

Geothermal Heat Pump as an Environmental Friendly, Renewable Energy Source for Sustainable Pig Production

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Abstract

This study was conducted to compare the heating effects of the geothermal heat pump (GHP) and traditional heating system (heating lamps) in the pig barn. A GHP system was installed at a pig farm to examine the effects on the growth performance, temperature, greenhouse gas emissions (CO₂), noxious gas emissions (NH₃ and H₂S) and energy savings. A total of 20 piglets having an initial body weight of 6.95 ± 0.5 kg were randomly divided into two identical pig barns for 8 weeks. The temperature inside the pig barn was significantly increased in the GHP-installed pig barn (P < 0.05). Similarly, the outflow temperature from the heat pump was higher (P < 0.05) than the inflow temperature. The NH₃ concentration, H₂S concentration and CO₂ concentration were decreased significantly (P < 0.05) in the GHP-installed pig barn relative to the control. Furthermore, electricity consumption was also reduced by heating the pig barn with a GHP system as compared to the traditional heating system. These results show that the GHP system can be used as an alternative and eco-friendly energy source in pig barns without having an adverse effect on growth performance.

Keywords: Electricity consumption; Pig barn; Greenhouse gas emission; Rural development

1. Introduction

Sustainable agriculture aims to limit the use of non-renewable energy sources due to the unstable fossil fuel prices, emission of greenhouse gases into the atmosphere and ozone depletion (Patel *et al.*, 2018). The cost and the impact of using energy on the environment in the animal-agriculture sector is of great concern (Islam *et al.*, 2016a). Therefore, the use of renewable energy sources is increasing throughout the world because of their environmental-friendly

nature, high production performance and low operating cost (Choi *et al.*, 2012). In the Republic of Korea, the government is also taking revolutionary steps to increase the use of renewable energy sources from 6% in 2021 to 11% by the end of 2030 (Lee *et al.*, 2009; Lola and Graham, 2021).

The outside temperature in Korea is below the freezing point in winter and piglets are susceptible to cold stress. The optimum temperature for weaning pigs is around 26 °C.

Therefore, heating the pig barn is essential and a significant cost is required for it (Riva *et al.*, 2000; Mun *et al.*, 2020). Pig farming in Korea has increased dramatically; as a result of the increased production, pig farms have become a significant contributor of carbon dioxide (CO₂) and ammonia (NH₃) emissions into the environment (Choi *et al.*, 2012). CO₂ is the most prevalent greenhouse gas (GHG), and about 32% of this gas is emitted as a result of electricity use for transportation, heat, and light (Islam *et al.*, 2016b; Bilen *et al.*, 2008). NH₃ is a notorious gas that has negative effects on pig production, health, and welfare. Furthermore, NH₃ emission into the atmosphere is the primary source of pollution linked with agriculture and livestock animals, accounting for 95% of all anthropogenic emissions (Galloway *et al.*, 2004). Hence, there is a strong need in the swine industry to utilize energy resources that can reduce dangerous gas emissions while also being safe for workers, pigs, ecologically friendly, and cost-effective (Mun *et al.*, 2020).

Geothermal energy is used for electricity generation, indirect and direct heating, and cooling via geothermal heat pumps (Wu, 2009). A geothermal heat pump (GHP) is a cost-effective and innovative energy technology that uses the groundwater or earth's natural heat storage capacity for heating and cooling (Mun *et al.*, 2020). GHP system can reduce noxious gas emissions (NH₃ and CO₂), dust concentration, and enhance sustainable development (Bostami *et al.*, 2016). Geothermal energy has been utilised in many countries and it has a great potential for extensive increase throughout the world (Bertani, 2009).

Therefore, GHP is considered to be the best energy-saving, environmentally safe and economical renewable energy source option. Despite the potentials of renewable energy sources, limited studies were conducted in application to swine production. Therefore, a study was conducted using the geothermal heat pump system to evaluate its impact on pigs' production performance, noxious gas emissions, internal housing environment, and energy cost.

2. Materials and methods

2.1 Location, animal care and housing

The experiment was conducted at the research farm of Suncheon National University, the Republic of Korea. The rearing of piglets was in accordance with the Animal Use and Care Council of the university (SCNU IACUC-2020-16).

