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A Biogas Desulphurization System with Water Scrubbing

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Abstract

The biogas is renewable energy with very good potential. It is a gas produced by the bacteria transformation of the organic substance under the anaerobic condition. It is a flammable gas because it contains the hydrogen sulfide (H_2S) in its composition. It will cause damage to metal equipment and the corrosion of the pipe. So before using the biogas, the desulphurization process should be carried on. The purpose of this study was to design a water scrubbing system for biogas and carry on the performance test of the desulphurization process in the hog farm. In the field test, the biogas flow rate is changed in the water scrubbing cylinder and under different external circulation water flow rate. The H_2S concentration in the biogas is detected before and after water scrubbing, and the desulphurization efficiency of biogas was discussed, furthermore, the pH value of water in the water storage tank was measured. When the H_2S adsorbed by water was at steady state, whether the pH value of external circulation water can meet the effluent standard was discussed. From the test results, it showed that the removal efficiency of H_2S was 47.7% in 30 minutes of water scrubbing time under 120 ℓ of total water amount, 80 cm of water level in the water scrubbing cylinder, 20 ℓ/min of internal circulation water flow rate and 10 ℓ/min of external circulation water flow rate, and 25 ℓ/min of biogas flow rate. The pH value of water in the water storage tank was 6.22, which met the effluent standard of regulation for discharging directly. This system can reduce the H_2S content in the biogas, and purify the quality of the biogas. The operation of this system is convenient and the fabrication cost is low, which is suitable for the small-scale hog farm to purify the biogas.

Keywords: biogas, water scrubbing, hydrogen sulfide, pH, desulphurization

1. Introduction

The biogas is considered as renewable energy with very good potential. It is a gas produced by the bacteria transformation of the organic substance under the anaerobic condition. It is a flammable gas, which contains 50-75% of methane (CH_4), 25-45% of carbon dioxide (CO_2), 0-20,000ppm of hydrogen sulfide (H_2S), and small amount of gases such as nitrogen (N_2), oxygen (O_2), hydrogen (H_2), and ammonia (NH_3) [1]. The production sources of biogas are much extensive, including animal droppings, wastewater, and rubbish landfill, etc. [2]. It can be applied in house fuel, warm-keeping light, generator, electric car, and warm-keeping facilities in the pigsty of hog farm, etc. [3].

The H_2S in the biogas is a gas having stink odor and toxicity. It has a very strong corrosive property to some metals. It will cause damage to machinery equipment. Therefore, the use of biogas as the fuel will be limited. Before using the biogas as the fuel, the H_2S must be removed [4]. The H_2S in the biogas can be removed through the physical, chemical and biological methods, such as the absorption, adsorption, and bio-reaction. The H_2S and CO_2 in the biogas are the acidic gases. They will be acidified after H_2S and CO_2 are adsorbed in the water [5-7]. The water scrubbing of biogas is a physical purification method. The solubility in water for various gases in the biogas is different. The methane gas is much more difficult to be dissolved in the

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water. This property is used to remove H_2S and CO_2 by water scrubbing, in order to increase the methane purity in the biogas [8-9]. When selecting the scrubbing column as water scrubbing purification equipment, the desulfurization performance would depend on the scrubber size and design, gas pressure, composition of raw biogas, water flow velocity and water purity. Water scrubbing as adsorbent mainly had the low cost and the easy operation, as well as easily increased the contact area and time of gas and liquid to accomplish the continuous purification [10].

The purpose of this study was to design a water scrubbing system for biogas and carry on the performance test of the desulphurization process in the hog farm. The test was carried under different biogas flow rate in the water scrubbing cylinder and external circulation water flow rate, the H_2S concentration in the biogas was detected before and after water scrubbing, and the desulphurization efficiency of biogas using water scrubbing was discussed, furthermore the pH value of water in the water storage tank was measured. When the H_2S adsorbed by water was at steady state, whether the pH value of external circulation water can meet the effluent standard was discussed. This system can reduce the H_2S content in the biogas, and purify the quality of the biogas.

