Advances in Technology Innovation, vol. 3, no. 2, 2018, pp. 86 - 93

Piglets Comfort with Hot Water by Biogas Combustion under Controllable Ventilation

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Received 05 June 2017; received in revised form 23 August 2017; accepted 13 September 2017

Abstract

The purpose of this study is to develop a hot-water heating system for pig farms which use biogas as the energy source while the air quality is regulated using an inverter-controlled fan. The biogas is a by-product from the 3-stage wastewater treatment process in regular pig farms. The biogas is burned for hot water which is circulated to warm piglet compartments with regulated, forced ventilation. The hot water is connected to a heat exchanger and hot air is hence blown into the pigsty. To maintain the pigsty at a comfort atmosphere, ventilation is regulated using an inverter-controlled fan. The mechanical ventilation is to be optimized as a compromise between indoor air quality and ventilation rate. The temperature uniformity and air quality in the pigsty is to be secured for comfortability. Experimental results show that hot water circulating at 0.043 m^3/min and 60°C could keep the pigsty at 28°C for a stocking density of 1.77 pig/m^2. Forced ventilation of 1.7 ACH (air change rate per hour) at 28°C could keep the pigsty comfort in terms of indoor temperature, relative humidity, and carbon-dioxide concentration.

Keywords: biogas, piglets, hot-water heating system, force ventilation

1. Introduction

Biogas is the combustible gas generated through the microorganism fermentation of organic waste under the anaerobic environment. It is one of the renewable energy to replace the requirement of future energy resource, the generated volume will be affected along with the factors of solid ingredients, fermented temperature, humidity, pH value, microbial strains and fermentation time of fermented organic matter so that the compositions are not exactly the same. The main constituent of biogas is methane (CH_4) which is around 55-70%, carbon dioxide (CO_2) approximately 30-40%, 0.2-05% of hydrogen sulfide (H_2S), and very small amounts of carbon monoxide, nitrogen and ammonia etc. Direct emission of methane in the atmosphere will cause the global greenhouse effect growing in intensity, and the capability of causing the greenhouse effect per unit of methane is 23 times of carbon dioxide, its harm to the earth environment for direct emission of biogas cannot be ignored indeed [1-4].

The process of 3-stage wastewater treatment facility promoted in the pig farms of Taiwan includes the three stages of solid-liquid separation of excreta, anaerobic treatment and aerobic treatment, and large amount of biogas is generated during the anaerobic process, however most of pig husbandry in Taiwan does not utilize the biogas but emits to the atmosphere directly. As pointed out from the research, the methane content as generated from pig sewage is higher than what is generated from the waste of crop farm, each hog sewage with the weight of 60 kg is able to generate approximately 0.23 m^3 biogas per

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day. Biogas has high heating value and the fuel characteristics as well, it has been considered as the energy resource worth to promote and utilize, after biogas is burned, methane becomes the carbon dioxide which is able to lower the greenhouse effect, if the heat energy generated from the burned biogas is able to utilize, it may save significant energy, therefore, through the utilization of biogas energy, the requirement of energy saving and carbon reduction can be achieved synchronously [5].

Piglet will be weaned about four weeks after birth, the piglet just off from the weaning is very sensitive to the temperature in pigsty, if the daily temperature in pigsty drop is over 2℃, it will introduce the group diarrhea and respiratory diseases, and significantly affect the growth performance for piglet. Therefore, the temperature control in pigsty is one of the key factors for enhancing the production performance and economic benefit of pig farms [6]. The ventilation of pigsty can be categorized as the natural ventilation and forced ventilation (mechanical ventilation). The main purpose of ventilation is to supply the oxygen required for the animal breathing, remove the excess heat and moisture, plus reduce the dust and limit the generation of harmful gases, such as ammonia and carbon dioxide etc. As pointed from the research, the staffs of livestock farm shall not expose to the environmental with the concentration of carbon dioxide (CO_2) over 1500 ppm and concentration of ammonia (NH_3) over 7 ppm, the effective ventilation system shall be able to provide the best microclimate condition for the working area of pig farmers and animal living area [7-8]. The design of heat preservation facility for piglets in Netherlands is to use the hot air from underground tunnels exchanged heat through the hot-water pipes to heat and preserve the heat for the piglet living area [9].