The experiment was performed for 8 weeks from 29th October 2020 to 31st December 2021. A total of 20 piglets [(Landrace × Yorkshire) × Duroc] having an average initial body weight of 6.95 kg were randomly divided into two rooms. The two rooms were further divided into ten pens for individual replication. One room was heated by installing a GHP system while the other room was heated by using 600W heating lamps (conventional heating system) on the top of each pen (Figure 1). The piglets were kept on the slatted floor and offered commercial feed and fresh drinking water ad libitum.



Figure 1. Inside view of pig barn with heating lamps and individual pen.

2.2 Geothermal heat pump system

The heating pump unit (Model DHGW 5N-C4-02) was manufactured by Daesung, Republic of Korea and installed at the experimental pig farm (Figure 2). The system is comprised of the following parts: 1) Borehole exchanger having a depth of 150m, 2) heat pump unit, 3) pumps for water circulation, 4) fan coil unit, and 5) a water storage tank has a capacity of 260L. The heating capacity and the energy consumption of the system were 19.66 kWh and 4.93kW, respectively. A total of 3 water circulating pumps (Wilo Pump, Republic of Korea) were equipped with the system to transfer water from ground to heat pump, heat pump to storage tank and storage tank to the pig barn. The environment-friendly R-410 A working fluid was used in the heat pump.

2.3 Growth performance

At the start and end of the experiment, the weight of the individual piglet was recorded. The body weight gain was calculated by subtracting the initial weight from the final weight. The feed was offered daily and residual feed was collected weekly to determine the feed intake. The feed conversion ratio was calculated by dividing the feed intake by weight gain.

2.4 Noxious gas concentration

The concentration of ammonia (NH₃) and hydrogen sulphide (H₂S) were recorded with the help of sensors (NH₃-3E-100 SE and H₂S-B4). The sensors were installed on the ceiling in the middle of the pig barn. The range of sensors lies between 0-50 ppm.

2.5 Temperature and humidity

The inside temperature and humidity were recorded with the help of T-type sensors having thermocouples and thermistors. The range for temperature and humidity is 80 °C to -2 °C and 0-100% respectively. The inflow (cold water) and outflow (hot water) from the heat pump was recorded with the help of the GPT-1000 pipe sensor.

2.6 Power consumption and concentration of CO₂

The consumption of electricity was measured with the help of two separate meters (LSis, LD 1210Ra-040) for each room. The emission of CO₂ was estimated in KgCO₂e (where 1 kWh= 0.483 kg CO₂ equivalent), as calculated by Islam *et al* (2016).



Figure 2. Geothermal heat pump system with heating tanks and water pipes.

2.7 Statistics

The Statistical Analysis System was used for statistical analysis (SAS Institute, 9.3 version, 2011). The analyzed results are the mean values with a standard error of the mean. Analysis of variance (ANOVA) was used to compare all parameters with subsequent Duncan’s multiple range test.

3. Results and Discussion

3.1 Pig barn temperature and relative humidity

Figure 3 shows the temperature distribution pattern for the inflow and outflow water from the heat pump. The average temperature inside the GHP-connected pig barn was significantly increased ($P < 0.05$) as compared to the outside and control. The temperature in the GHP attached pig barn was increased by 69% and 3% as compared to the outside temperature and control barn temperature respectively (Table 1).

Swine production depends on the housing conditions like inside temperature and a slight variation in this parameter may cause heat or cold stress. Piglets are more prone to cold stress, particularly in harsh weather conditions. The efficiency of the GHP system during the winter season has been reported in swine farms (Krommweh et al., 2014). In the present study, the increased and uniform temperature inside the pig barn heated by the GHP system is might be due to the efficient conversion of heat from underground water and then transfer this heat uniformly by the fan coil of the GHP system (Islam et al., 2016). The GHP system used in our study was a single loop configuration (direct heat exchange system), in which there is no need for a ground loop to heat GHP exchangers because the working fluid of the heat pump flows only in the ground heat exchanger (Omer, 2008). This system helps the GHP system to increase the inside temperature of the pig barn in the severe winter season. The increased temperature shows the efficiency of the GHP system that it can provide enough heat to maintain the required temperature for piglets by converting geothermal energy to heat.