2. Materials and Method

2.1. Design of water scrubbing and desulphurization system

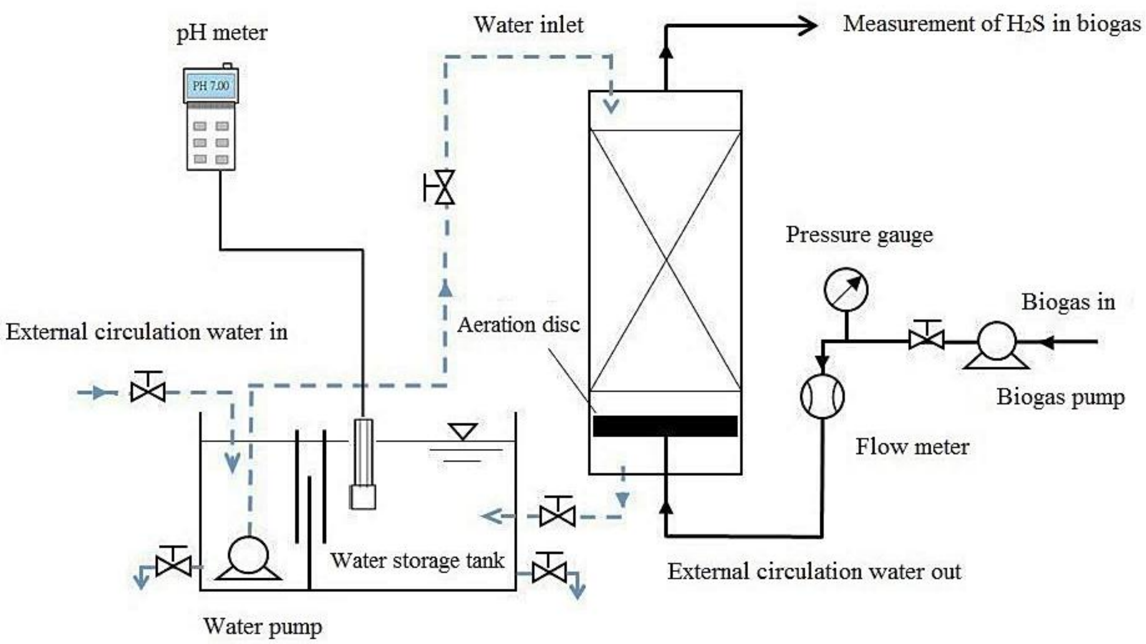

Fig. 1 Illustration of water scrubbing and desulphurization system for biogas

The water scrubbing and desulphurization system for biogas is illustrated in Fig. 1. The water scrubbing cylinder with 0.003 m thickness made by transparent acrylic is 0.25 m in diameter and 1.20 m in height. It is the main body of water scrubbing and desulphurization system, which is used to observe the internal biogas bubbles and the reaction situation in the water scrubbing cylinder. There are an internal circulation water inlet and an outlet for measurement of H_2S in biogas after water scrubbing and desulphurization at the top of the water scrubbing cylinder. There are water outlet and aeration disc at the bottom of water scrubbing cylinder. The aeration disc with 0.23 m in diameter is placed at the bottom of water scrubbing cylinder. There is a biogas inlet under aeration disc. A biogas pump is used to pressurize the biogas. A pressure gauge is used to measure the pressure of biogas flowing into the water scrubbing cylinder. The biogas flow rate is measured by a float type gas flowmeter (F20-100NLPM, LORRIC®, Taiwan). The biogas enters the water scrubbing cylinder through the bottom of the aeration disc. Because there are a lot of holes on the surface of aeration disc, the biogas will enter into the water scrubbing cylinder in a way of many small bubbles, so that the biogas bubbles will contact with water sufficiently for reacting.

The internal circulation water and external circulation water are used for the field test. At the internal water circulation, the water pump is used to pump the circulation water into the water scrubbing cylinder from the top of water scrubbing cylinder, so that the biogas bubbles will contact with water sufficiently for reacting that increase solubility in water, in order to remove the H_2S in biogas, and flow back to the water storage tank from the water outlet at the bottom of water scrubbing cylinder. At water external circulation, the external circulation water without adsorbing H_2S flows into the water storage tank to upgrade the inner circulation water. The water absorbing H_2S is discharged from the water storage tank. The biogas after water scrubbing and desulphurization is discharged from the outlet at the top of the water scrubbing cylinder. The H_2S detecting device (120-SM, Kitagawa, Japan) is used to measure the H_2S concentration versus water scrubbing time, in order to calculate the removal H_2S efficiency of water scrubbing and desulphurization. At the same time, the pH meter (TS100, SUNTEX, Taiwan) is used to measure and record the variation of pH value for the water in the water storage tank during water scrubbing and desulphurization process.