The purpose of this research is to develop a set of hot-water heating system using biogas as the fuel, and take the advantage of biogas energy generated from the 3-stage wastewater treatment process and apply it to pig farms for the heat preservation of piglets. Utilize the burning of biogas and heating the water, delivered to the pigsty via pipeline, the hot-water flow blowers to blow the hot air through the air heater and exchanges heat in the pigsty to proceed the heating preservation for piglets, the pigsty collocates with the inverter fan to proceed the mechanical ventilation test with different forced ventilation temperature and regular ventilation percentage, and explore against the temperature uniformity and air quality in the pigsty.

2. Material & Method

2.1. Experimental equipment

The biogas generated from the pen manure of pig farms through the anaerobic fermentation process treatment, use the pipeline delivered/centralized to store in the red mud rubber bags, since the biogas contains the hydrogen sulfide which is corrosive to the metal equipment, use the blower to draw the biogas with the averagely negative pressure of 0.2 MPa through the biogas purification device to remove the hydrogen sulfide in the biogas, and then deliver to the biogas burning furnace as the source of burning energy. The schematic image of biogas burning hot-water piglet heat preservation system is shown in the Fig. 1. The implementation of biogas burning hot-water heat preservation system can be categorized as the biogas hot-water heating device, enclosed pigsty heat preservation system and inverter fan control system. The biogas hot-water heating device includes the biogas-burning furnace, electrical auxiliary heating device and hot-water storage tank. Inside the main body of biogas-burning furnace is able to store approximately 0.7 m^3 water, and 52 pcs of stainless steel pipes are installed as the passage for hot air, when the biogas furnace is burned/heated from the bottom, the heated area will be able to increase via the hot air passed through the hot air passage, so that the heating efficiency is enhanced and the temperature of hot-water increases rapidly, while an electrical auxiliary heating device is added to deal with the situation of insufficient biogas volume, and the temperature sensor of hot-water is installed to measure the hot-water temperature (T_w), so that the heating device is able to operate year-round.

When the thermocouple temperature of air (Tc) in the enclosed pigsty is lower than the default temperature (T_{set}), the piglet heat preservation system starts the external circulation, deliver the hot-water through the inverter motor and enter into the circulation-type blower in the pigsty to proceed the heat exchange, heat up the air inside the pigsty by blowing the hot air in order to achieve the effect of temperature control and heat preservation in the pigsty. Since the pigsty is an enclosed space, the ventilation system is required to ventilate and change air in order to avoid the high concentration of noxious gas in the pig sty, this research uses the inverter fan control system to perform the ventilation and air change of pigsty, the inverter fan system consists of 2 inverter fans with the ventilation efficiency of 0.64 m^3/s (SLF-730, Autofan, Korea) collocating with the inverter control system (ECS-3M, Varifan, USA), plus integrates the default temperature (T_w) and the defaulted setting of air temperature in the pigsty (T_{set}) together with the low limit air temperature setting function.

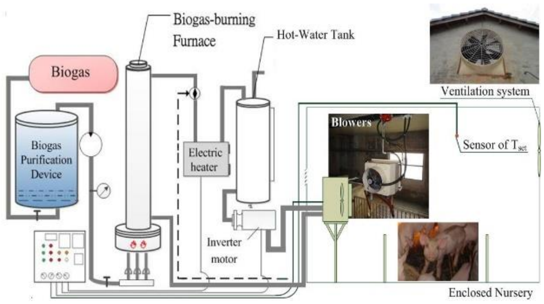


Fig. 1 Schematic image of biogas burning hot-water piglet heat preservation system

