การประเมินหัวจ่ายอากาศแบบดรายเดนเปรียบเทียบกับหัวจ่ายอากาศแบบละเอียดทั่วไป

EVALUATION OF DRYDEN AIR DIFFUSER COMPARING WITH CONVENTIONAL FINE BUBBLE DIFFUSERS

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Received: *May 24, 2018;* ***Revised:*** *September 21, 2018;* ***Accepted:*** *October 2, 2018*

บทคัดย่อ

ในการประเมินผลของอัตราการถ่ายเทออกซิเจนให้กับน้ำและค่าการสูญเสียแรงดันของหัวจ่ายอากาศแบบดรายเดนซึ่งทำจากผ้าโพลีโพรพีลีน ซึ่งได้ทำการวัดค่าและเปรียบเทียบกับหัวจ่ายอากาศแบบละเอียดทั่วไปที่ทำจากโพลียูรีเทน (PU) และเมมเบรนโพลีเอทีลีนที่มีความหนาแน่นสูง (HDPE) โดยอัตราการถ่ายเทออกซิเจนของหัวจ่ายอากาศแบบดรายเดนที่วัดได้ คือ 12.3% ด้วยอัตราการไหลของอากาศที่ 50 ลิตรต่อนาที ส่วนอัตราการถ่ายเทออกซิเจนของหัวจ่ายอากาศแบบละเอียดทั่วไป ได้แก่ หัวจ่ายอากาศแบบแผ่นพ่นอากาศขนาดเล็ก หัวจ่ายอากาศแบบแผ่นเมมเบรน และหัวจ่ายอากาศแบบรูจ่ายอากาศขนาดใหญ่ จะอยู่ที่ 9.8%, 8.1% และ 3.3% ตามลำดับ ด้วยอัตราการไหลของอากาศที่เท่ากัน อย่างไรก็ตาม ค่าการสูญเสียแรงดันของหัวจ่ายอากาศแบบดรายเดนนั้นสูงกว่าหัวจ่ายอากาศแบบละเอียดทั่วไป

คำสำคัญ: อัตราการถ่ายเทออกซิเจน หัวจ่ายอากาศ ฟองอากาศขนาดเล็ก แผ่นเมมเบรน

Abstract

Oxygen transfer rate (OTR) and pressure loss of Dryden air diffuser, which is made of polypropylene cloth, were measured and compared with conventional fine bubble diffusers made of polyurethane (PU) and high-density polyethylene (HDPE) membrane. OTR of Dryden diffuser were 12.3% at the air flow rate of 50 L/min. OTR of AEROSTRIP diffuser was 9.8%, Membrane diffuser was 8.1%, and A large hole diffuser was 3.3% at the similar air flow rate. However, the pressure loss of Dryden diffuser was higher than conventional membrane diffusers.

Keywords: Oxygen transfer rate, Air diffuser, Fine bubble, Membrane

Introduction

Aerobic treatment is one of the essential process of city sewage, industrial organic waste water and livestock agriculture sewage treatment [1]. Aeration is most popular method of aerobic treatment. There are various machines and equipment of aeration such as paddle wheel, surface aerator, submergible aerator, coarse or fine bubble diffusers and others. [2-3]

Fine bubble diffuser system is one of the most popular aeration methods. Fine bubble diffuser system is composed of an air blower and a diffuser. Blower compressed air is blown into waste water through a diffuser membrane with fine holes. Oxygen in the fine air bubble dissolves into the waste water. Aerobic microorganism decomposes biological organic ingredients in the waste water consuming the oxygen.

Rosso and Stenstrom [4] reported that 45-75% of plant energy is consumed by the aeration process. Of course, when the oxygen transfer rate (OTR) is high, air volume blown in water is less. As a result, higher the OTR, lesser electric power will be consumed to aeration. Therefore, oxygen transfer rate (OTR) from air bubble into water is main conscious of the function of diffusers.

Actual OTR is influenced by many factors such as water depth, altitude, temperature, total dissolved salt, amount and kind of surfactant and others [3, 5]. Then, OTR of a diffuser is evaluated using pure water [6].

Fine bubble diffuser is mostly made of membrane such as high-density polyethylene (HDPE) and polyurethane (PU). Silicone is also used for high temperature applications. HDPE membrane diffuser is most popular.