2.2. Performance test of water scrubbing and desulphurization system

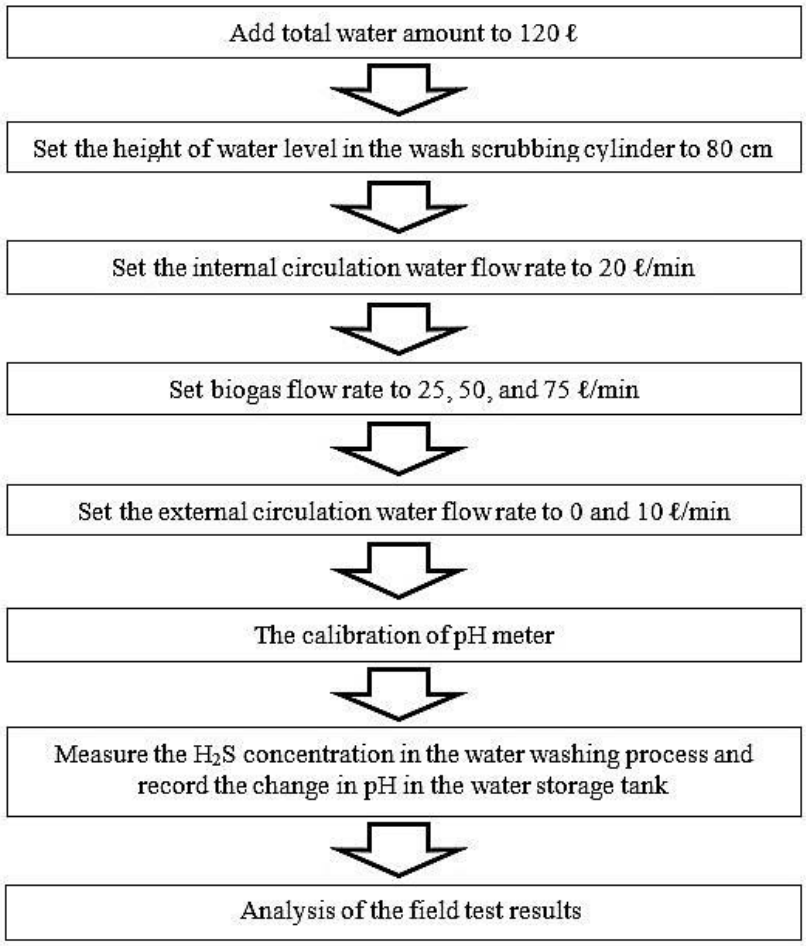

Fig. 2 The test flow diagram of water scrubbing and desulphurization system for biogas

After the assembly of this water scrubbing and desulphurization system is finished, it is moved to the hog farm to carry on the field test. The biogas used for the test is the swine wastewater treated through the three-step system and produced from the anaerobic fermentation process. Before the field test, the total water amount is 120 ℓ in the water storage tank and the acrylic water scrubbing cylinder, the height of water level in the water scrubbing cylinder is 80 cm, and the flow rate of internal circulation water is 20 ℓ/min. The biogas flow rate is changed to 25, 50, and 75 ℓ/min and the external circulation water flow rate is changed to 0 and 10 ℓ/min for carrying on the field test. Before the field test, the two-point standard buffer pH 4 and pH 7 were used to calibrate the slope of the electrode for pH meter, and the set time interval was recorded once per minute for pH value. Every test time for water scrubbing is 30 minutes.

Before starting the field test, the detecting device is used to measure the H_2S concentration in biogas without water scrubbing and desulphurization. Measure and record the H_2S concentration in biogas and the variation of pH value for the water in the water storage tank during water scrubbing and desulphurization process. Fig. 2 shows the test flow diagram of water scrubbing and desulphurization system for biogas. The removal efficiency of H_2S in the biogas is shown in Eq. (1).

$$\mathit{The\ removal\ efficiency}(\%) = [(A - B)/A]100 \tag{1}$$

where A is the H_2S concentration (ppm) before water scrubbing of biogas and B is the H_2S concentration (ppm) after water scrubbing of biogas.

