1:1 gas–liquid ratio. Results are shown in Fig. 6.

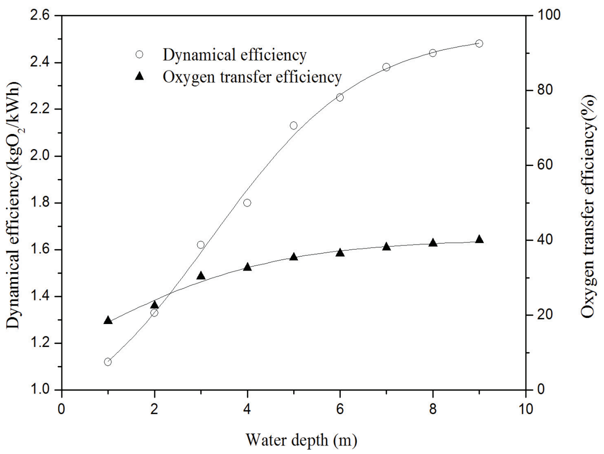

Fig. 6. Variation in the dynamical efficiency of air jet aeration at different water depths

Fig. 6 shows that as the water depth increased, the dynamical efficiency and the oxygen transfer efficiency curves of the jet aerator correspondingly increased. However, the dynamical efficiency increased more rapidly than the oxygen transfer efficiency, which became steadier after the water depth reached 5 m. This observation shows that the dynamical and oxygen transfer efficiencies of the jet aerator are related to the volume of aerated water. These parameters were stable under the surface area and were closely linked to water depth.

Based on the relationship between oxygen mass transfer coefficient K_{La} and the water depth of the aeration tank, results showed that a deeper water level resulted in a lower oxygen mass transfer coefficient. Thus, we conclude that at a deeper water level, the jet aerator is more useful, and its dynamical efficiency becomes higher.

3.4. Variations in DO over time

DO is a reflection of the treatment effect of jet aeration. At a working pressure of 0.088 MPa, water depth of 9 m, and gas–liquid ratio of 0.8:1, two selected aerators were used to treat 100 m^3 printing and dyeing wastewater. The average DO in the front-end of the aeration tank was 1.43 mg/L, and the verified range was from 1.02 mg/L to 4.2 mg/L.

The other DO peak was 2.96 mg/L, which was measured after installing the jet aerator. DO decreased rapidly afterwards. After 25 d, DO in the wastewater stabilized at approximately 1.21 mg/L. The DO average in the back-end of the aeration tank was 3.33 mg/L, and the verified range was from 0.99 mg/L to 5.08 mg/L. The peak was similar to the concentration in front-end of the aeration tank. The lowest concentration appeared after 2 d, when the DO in the front-end of the aeration tank was higher than that in the back-end. This condition could have been caused by the organism entering a logarithmic proliferation period during which a great deal of DO was consumed. After 18 d, the DO of the effluent exceeded 3 mg/L (Fig. 7).

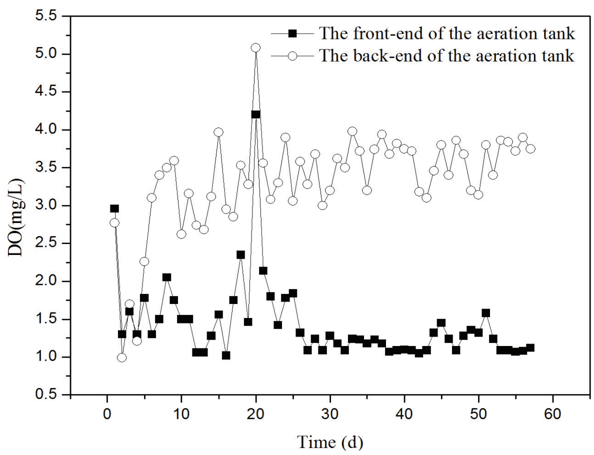

Fig. 7. Variations in DO over time

4. Conclusions

Dynamical efficiency of the jet aerator decreased as the working pressure increased. When the gas–liquid ratio was between 0.6 and 1.4, a greater amount of bubbles formed per unit area of the gas–liquid mixture in the jet aerator's interior. When the gas–liquid ratio was 1:1, the dynamical efficiency slowly increased as the gas–liquid ratio increased.

Oxygen utilization and dynamical efficiency increased with the jet aeration water depth.

Acknowledgements
This work was supported by the National Natural Science Funds (Grant No. 51208068).

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