Dryden diffuser [7] is the product of Dryden AQUA Ltd. in Scotland. It is very different from conventional membrane diffusers, for example, the figure is like a hose and the hose is flexible. Conventional membrane diffusers are usually connected to a solid pipe which is anchored to the bottom of a pond. On the other hand, Dryden diffuser is just put on the pond bottom connected to flexible hose without fixing the pond bottom. In this sense, Dryden diffuser is expected to be suitable for rather large lagoon which is popular in Thailand and other south-east countries.

The catalogue of Dryden diffuser says that OTR of Dryden diffuser is good. However, the catalogue describes the OTR data at the condition of 50% oxygen saturation and the method of measurement is not opened in the catalogue. Generally, measurement of OTR start at 0% oxygen concentration water. Therefore, OTR data of Dryden diffuser can’t be compared with other diffusers.

The objective of this experiment is to measure the OTR of Dryden diffuser in the same method and conditions and compare the OTR with other conventional diffusers.

Objectives

1. OTR of Dryden diffuser is measured at the same method together with several conventional diffusers such as AEROSTRIP, membrane diffuser and simple large hole, to compare the OTR.

2. Pressure loss of all samples is also measured in the experiment, because the pressure loss is proportional to the energy consumption of blower.

Methods

Samples

Samples used for the experiment are shown in Figure 1.

Dryden diffuser [7] in Figure 1(A) has round rod like shape and the outer surface is a cloth made of polypropylene fibers. Glass beads is filled inside the cloth tube as a heavy stone. AEROSTRIP [8] in Figure 1(B) is a square shape diffuser made of polyurethane film. Round fine bubble diffuser [9-10] in Figure 1(C) is one of the most popular diffusers made of EPDM film. The stand in Figure 1(D) is the foundation to fix the round diffuser. It has only one hole with diameter of 20 mm.

Main characteristics of samples are shown in Table 1.

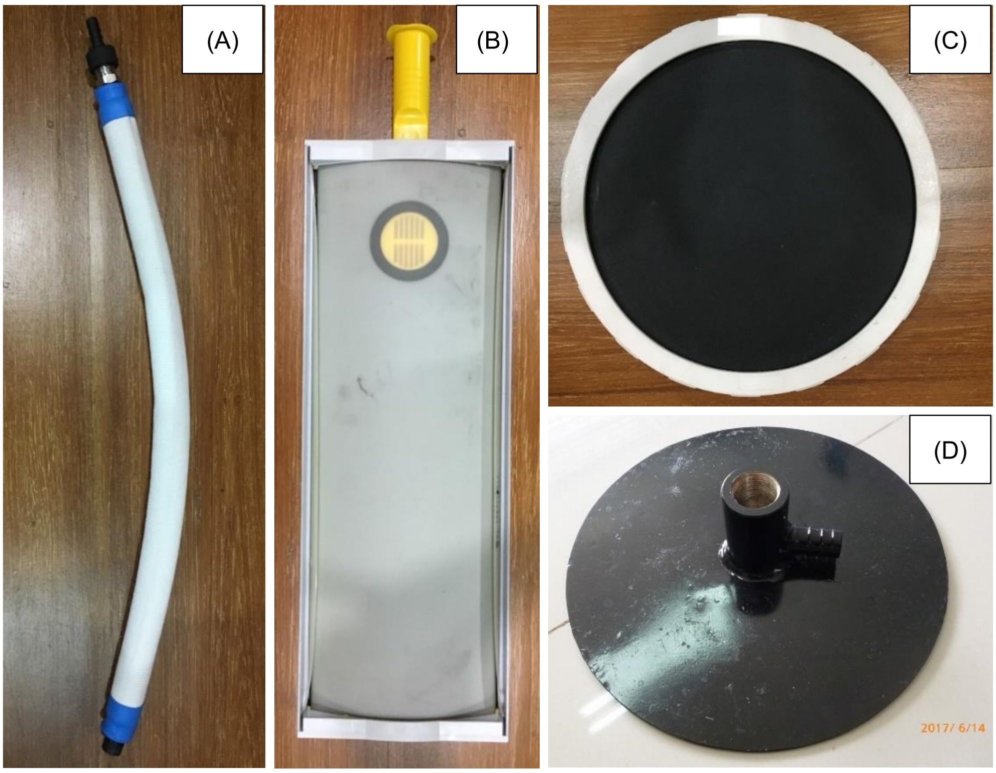

Figure 1. Samples used for the experiment; (A) Dryden diffuser; (B) AEROSTRIP; (C) Membrane; (D) A large hole.