3. Result and Discussion

3.1. Variation of removal H_2S efficiency

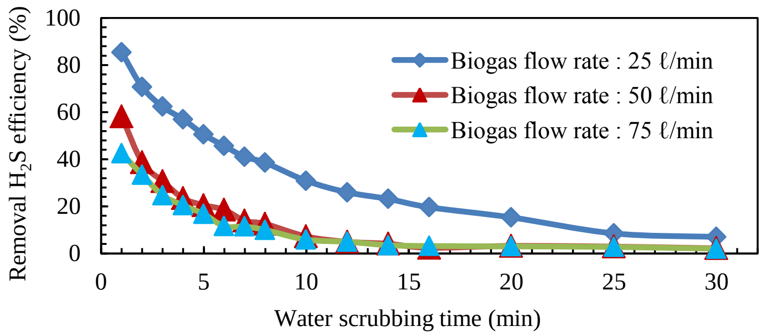

Fig. 3 The removal of H2S efficiency versus water scrubbing time for different biogas flow rate under 0 ℓ/min of external circulation water flow rate

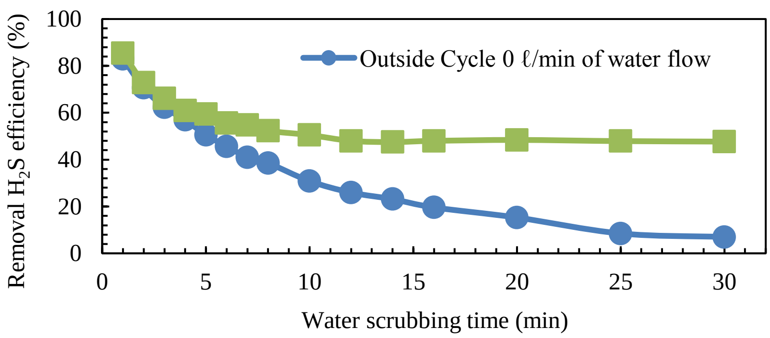

Fig. 4 The removal H2S efficiency versus water scrubbing time for 0 and 10 ℓ/min of external circulation water flow rate under 25 ℓ/min of biogas flow rate

During the performance test of this system, the total water amount is 120 ℓ, the height of water level in the water scrubbing cylinder is 80 cm, and the flow rate of internal circulation water is 20 ℓ/min. Under the external circulation water flow rate is 0 ℓ/min, and the removal of H_2S efficiency versus water scrubbing time for the different biogas flow rate is measured and recorded, as shown in Fig. 3. From the Figure, it is shown that the removal of H_2S efficiency is decreased with the increase of water scrubbing time. Under 50 and 75 l/min of biogas flow rate, at 12 minutes of water scrubbing time, the removal H_2S efficiency is dropped to 4.9% rapidly. After 12 minutes of water scrubbing time, the H_2S adsorbed by water has already been closed to the saturated condition, and there is almost no removal H_2S efficiency. Under 25 l/min of biogas flow rate, at 12 minutes of water scrubbing time, the removal H_2S efficiency is dropped to about 24.9%. At 30 minutes of water scrubbing time, the removal of H_2S efficiency is dropped to below 7.0%. The water in the water scrubbing cylinder and water storage tank is not discharged by the external circulation water flow. The H_2S content in water is increased with the increase of water scrubbing time and reached to the saturated condition finally. Under 25 ℓ/min of biogas flow rate, the removal H_2S

efficiency versus water scrubbing time for 0 and 10 ℓ/min of external circulation water flow rate is shown in Fig. 4. When the external circulation water flow rate is 10 ℓ/min, the H_2S adsorbed in water will not reach the saturated condition after 12 minutes. The removal of H_2S efficiency is kept at a steady value. The external circulation water without adsorbed H_2S is added to replace the old water adsorbed H_2S can increase the desulphurization effect.

Fig. 5 illustrates the removal of H_2S efficiency versus water scrubbing time for different biogas flow rate under 10 ℓ/min of external circulation water flow rate. 10 minutes before water scrubbing time, the removal of H_2S efficiency is decreased with the increase of water scrubbing time under 25, 50, and 75 ℓ/min of biogas flow rate. 10 minutes after water scrubbing time, the variation of removal H_2S efficiency is not large. When the water scrubbing time is 30 minutes, the removal H_2S efficiency is kept at a constant value respectively under 25, 50, and 75 ℓ/min of biogas flow rate. The removal of H_2S efficiency is decreased with the increase of biogas flow rate. From the test results, it is known that when the external circulation water flow rate is increased to 10 ℓ/min, the H_2S concentration in water will not reach the saturated condition, and the desulphurization rate will be kept at a certain level steadily.