*2.2. Experimental meth*ods

PLEASE LOCATE FIG. 2. UNDER THE TEXT

This research uses temperature/humidity sensing recorder (U10-003, HOBO-Onset, USA) and carbon dioxide sensing recorder (attach with temperature/humidity sensing, Telaire 7001, Telaire, USA) to measure the air temperature, humidity and concentration of carbon dioxide in the pigsty. Their planned locations are shown in the Fig. 2. Temperature/humidity sensing recorders are located left front (LF), left rear (LR), right front (RF) and right rear (RR) separately, their height from the raising bedding is 80 cm, the height from the raising bedding is 25 cm for rear front down (RFD) and right rear down (RRD), the carbon dioxide sensing recorder is erected at the central location of pigsty, the height from the raising bedding is 90 cm, it is able to measure the central air temperature (T_M), central relative humidity (RH_M) and concentration of carbon dioxide (CO_2) of central location in the pigsty simultaneously, both temperature/humidity sensing recorders and carbon dioxide sensing recorder are configured to record the data once every 30 seconds.

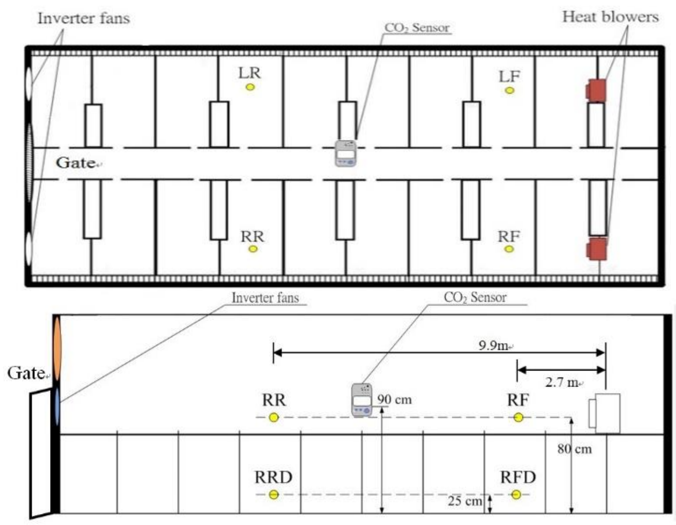


Fig. 2 Schematic image of temperature/humidity sensing recorders and carbon dioxide sensor location in enclosed pigsty

The stocking density of piglets in the pigsty is 1.77 pig/m^2, it is assumed that the pigsty is fully enclosed and the air amount flowed into the pigsty (Q_{in}) is equal to the air amount flowed out from the pigsty (Q_{out}), while define the air change rate per hour (ACH) in the enclosed pigsty is the times that the outside air amount of pigsty to replace the equivalent amount of volume space in the pigsty, its calculation formula is shown as eq. (1).

$$ACH = Q_v / V \quad (1)$$

In which, ACH: air change rate in pigsty (time/hr), Q_v: air amount flowed into pigsty from outside of pigsty per hour (m^3/hr), V: total volume of enclosed pigsty is 287.28 m^3, when perform the ventilation and air change at the regular ventilation percentage of 10%, 20% and 30%, after conversion, its ventilation and air change rate is 1.7 ACH, 3.4 ACH and 5.1 ACH separately.

The hot-water temperature (T_w) configured at experiment is 60˚C, hot-water flow rate is 0.043 m^3/min and the default temperature in the pigsty (T_{set}) is 28˚C, and collocate with the inverter fan control system to perform the ventilation and air change to maintain the air quality. As to the setting part of forced ventilation temperature, when the inside air temperature of pigsty is higher than the forced ventilation temperature, then start the inverter fan, continue to operate with the bleed air rate of 1.27 m^3/s until the thermocouple temperature in the pigsty (T_c) consistent with the forced ventilation temperature, and the stop. As to the setting part of regular ventilation percentage, the ventilation and air change cycle is once per 10 minutes, if the configured ventilation percentage is 10%, the inverter fan operates 1 minute and then stops for 9 minutes, if the configured ventilation percentage is 30%, the inverter fan operates 3 minutes and then stops for 7 minutes.