Table 1 Main characteristics of specimens.

Sample	Membrane	Dimension (mm)	Effective surface area (cm^2)	Number of holes (pc/cm^2)
Dryden diffuser	Cloth (PP)	Ø32 × L1,000	669	80
AEROSTRIP	Polyurethane	W18 × L500	845	42.5
Membrane	EPDM	Ø322	634	15.3
A large hole	–	Ø20	3.1	1

Dimension is the outer size. Effective surface area is the area of membrane. Number of holes of AEROSTRIP and round diffuser were counted by naked eye for 4 times and averaged. The catalogue of AEROSTRIP [8] says that the number of holes is 400,000 pcs/m^2. It is similar with our observation. The holes are cut in the plastic sheets.

Dryden diffuser is made of cloth of PP yarns. Each yarn is composed of more than 100 fine single fibers and has around the diameter of 1mm. The cloth is woven with 4 weft yarns and 10 warp yarns. The intersection of the warp yarns looks like a hole. The number of hole was observed using 15 times loupe.

Experimental apparatus

Specifications of each part are shown in Table 2.

The apparatus for the experiments is shown in Figure 2.

Table 2 Name and specifications of part.

Name of part	Specification
Water tank	Diameter: 1.1 m, Height: 2.0 m
Blower	HIBLOW HP200, Max Air Flow 280 L/min
Flow meter	KOFLOC RK2000
Pressure meter	NKS 0–0.1 MPa
Pump	EUM–1200, Max 300 L/min
DO meter	HANNA HI9146

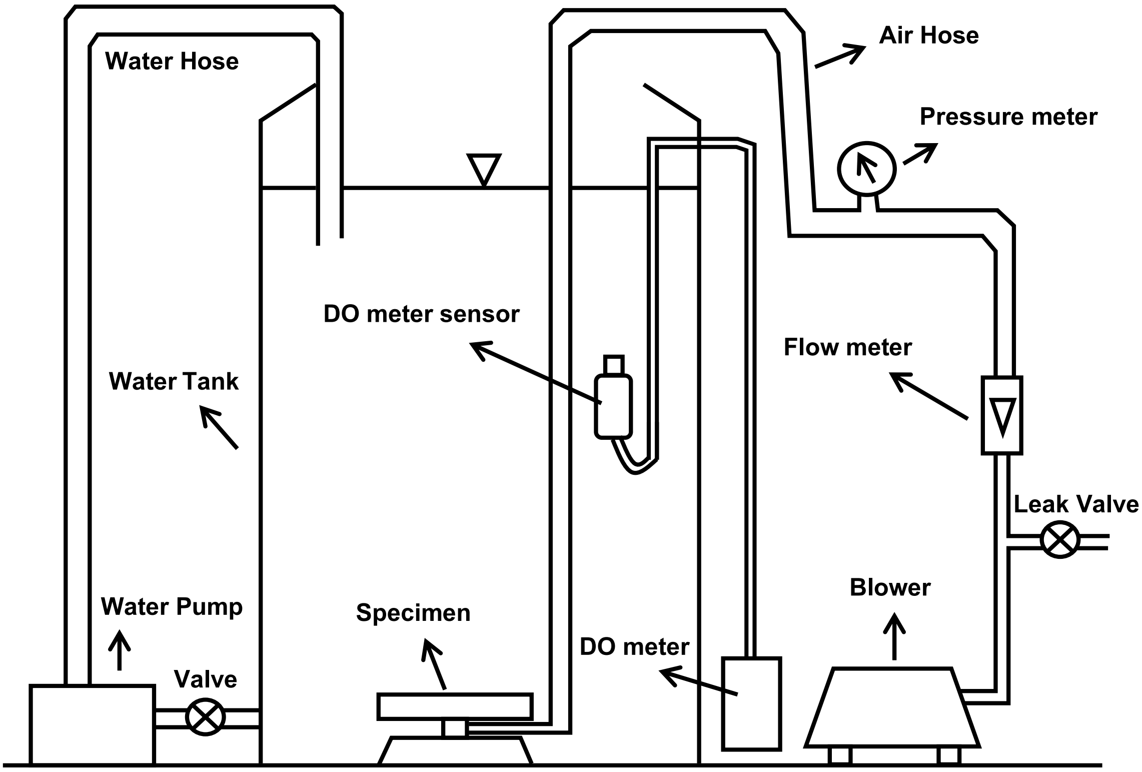

Figure 2. The schematic diagram of experiment apparatus.