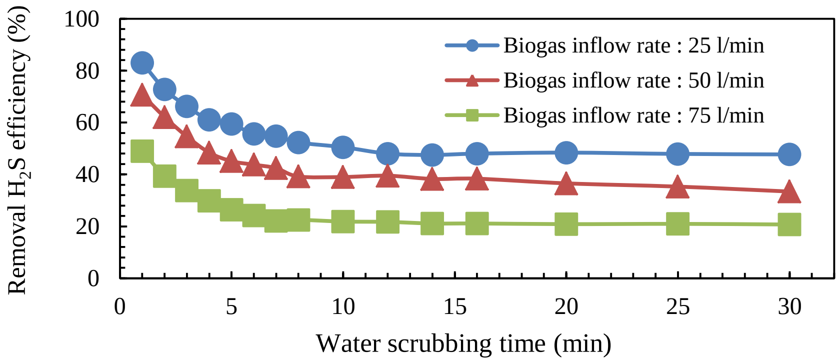

Fig. 5 The removal H2S efficiency versus water scrubbing time for different biogas flow rate under 10 ℓ/min of external circulation water flow rate

Table 1 shows the removal of H_2S efficiency versus water scrubbing time for different biogas flow rate under 0 and 10 ℓ/min of external circulation water flow rate and 30 min of water scrubbing time. Under 0 ℓ/min of external circulation water flow rate and 30 min of water scrubbing time, the removal H_2S efficiency at 25, 50, and 75 ℓ/min of biogas flow rate is 7.0%, 2.1%, and 2.0% respectively, nearly reach the saturated condition. Under 10 ℓ/min of external circulation water flow rate and 30 min of water scrubbing time, the removal H_2S efficiency at 25, 50, and 75 ℓ/min of biogas flow rate is 47.7%, 33.4%, and 20.7% respectively. It can be seen the removal H_2S efficiency in biogas upgrades as the external circulation water flow increases, and steadily remain in a certain one without saturation; this is because the water in the water storage tank is continuously changed so that the removal H_2S efficiency can steadily remain after certain water scrubbing time. It is also known that the removal of H_2S efficiency is decreased with the increase of biogas flow rate.

Table 1 The removal H_2S efficiency for different biogas flow rate under 0 and 10 ℓ/min of external circulation water flow rate and 30 min of water scrubbing time

	External circulation water flow (ℓ/min)					
	10			0		
Biogas flow (ℓ/min)	25	50	75	25	50	75
Trial[1]	3	3	3	3	3	3
Concentration of H_2S (ppm)	5230	7990	9950	11770	12170	12120
The removal efficiency (%)	47.7±0.3	33.4±0.1	20.7±0.9	7.0±0.7	2.1±0.6	2.0±0.1

[1] The total water amount is 120 ℓ of, the height of water level in the water scrubbing cylinder is 80 cm and the internal circulation water flow rate is 20 ℓ/min

3.2. Variation of pH value in the water storage tank

Fig. 6 show that the pH value in water storage tank versus water scrubbing time for 0 ℓ/min and 10 ℓ/min external circulation water flow rate under 25 ℓ/min of biogas flow rate. The pH value in the water storage tank decreases with the increase of the washing time before 10 minutes of the water scrubbing time. The pH value in the water storage tank tends to be saturated after 10 minutes of the water scrubbing time, it can be seen that the pH value in water storage tank of the external circulating water flow 0 ℓ/min after 10 min of water scrubbing time is lower than the pH value in water storage tank of the external circulating water flow 10 ℓ/min. Fig. 7 illustrates the pH value in water storage tank versus water scrubbing time for different biogas flow rate under 10 ℓ/min of external circulation water flow rate. The pH value in water storage tank for the different biogas flow rate is decreased with the increase of water scrubbing time. 10 minutes before water scrubbing time, the pH value in the water storage tank is decreased with the increase of water scrubbing time under 25, 50, and 75 ℓ/min of biogas flow rate. 10 minutes after water scrubbing time, the variation of pH value in water storage tank saturates to a certain value, which is also similar to the variation of removal H_2S efficiency versus water scrubbing time.