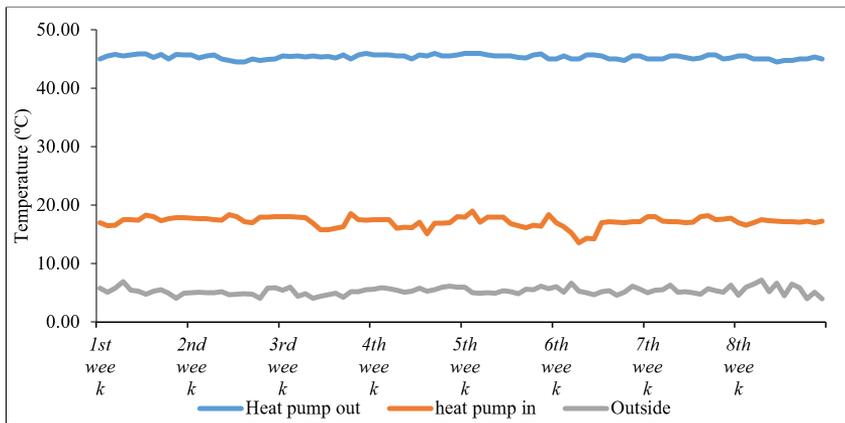


Figure 3. The inflow and outflow water temperature from the heat pump.

Table 1. Effect of the geothermal heat pump (GHP) system on the temperature and humidity inside the pig barn.

Item	Outside	Control	GHP	SEM	P value
Temperature (°C)	7.14	22.87 ^b	23.53 ^a	3.26	0.0001
Humidity (%)	64.05	48.46 ^a	39.09 ^b	18.43	0.0001

^{a,b} Mean in the same row without a common letter are different at $P < 0.05$.

3.2 Noxious gas emission

The effect of GHP on the concentration of NH₃ and H₂S is displayed in Figure 4. The concentration of both gases were significantly reduced in the GHP-connected pig barn relative to the traditional heating system (P < 0.05).

The emission of harmful gases (NH₃ and H₂S) from livestock farms have negative effects on animal production and health, health and welfare of workers and the environment (Dilawar et al., 2019). The concentration of these gases in animal farms depends on the ambient temperature, ventilation rate and housing conditions (Philippe et al., 2011). The recommended concentration of NH₃ is 20 ppm (Soren, 2002) and the pig production may be slowed up to 30% due to the high NH₃ concentration inside the closed swine barns. The concentration of NH₃ and H₂S in the swine farm is in the range of 0 - 40 ppm and less than 2 ppm respectively (Ni et al., 2017). In the present study, the concentration of both gas were reduced due to the better air quality inside the GHP-connected pig barn. The GHP system has ability to provide fresh air continuously

which dilutes the NH₃ (Choi et al., 2010). It was also reported previously that the concentration of NH₃ was reduced by 30% when the GHP system was installed at the pig barn for heating purposes (Jacobson, 2012). There is no direct fuel combustion in the GHP system which might decrease the concentration of harmful gases. Furthermore, geothermal energy and geothermal heating pump system is recognized as greener and renewable energy source that is playing a vital role in increasing energy security, reduction in climate change and protecting animal and public health (Pulat et al., 2009).

3.3 Electricity consumption and concentration of CO₂

The consumption of electricity and CO₂ concentration of both barns is presented in Table 2. During the experimental trial, the electricity consumption was decreased by 1125 kWh (30%) in the GHP system relative to the traditional heating system. Similarly, the CO₂ concentration was also lower by 687 kg (30.5%) in the GHP connected barn as compared to the control.

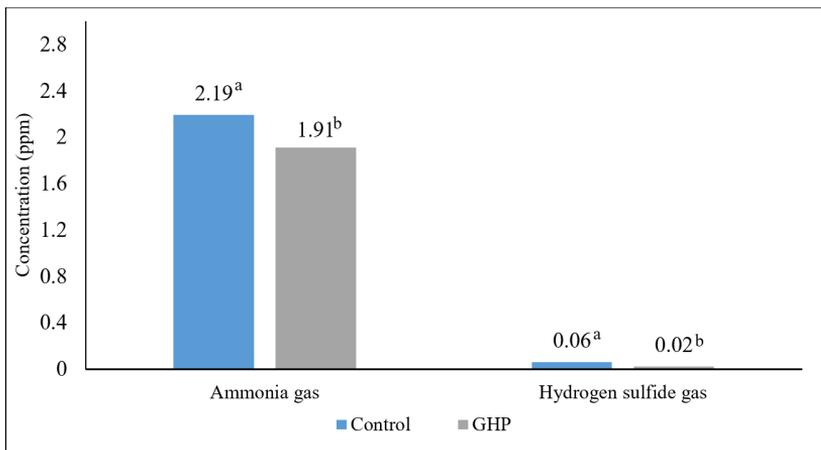


Figure 4. Effect of the Geothermal heat pump (GHP) on the noxious gas emission.