Experimental procedure

Experimental conditions are basically in a similar way written in the reference paper [11].

Tap water is filled to the water tank until 1.85 m. DO meter is set at about 1m from the bottom and near the wall of the tank. The sensor part of DO meter (Figure 3) is set as shown in Figure 2, so that the tip of sensor faces upward. When sensor tip faces downward, DO value fluctuates seriously because a floating up air bubble stick under the sensor film at the sensor tip.

The DO value of tap water was around 6 mg/L. Na_2SO_3 was used to make DO zero with the help of $CoCl_26H_2O$ as a catalyst to make Na_2SO_3 easily dissolve in water. When Na_2SO_3 is added to water, it reacts with oxygen in water and to Na_2SO_4. The added amount of $CoCl_26H_2O$ was 4 g to 1 m^3 water. Amount of Na_2SO_3 depends on the DO value of water. The amount is 7.88 g/m^3 × DO value of water × volume of water.

Figure 3 Sensor of DO meter (Polarographic Dissolved Oxygen Probe).

$CoCl_26H_2O$ and Na_2SO_3 are put in a small bucket with water and mixed well until both chemicals dissolve perfectly. Then the water was poured in the water tank. Water pump was ON until DO value reaches to nearly zero.

Amount of air was controlled changing the opening of the by–pass valve.

DO value with time is recorded manually. Amount of air flow, pressure and water temperature were also recorded.

OTR analysis

Oxygen transfer from gas bubble to water is modeled as shown in Equation 1 [6][11]:

$$\frac{dC}{dt} = KLa\left(Cs\text{-}Ct\right) \tag{1}$$

Where K_{La} is overall oxygen transfer coefficient, Cs is saturated oxygen concentration (mg/L), and Ct is oxygen concentration at time t (mg/L)

Then, K_La is calculated from the experimental data as shown in Equation 2:

$$KLa = \left(\frac{1}{t2\text{-}t1}\right) ln \left(\frac{Cs\text{-}Ct1}{Cs\text{-}Ct2}\right) \tag{2}$$

Where Ct_1 is oxygen concentration at time t_1 (mg/L) and Ct_2 is oxygen concentration at time t_2 (mg/L)

Oxygen transfer rate (%) is calculated as shown in Equation 3:

$$OTR = \left(\frac{Cs\times KLa\times V\times 10^{-3}}{Q\times 0.27}\right)\times 100 \tag{3}$$

Where V is volume of water in the tank (m^3), Q is volume of air blown in water (m^3/h), and 0.27 is weight of oxygen in 1 m^3 air at 30ºC (kg/m^3-air).

Ordinary, OTR and other factors are normalized to 20ºC. However, the air temperature and waste water temperature are around 30ºC in Thailand. The water temperature in this experiment was in the range of 27.9–28.8ºC. Therefore, the weight of oxygen in 1 m^3 air was regarded as 0.27 kg/m^3–air.

Results

Dissolved oxygen (DO) as a function of time are shown in Figure 4 for 4 specimens at the air flow rate of about 50 L/min. The air flow rate was set controlling the leak valve in Figure 2 manually. As shown in the Figure 4, DO of Dryden diffuser increased quickly, on the other hand DO of hole increased slowly even the similar air flow.