The calculation method of temperature uniformity (T_u) is to take the air temperature of different measuring location to subtract the air temperature of central location (T_M) separately, then select the average value of two maximum air temperature difference, this average value is the temperature uniformity, shown as eq. (2).

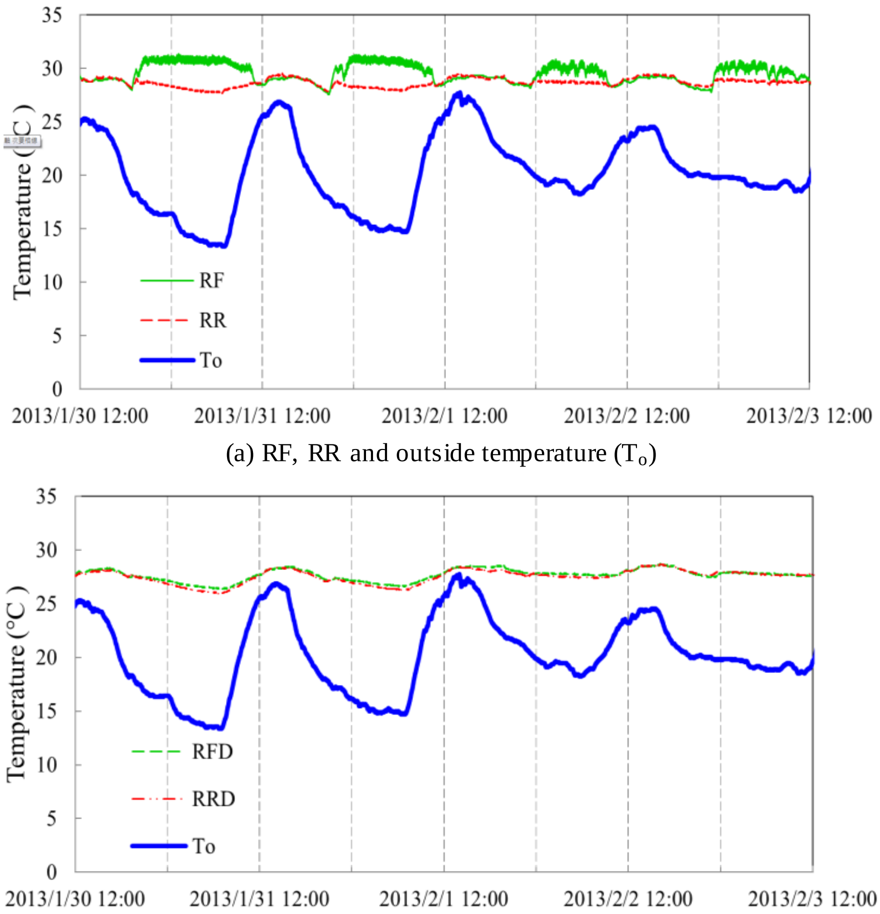
$$T_u = (TD_1+TD_2)/2 \quad (2)$$

In which, TD_1: largest air temperature difference between different measuring location and central location (˚C), TD_2: second largest air temperature difference between different measuring location and central location (˚C).

This research performs the ventilation and air change of enclosed pigsty by using the biogas burning hot-water heat preservation system collocated with the inverter fan, and performs the experiment in the pigsty with stocking density of 1.77 pig/m^2, measures the air temperature, humidity and concentration of carbon dioxide at different location in the pigsty, the forced ventilation temperature configured by the inverter fan is 28˚C, and changes the air change rate of ventilation to 1.7 ACH, 3.4 ACH and 5.1 ACH separately, from the calculated temperature uniformity, explore if the air temperature distribution in the pigsty is uniform or not, and illustrates if the air quality is suitable or not by the concentration of carbon dioxide in the pigsty.