^{a,b} Mean in the same row without a common letter are different at P < 0.05.

Table 2. Effect of the geothermal heat pump (GHP) system on electricity consumption and CO₂ emission.

Item	Control	GHP	Reduction
Electricity consumption (kW · hr/ 8 weeks)	4,110	2,855	1125
Electricity consumption per animal	411	286	126
Carbon dioxide concentration (kg)	2248	1561	687

Fossil fuels are depleting throughout the world and their price is increasing continuously. Farmers find it difficult to bear the cost of heating livestock facilities. Therefore, renewable energy sources must be introduced in the agriculture sector for sustainable food production. In the present study, a decrease in the electricity consumption by using the GHP system is might be due to the uniform and efficient heat distribution by the geothermal heat pump. Another reason for this is the fewer operating hours and high COP of the GHP system. It was reported earlier that GHP can supply three units of electricity for every one-unit consumption, which is also one of the reasons for a decrease in electricity consumption (Charoenvisal 2008). These results are in agreement with the previous studies that the GHP system decreased the cost of electricity for heating buildings and livestock and agricultural farms (Barbier, 2002; Mun et al., 2022).

One of the largest sources of greenhouse gas emissions (GHE) is electricity production, which can deteriorate public health and also be harmful to the environment (EPA, 2020). CO₂ is the main greenhouse gas, and the release of this gas into the atmosphere will cause a temperature increase from 1.1 to 6.4 °C at the end of this century (Solomon et al., 2007). As a result, the demand for alternative energy resources to protect the environment is increasing throughout the world. The utilization of geothermal energy prevents 74.1 million tons of CO₂ from being emitted to the atmosphere (Xia et al., 2021). In our study, the GHP system reduced the CO₂ emissions by 687 kg as compared to the control, which is important for not only the well-being of animals and humans but also for environmental protection (Jacobson, 2012). Supporting our

results, other scientists also evaluated that the energy consumption (electricity production due to fossil fuels) and CO₂ emissions were reduced by replacing the traditional heating system in buildings and animal farms with the GHP system because it is energy efficient (Islam et al., 2016; Barbier, 2002).

3.4 Growth performance

The effect of GHP and conventional heating system on the growth performance of pigs was presented in Table 3. There was no significant difference ($P > 0.05$) observed in the weight gain and feed intake of pigs reared in two different heating systems. Similarly, the GHP system had no negative effect on the FCR.

Bodyweight gain and FCR are the important growth parameters in swine production (Kim et al., 2005), which cannot be taken for granted while introducing new technology. In this study, heating the pig barn by installing a GHP system had no harmful effect on these parameters. These results are in line with the previous studies that the GHP system can be used in pig production for heating purposes without harming growth performance (Choi et al., 2010; Mun et al., 2020). Sometimes, the weight gain, FCR and feed intake were reduced in the heating systems using LPG gas system for heating because of the elevated fume concentration inside the pig barn. However, there is no direct combustion in the GHP system. Therefore, using the GHP for heating pig barns prevents the piglets from cold shock without decreasing animal production parameters. Hence, installing the GHP system based heating system is essential for livestock farmers to keep piglets at optimum temperature, saving energy and protecting the environment.

Table 3. Effect of Geothermal heat pump (GHP) on the growth performance of the piglets.

Item	Control	GHP	SEM	P value
Initial Weight (kg)	6.95	6.95	1.46	0.9976
Final Weight (kg)	46.60	44.82	5.01	0.4514
Weight gain (kg)	39.65	37.87	4.42	0.3871
Feed intake (kg)	76.74	75.14	6.60	0.5940
FCR	1.94	1.98	0.22	0.6389

4. Conclusion

The installation of the GHP system could enhance the housing conditions inside the pig barn without affecting growth performance. Similarly, the concentration of CO₂, NH₃ and H₂S significantly decreased in the GHP-connected pig barn. Furthermore, the government should give subsidies to the rural farmers to install the GHP system because of its high cost to promote sustainable livestock production and rural development. Considering the beneficial effects on the environment and energy savings, the GHP system can be implemented as an environmentally friendly alternative heating source.

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