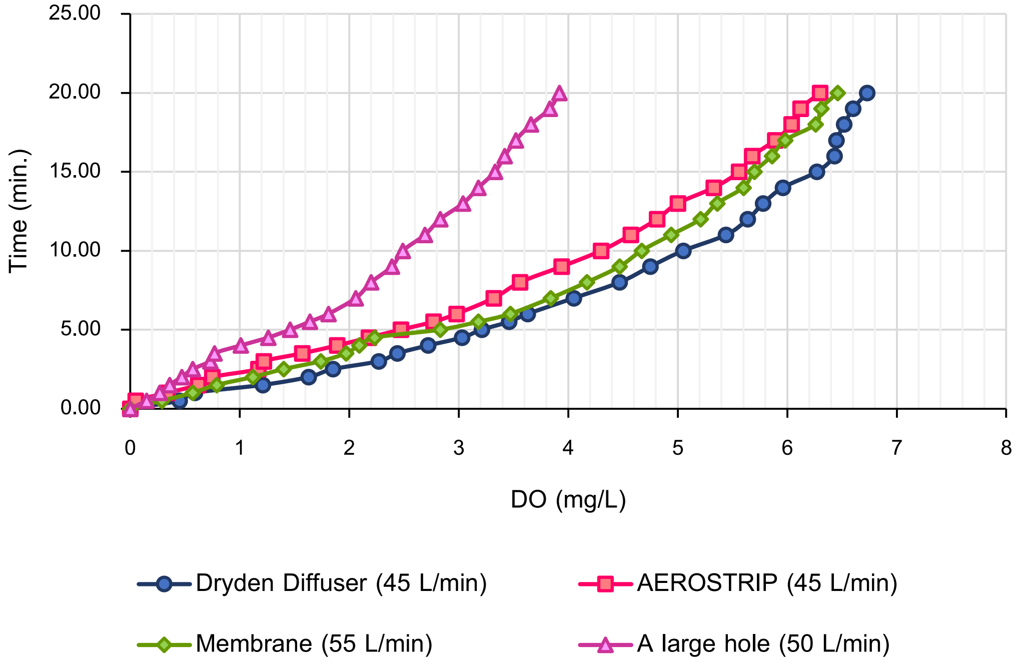

Figure 4. The relation between DO and time for 4 specimens.

Oxygen transforms from the surface of air bubble to water. When air bubble diameter is small, total surface area of air bubble per same amount of air is large. As a result, DO increment speed of smaller air bubble diffuser will be faster than larger air bubble diffuser. The air bubble was observed using a water tank of transparent wall. Though the bubble diameter couldn't be measured quantitatively, bubble size from Dryden diffuser was smaller than other diffusers qualitatively when observed it with naked eye. Air from a large hole is not bubble, but the air flow looks white. Air flow might break to many air flows. Considering DO vs time curve of Figure 4, the air flow from a large hole does not have so large surface area. It is assumed that larger the number of holes, smaller the size of bubble. The total hole number of 3 samples are calculated from membrane surface area and number of holes shown in Table 1. The total numbers of holes in Dryden diffuser, AEROSTRIP and round membrane are 53,500 pcs, 35,900 pcs and 9,700 pcs, respectively.

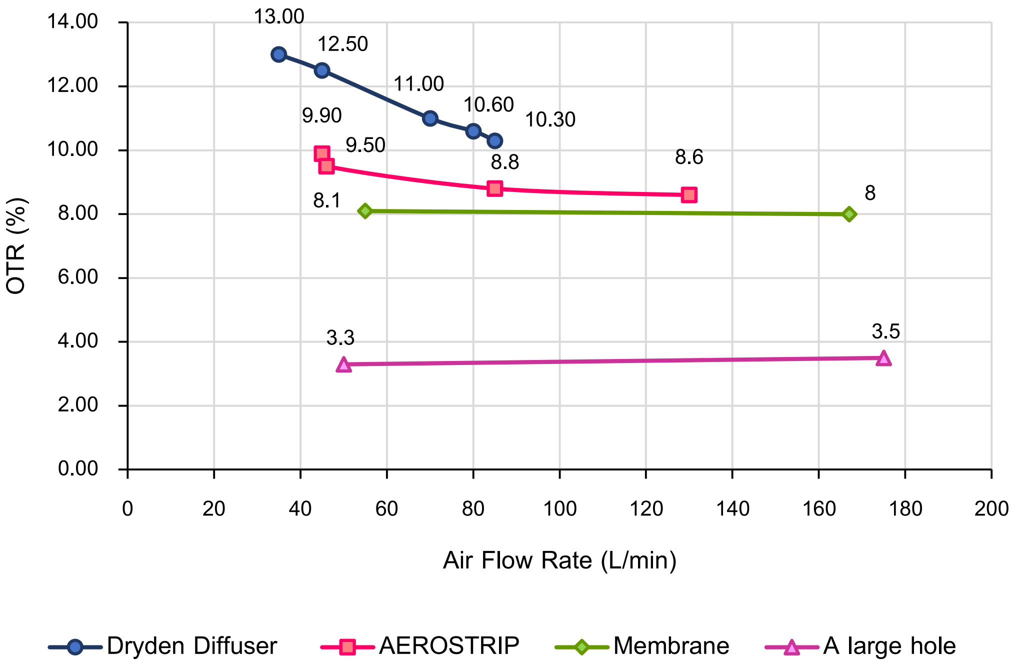

Figure 5. The relation between OTR and air flow rate for 4 specimens.