3. Results & Discussion

When the forced ventilation temperature is 28˚C and air change rate of regular ventilation is 3.4 ACH, the typical diagram of time variation of the right front (RF), right rear (RR) and right front down (RFD), right rear down (RRD) temperature in the pigsty versus the outside temperature of pigsty (T_0) for 4 consecutive days is shown as Fig. 3, it can be seen from Fig. 3a, the outside temperature fluctuation of T_0 is more obvious in the day and night. The temperature of right front is slightly greater than temperature of right rear in the night which indicates that the pigsty has greater impact by the hot air blown from the air heater. However, on the whole, the temperature change of RF and RR is not much, it indicates that the overall temperature change in the pigsty is quite stable. The temperature change of RFD and RRD can be considered as the temperature change of activity range for piglets, therefore, it can be seen from Fig. 3b, the temperature variation curves of RFD and RRD nearly overlap which indicates that the temperature change of activity range for the piglets in the overall pigsty is quite consistent.



(a) RF, RR and outside temperature (T_o)

(b) RFD, RRD and outside temperature (T_o)

Fig. 3. Typical diagram of RF, RR, RFD and RRD versus outside temperature of pigsty (T_0) for 4 consecutive days under 28˚C for forced ventilation temperature and 3.4 ACH for Regular Ventilation

Under the condition of 28˚C for the forced ventilation temperature and 3.4 ACH for the air change rate of regular ventilation, the typical diagram of time variation of the right front (RF), right rear (RR), left front (LF) and left rear (LR) temperature in the pigsty for 4 consecutive days is shown as Fig. 4, it can be seen from the figure, the temperature change of right front (RF) and left front (LF), right rear (RR) and left rear (LR) nearly overlap which indicates that the temperature change of left and right sides on the pigsty is quite consistent.

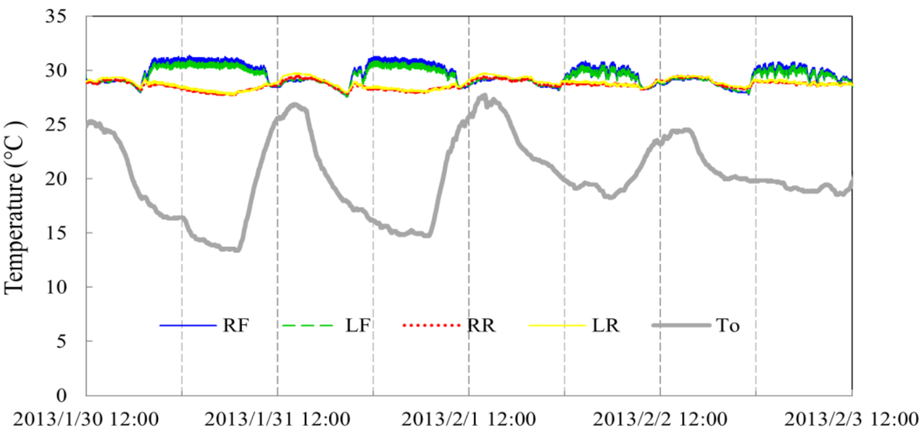


Fig. 4 Typical diagram of RF, RR, RR and LR versus outside temperature of pigsty (T_0) for 4 consecutive days under 28˚C for forced ventilation temperature and 3.4 ACH for regular ventilation.

