**Combined heating system of a biogas reactor on base the solar heat pump system**

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**Abstract** Biogas heating system has disadvantages such as low energy efficiency and high energy consumption in winter season. In a biogas reactor it is necessary to maintain the thermophilic regime inside it. In this research, a solar heat pump system is developed for heating a 10 m3 multiphase flow bioreactor. To research the operational effects, two regimes were defined depending on the solar substitution in different regions of the republic. Thermodynamic calculations and simulation modelling analysis were performed, and the solar collector area (*Ac*) and the minimum length of the sewer two-pipe heat exchanger (min) were calculated for the two regimes. Regime 1 can be used when the solar substitution is < 0.3, and regime 2 can be used when the solar substitution is > 0.55. The results showed that *Ac* and min for regime 2 were larger than those of regime 1 under different solar substitutions. The results of the performed modeling also substantiate the possibility of implementing energy-efficient heat pump district heating in the studied range of regimes, provided that the project for utilizing the calorific value of biogas in a combined-cycle power generating installation with high efficiency values is implemented.

**INTRODUCTION**

Biogas is produced by anaerobic fermentation of manures at a warm temperature, pH and mass [1]. Temperature is the main factor defining the anaerobic decomposition of the substrate [2]. A decrease in temperature during the cold season significantly affects the bacterial fermentation process of at least 550C with changing no more 30C per hour [3]. If the fermentation temperature changes more than 50C for a short period of time, the rate of biogas production processes may stop [4]. Therefore, it is necessary to maintain a constant temperature during fermentation in the biogas reactor, traditionally working with external heating system for maintaining regime of biogas production in cold days [5].

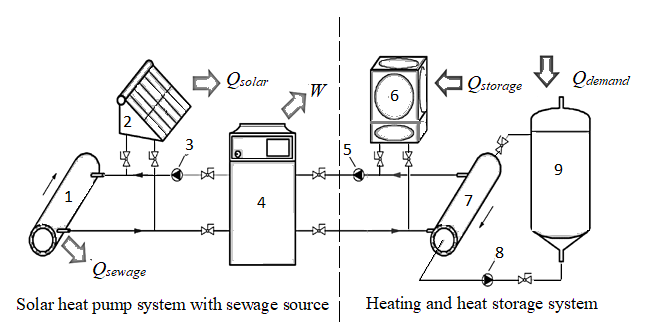
Obviously, methods of maintaining temperature conditions in a biogas installation include waste heat recovery, biogas boiler heating, active and passive solar heating and heat pump heating [6]. In recent years, in order to reduce grid power consumption and avoid high initial costs and instability problems when using autonomous solar energy [7]. The solar integrated heat pump heating methods have become a research topic [8-9]. These methods include using solar heat pump heat, solar heated air and a combination of solar heat with low-grade manure from livestock’s farm heat [10]. However, solar integrated heat pump heating methods have many disadvantages, which limits their application. Firstly, the heating system of a biogas installation has a low energy efficiency in winter [11]. In [12] there are used solar heat pump to heat 60 m3 of anaerobic digester and the energy efficiency of the system is 2.6. Another disadvantage of solar ground source heat pump heating method is the decrease in energy efficiency over time, which is due to the imbalance of heat storage in winter and summer [13]. The disadvantage of solar air heating method is icing in winter [14]. Heat pump heating using solar collectors as a low-grade source is different from the other two methods and has the advantages of higher energy efficiency, lower initial cost and easy maintenance [15]. However, corrosion and fouling of heat exchangers are serious problems affecting the application of the system [16].

According to the scheme shown in the figure [1](https://www.hindawi.com/journals/ijp/2020/8821687/fig1/), the dynamic fermentation system of the 9 m3 bioreactor is heated by a solar heat pump system. Full-scale field experiments were conducted on the biogas production rate of the system at different temperatures, as well as the dynamic fermentation and dynamic heating of the system. The results showed that the temperature significantly affected the biogas production rate of the biogas installation reactor. Although the biogas boiler system had the advantages of convenient operation and easy maintenance after long-term operation, the high energy consumption and low energy efficiency reduced the overall efficiency of the biogas installation, making it difficult to maintain stable long-term operation.

Accordingly, in this research, an heating system on base of heat pump and solar thermal collectors and manure substrate source for the reactor of biogas installation was developed [17]. The heat exchanger used is a pipe-in-pipe heat exchanger, which extracts thermal energy from raw manure from livestock’s farm. The structure of the device can avoid the problems of corrosion and clogging, expanding the application range of the heating system. In addition, the system does not require biochemical manure from livestock’s farm treatment [18]. Two operating regimes are researched depending on the amount of solar energy in different regions. The changes in the solar collector area (*Ac*) and the minimum length of the two-pipe manure from livestock’s farm heat exchanger () under two operating regimes. As well as the applicate of the operating regimes, were obtained through thermodynamic calculations and working modelling analysis. defined. In order to quantitatively compare the advantages of the heat pump system of the heat source from solar thermal collectors over various heating systems, a comprehensive assessment of various biogas heating systems is carried out, and were calculated by two methods. These studies allow to prove the use of an integrated heat pump with a low-potential source from solar energy and a manure taking system for a biogas installation [19]. Thus, this research is aimed at increasing the volume of biogas production and maintaining the stability of the operating regimes of biogas installations in winter.