Oxygen transformation rate (OTR) calculated from DO vs time curve are shown in Figure 5. OTR of Dryden diffuser is larger than other 2 membranes. OTR of 3 diffusers decrease with increasing the amount of air as shown in Figure 5. The tendency is same with many published catalogue data and a summary report [10]. The reason of the tendency is explained that when the air amount increase, the size of air bubble increase. As a result, the specific surface area of air bubble decrease [11].

OTR of AEROSTRIP is suggested to be 16–17% at 2 m in the catalogue [8]. It is roughly 14.8–15.7% at 1.85 m. The value is a little higher than the value of 9.9% in this experiment.

The OTR of 7 kinds diffusers in Japan is reported as 20–25% at water depth of 5 m [11]. The influence of water depth (H) on the value of OTR is suggested as shown in Equation 4 [12].

$$OTR_{(H)} = OTR_{(5)} \times \left(\frac{H}{5}\right)^{0.72} \tag{4}$$

Calculating according to Equation 4, 20–25% at 5 m is 9.6–12% at 1.85 m in this experiment. Then, OTR of 2 membrane diffusers in this experiment are similar with the value in the reference [12].

OTR at the similar air flow of 50 L/min is 12.3% (Dryden diffuser), 9.8% (AEROSTRIP) and 8.1% (Membrane). Then the ratio of OTR when OTR of AEROSTRIP is regarded as 1.0 is 1.2, 1.0 and 0.8. On the other hand, the total number of holes ratio is 1.5, 1.0 and 0.27. Obviously, the tendency is qualitatively true, but quantitatively not good. One reason will be come from heterogeneity of holes. It was observed that some bubble is small, but some bubble is large. Second reason will be joining of bubbles just after separated from the membrane surface. As a result, the bubble size immediately changes to large size.

Then, the more the number of holes in a certain area, OTR will be high. However, the diameter of bubbles is not consistent. As a result, OTR will in proportion to the hole density only qualitatively.

OTR of a large hole was almost same for the air amount 50 L/min and 175 L/min. It is reported that the OTR vs air flow rate of coarse diffuser such as hole in this experiment show slightly reverse trend with those of fine diffuser. That is, when air flow rate increase, OTR also increase [10]. The reason is assumed that when air flow rate high, air disturbance caused by collision of air and water increase. In this experiment, the difference of air amount might not be so much to show clear increase of OTR at 175 L/min.

A measured pressure loss of the pressure meter is the sum of water pressure and pressure loss of diffuser. The pressure loss of diffuser is shown in Figure 6. As seen in the figure, Dryden diffuser has rather high pressure-loss comparing with other two diffusers. The hole doesn’t have detectable loss by the pressure meter.