Under the condition of 28˚C for the forced ventilation temperature, the statistic table of temperature and relative humidity for the right front (RF), right rear (RR), left front (LF), left rear (LR), right front down (RFD) and right rear down (RRD) to the different air change rate of regular ventilation is shown as Table 1. It can be seen that the temperature of each location in the pigsty is quite close to the defaulted temperature of 28˚C in the pigsty which indicates that the temperature change in the overall pigsty is quite uniform and stable, however, the temperature of RFD and RRD is slightly lower than 28˚C, its temperature difference is only 0.29˚C ~1.39˚C approximately. It can also be seen that since the location of RR and LR are more close to the inverter fan, RR and LR has higher relative humidity as relative to RF and LF, however, the relative humidity of piglet growth area (RFD, RRD) does not change along with the air change rate of regular ventilation i.e. maintains between 80%-89%.

Table 1 Under 28˚C for the forced ventilation temperature, at the different air change rate of regular ventilation, the statistic table of temperature and relative humidity for its right front (RF), right rear (RR), left front (LF), left rear (LR), right front down (RFD) and right rear down (RRD)

Temperature (℃)	Air change rate per hour (ACH)			Relative humility (%)	Air change rate per hour (ACH)		
	1.7 ACH	3.4 ACH	5.1 ACH		1.7 ACH	3.4 ACH	5.1 ACH
RF	30.17±0.86[*1]	29.57±0.84	30.09±0.74	RF	66.76±9.69	75.71±9.21	65.37±7.37
RR	28.29±0.39	28.71±0.40	28.24±0.28	RR	77.05±6.30	81.67±6.02	77.23±4.57
LF	29.93±0.73	29.44±0.71	-[*2]	LF	69.26±9.05	77.91±8.74	-[*2]
LR	28.32±0.44	28.82±0.43	28.02±0.30	LR	84.96±8.92	86.37±2.77	83.40±2.05
RFD	27.03±0.52	27.71±0.53	27.12±0.43	RFD	87.41±3.74	89.29±4.57	84.91±2.79
RRD	26.61±0.73	27.59±0.62	26.89±0.50	RRD	81.83±4.72	83.79±4.28	80.02±3.42

[*1]: mean ± std [*2]: Lost data due to bit off by the piglets.

Under the condition of 28˚C for the forced ventilation temperature and 3.4 ACH for the regular ventilation, the typical diagram of central temperature (T_M), concentration of carbon dioxide in the pigsty and outside temperature of pigsty (T_o) is shown as Fig. 5. It can be seen from the figure, the central temperature (T_M) does not have the great fluctuation along with the outside temperature change of pigsty, its temperature value stably maintains around 28˚C. The concentration of carbon dioxide changes along with the time and has the significant fluctuation, it shall be relative to the lifestyle of piglets. As shown in the figure, the sudden drop of carbon dioxide (arrow 1) is caused due to the owner entered into the pigsty to observe the night life situation of piglets; the sudden drop of rear section (arrow 2) is caused due to the owner entered into the pigsty for cleaning.

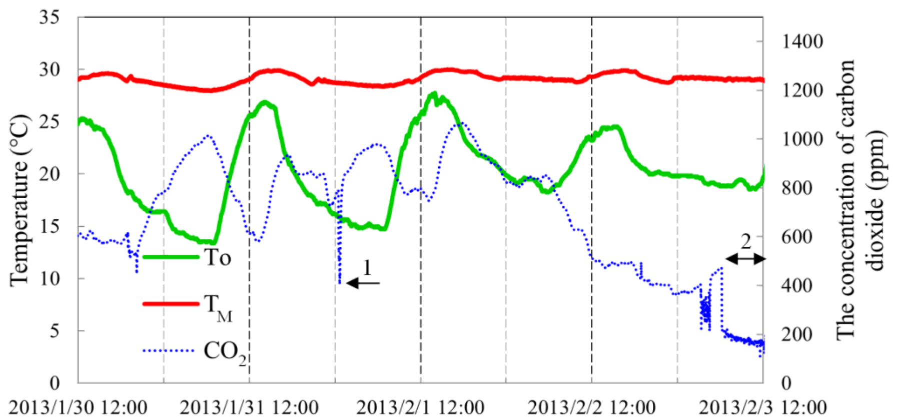


Fig. 5 Typical diagram of central Temperature (T_M), concentration of carbon dioxide and outside temperature of pigsty (T_0) for 4 consecutive days under 28˚C for forced ventilation temperature and 3.4 ACH for regular ventilation