Table 2 shows the pH value in the water storage tank versus water scrubbing time under 10 ℓ/min of external circulation water flow rate and 30 min of water scrubbing time. Under 30 minutes of water scrubbing time, the pH value in water storage tank for 25, 50, and 75 ℓ/min of biogas flow rate is dropped to 6.22, 6.22, and 6.24 respectively. According to the effluent standard of wastewater specified in government regulation for Taiwan, the pH value of the effluent standard is 6.00-9.00. The pH value of field test result does not exceed the effluent standard, and the water can be discharged directly without special wastewater treatment [11].

Table 2 The pH value in the water storage tank at different biogas flow rate under 10 ℓ/min of external circulation water flow rate and 30 min of water scrubbing time

Biogas inflow (*l*/min)	25	50	75
Trial[1]	3	3	3
pH in 0 min	7.15	7.19	7.15
pH in 30 min	6.22±0.01	6.22±0.03	6.24±0.01

[1] The total water amount is 120 ℓ of, the height of water level in the water scrubbing cylinder is 80 cm and the internal circulation water flow rate is 20 ℓ/min

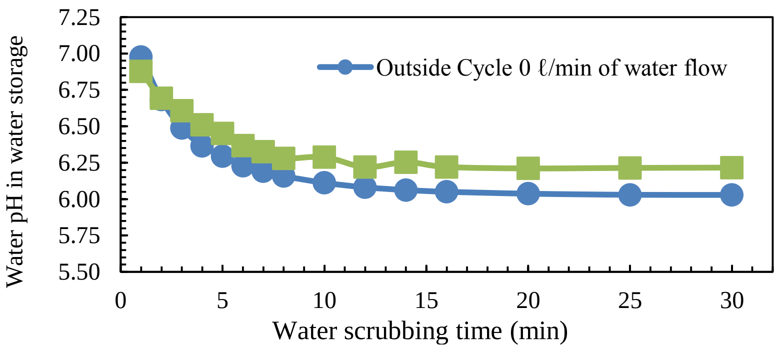

Fig. 6 The pH value in water storage tank versus water scrubbing time for 0 ℓ/min and 10 ℓ/min external circulation water flow rate under 25 ℓ/min of biogas flow rate

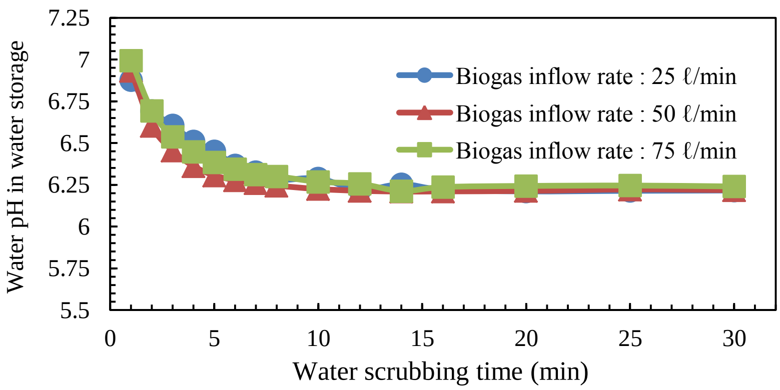

Fig. 7 The pH value in water storage tank versus water scrubbing time for different biogas flow rate under 10 ℓ/min of external circulation water flow rate

4. Result and Discussion

A water scrubbing and desulphurization system were designed and the performance test of the desulphurization process was carried on in the hog farm. 10 minutes before water scrubbing time, the removal of H_2S efficiency is decreased with the increase of water scrubbing time under 25, 50, and 75 ℓ/min of biogas flow rate at 120 ℓ of total water amount, 80 cm of water level, 20 ℓ/min of internal circulation water flow rate and 10 ℓ/min of external circulation water flow rate. 10 minutes after water scrubbing time, the removal H_2S efficiency was kept at a constant value under three different biogas flow rates. Under 25 ℓ/min of biogas flow rate, the removal H_2S efficiency was 47.7% in 30 minutes of water scrubbing time, and the pH value in the water storage tank was 6.22 in 30 minutes of water scrubbing time, which met the effluent standard of regulation and can be discharged directly. As for this water scrubbing and desulphurization system, was often used as a pre-treatment equipment for heating water of biogas combustion, the operation is convenient and the fabrication cost is low, which is suitable for the small-scale hog farm to purify the biogas.

Conflicts of Interest

The authors declare no conflict of interest.

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