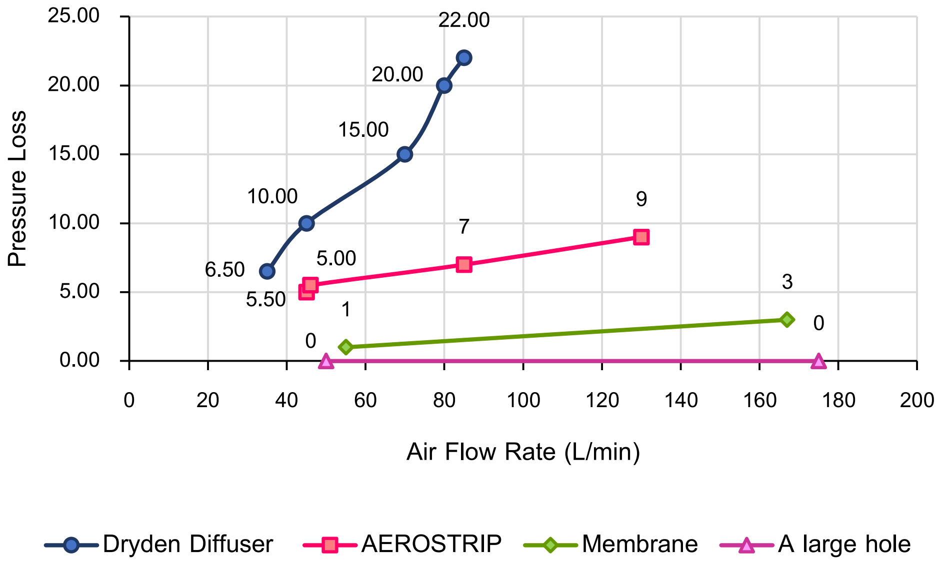

Figure 6. The relation between pressure loss and air flow rate for 4 specimens.

The pressure loss affects the power consumption of air blower. The energy efficiency of diffuser is evaluated by kg–O_2/kWh. Kg–O_2 is the amount of oxygen absorbed to water. The efficiency is calculated for water depth of 1.85 m in this experiment as shown in Table 3.

Energy efficiency of Dryden diffuser is higher than other 2 diffusers when the air flow rate is 50 L/min. On the other hand, the efficiency becomes lower when air flow rate is 100 L/min. The reason comes from the high pressure-loss as seen in Figure 6.

Dryden diffuser has large OTR, however pressure loss is higher than other 2 diffusers, especially at higher air flow rate. Then, Dryden diffuser has merit for the usage condition of lower air flow rate per diffuser. Technical date of Dryden diffuser recommends that the standard air flow rate for 1m length diffuser (product article 70002) is 3 m^3/h (±20%), which is 50 L/min. The specification is reasonable from this experimental result.

Table 3 The energy efficiency of 3 diffusers and a large hole.

Sample	OTR (%)		Kg-O_2 (kg–O_2/h) #1		Electric power (kW/(m^3/min)) #2		Energy efficiency#4 (kg–O_2/kWh)	
	50 L/min	100 L/min	50 L/min	100 L/min	50 L/min	100 L/min	50 L/min	100 L/min
Dryden diffuser	12.3	10#3	2.0	1.6#3	0.72	1.18	2.8	1.4
AEROSTRIP	9.8	9.0	1.6	1.5	0.62	0.67	2.6	2.2
Membrane	8.1	8.0	1.3	1.3	0.50	0.53	2.6	2.5
A large hole	3.3	3.3	0.5	0.5	0.48	0.48	1.1	1.1

#1 = Oxygen in air of 1 m^3/min at 30ºC is 60 × (32/22.4) × 0.21 × (273/303) = 16.2 kg–O^2/h. When OTR is 12.3%, practical dissolved oxygen is calculated as 16.2 × 0.123 = 1.99.

#2 = from the catalogue [13]

#3 = estimated value from asymptote of the data in Fig. 5 and Fig. 6

#4 = #1/#2

In this experiment, only one EPDM diffuser was tested comparing with Dryden diffuser. Fine bubble diffuser made of EPDM is very popular in the world. Mr. Homma reported the OTR of 3 EPDM diffusers, 3 polyurethane diffusers and one ceramic diffuser made in Japan [11]. In Thailand there are many different manufacturer's diffuser in market. The catalogue data of OTR and pressure loss are sometimes not exact. Therefore, measuring OTR and pressure loss of several diffusers with same method and condition is useful for comparing and selecting a good diffuser in market. The experiment to know the properties and effect of hole density will be planned.

Conclusions and Discussion

Dryden diffuser made of cloth, AEROSTRP made of polyurethane film, a round fine bubble diffuser made of EPDM and a large hole were tested using water tank with diameter of 1.1 m and height 2 m.

1. Oxygen transformation rate (OTR) were 12.3%, 9.8%, 8.1% and 3.3%, respectively at the air flow rate of 50 L/min. The OTR of the four diffusers are quantitatively in proportion to the number of holes per unit area.

2. Pressure loss of Dryden diffuser was higher than other three diffusers and it increased with the amount of air volume. As a result, energy efficiency of 2.8 kg–O_2/kWh was best in the four diffusers at a low air flow rate of 50 L/min. On the other hand, energy efficiency decreased to 1.4 kg–O_2/kWh with

increasing air flow rate to 100 L/min, which were lower than other three diffusers, due to its high pressure loss.

Acknowledgements

Thanks to Shigetaka Wada for supporting the costs of this research.

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