At the condition of 28˚C for the forced ventilation temperature, the statistic of central temperature (T_M), temperature error rate, central relative humidity (RH_M) and concentration of carbon dioxide (CO_2) in the pigsty under the different air change rate of regular ventilation is shown as Table 2. It can be seen from the table, under the different setting of air change rate for regular ventilation, central temperature (T_M) is stable between 28˚C-29˚C and the standard deviation is very small, it is indicated that the temperature change in the pigsty is quite stable, and the temperature error rate is around 1.93%-3.88%, this also indicates that the temperature control of this heat preservation system is quite stable. The central relative humidity (RH_M) is stable between 73.11%-82.21% at different air change rate of regular ventilation, and the concentration of carbon dioxide is maintained under 1000 ppm. When the air change rate of regular ventilation is 5.1 ACH, the concentration of carbon dioxide in the pigsty is very close to the outdoor concentration of carbon dioxide, the air quality in the pigsty is good.

Table 2 Statistic of central temperature (T_M), temperature error rate, central relative humidity (RH_M) and concentration of carbon dioxide (CO_2) in pigsty at 28˚C for forced ventilation temperature under different air change rate of regular ventilation

	Air change rate per hour (ACH)		
	1.7 ACH	3.4 ACH	5.1 ACH
T_M(℃)	28.49±0.52	29.09±0.46	28.79±0.31
E. R.*(%)	1.93%±1.68%	3.88%±1.65%	2.83%±1.12%
RH_M(%)	73.11±12.94	77.19±15.99	82.21±8.54
CO_2(ppm)	896.26±145.08	598.57±294.02	406.80±108.18

*E. R. : Error rate (%) =[(T_{set}-T_M) /T_{set}]*100% , T_{set} =28˚C

Take the measured temperature of RF, RR, LF, LR, RFD & RRD and the central temperature (T_M) to perform the calculation of temperature uniformity, the results are shown as Table 3, it can be seen from the table, at the defaulted temperature 28˚C in the pigsty, the temperature uniformity of enclosed pigsty under different air change rate of regular ventilation is between 0.99˚C -1.78˚C, under the condition of 3.4 ACH for the air change rate of regular ventilation and 28˚C for the forced ventilation temperature have better temperature uniformity inside the pigsty.

Table 3 Temperature Uniformity in enclosed pigsty under the different air change rate of regular ventilation at 28˚C for forced ventilation temperature

	Air change rate per hour (ACH)		
	1.7 ACH	3.4 ACH	5.1 ACH
Temperature uniformity (℃)	1.78	0.99	1.6

4. Conclusions

The stoking density of piglets in the enclosed pigsty is 1.77 pig/m^2, under the setting of 28˚C for both defaulted air temperature and forced ventilation temperature in the pigsty, collocate with different air change rate of regular ventilation, i.e. 1.7 ACH, 3.4 ACH and 5.1 ACH to perform the experiment. The concentration of carbon dioxide at different air change rate of regular ventilation are lower than 900 ppm, it is able to stably maintain the temperature, relative humidity and concentration of carbon dioxide in the nursery, and achieve the effective heat preservation effect, and maintain the good air quality in the pigsty. When the air change rate of regular ventilation is configured as 5.1 ACH, the concentration of carbon dioxide in the pigsty is quite close to the 400 ppm concentration of carbon dioxide outside the nursery, it is indicated that the air quality in the pigsty is very good. As known from the experimental results, this biogas burning hot-water system collocating with inverter fan to perform the ventilation in enclosed the pigsty, the temperature change in the pigsty is quite uniform, apply to the heat preservation for the enclosed pigsty is feasible and efficient.

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