**THEORETICAL RESEARCH**

The proposed (Fig.[1](https://www.hindawi.com/journals/ijp/2020/8821687/fig2/)) system consists two technician zonas: solar heat pump system and system for heating manure intro biogas installation and heat storage. It includes solar collector 2, heat pump unit 4, a “pipe in pipe” heat exchanger 1 and water pumps 3. Heat exchanger 3 (Fig.[1](https://www.hindawi.com/journals/ijp/2020/8821687/fig3/)) is part of the sewerage network. Manure from livestock’s farm enters the inner pipe, and water as a heat carrier enters the space between the inner and outer pipes. The heat energy of the manure from livestock’s farm is transported through the inner wall of the pipe to cool water, which after heat exchange is directed to the heat pump. Solar collectors provide part of the heat for heating this water. The heated water is then directed by a pump to the heat pump unit, and after heat exchange is directed again to the two-pipe heat exchanger 7. After transfer and conversion by the heat pump, the thermal energy is transported to the biogas substrate in heating system and the heat storage system using a hot water pump 8. In the biogas substrate dynamic heating and heat accumulation system, thermal energy is transported to the substrate through a two-pipe heat exchanger, and the heat received from the solar heat pump system is stored in a heat storage tank in the form of heated water.



**Fig.1.** Schematic diagram of a solar heat pump and a heating and heat storage system in a biogas installation:

1 - two-pipe heat exchanger for waste water; 2 - solar collector; 3 - pump for water used as a heat carrier; 4 - heat pump unit; 5 - cooling water pump; 6 - heat accumulator; 7 - "pipe-in-pipe" heat exchanger; 8 - pump for pumping manure substrate; 9 - biogas installation reactor

A heat pump is used as a heat source for heating in the system. Nominal power, coefficient of performance and voltage of the heat pump were 1,2 kW, 4.2 and 380 V, respectively. To reduce the power, an accumulator tank is used when selecting the heat pump. The sizes of the tank were: volume 2,2 m3: length 1.0 m, width 1.0 m , height 2.2 m. The storage temperature is set to 41.5 0C.

**Minimum length of a two-pipe heat exchanger**

The temperature of the manure substrate in winter is 12, 3 ÷14, 6 0C, and the temperature fluctuations were small. Thus, it is assumed that the temperature of the manure from livestock’s farm is constant at 13,45 0C.

As shown in the figure [1](https://www.hindawi.com/journals/ijp/2020/8821687/fig2/), in the heat exchanger the water-water heat transfer in the opposite direction is maintained. The flow of waste water in the inner pipe is natural convection, and the flow of heated water in the outer pipe is forced convection. it would be shown as follows [20]:

(1)

(2)

(3)

=2 (9)

here –minimum length of a two-pipe heat exchanger for manure from livestock’s farm (m); - estimated temperature of manure from livestock’s farm in winter (0C); , average temperatures of the heated water at the inlet and outlet of the heat exchanger, respectively (0C);–thermal transferring coefficient of the heat exchanger (W·m-1·K-1); represents the resistance to fouling of heat exchanger tubes equal to 0.00016 m·kW-1 [20]; - coefficient of convective heat transfer of the inner surface of the inner pipe (W·m-2·0C-1); is the radius of the inner pipe of a two-pipe sewer heat exchanger (m); is the outer radius of the pipe of a two-pipe heat exchanger (m); represents the thickness of the inner wall of the pipe (in m); is the thickness of the outer wall of the pipe (in m); is the thermal conductivity coefficient of chilled water (W·m-1·K-1); - Nusselt number value; is the characteristic length of the pipe-in-pipe heat exchanger in livestock’s farm (m).

**SOLAR HEATING SYSTEM**

After definition the solar collector area can be calculated for a specific solar energy substitution of generated heat capacity. The direct system is chosen and *Ac* can be expressed as follows [8]:

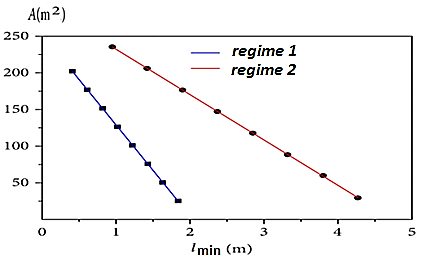
· (4)

here represents the area of ​​the direct system (m2); *f* - solar substitution, which is the average daily amount of solar radiation (7.0 MJ·m-2·day-1) [9]; represents the average collection efficiency of the solar collector (0.23–0.4; in this research, the value 0.37 is based); represents the average rate of heat loss in the tubes of solar collector (0.18–0.27; in this research, the value 0.19 is based); represents the heat loss efficiency of the direct system (near 0.048); and represents the heat load of the solar system (MJ·day-1).

**RESEARCH RESULTS**

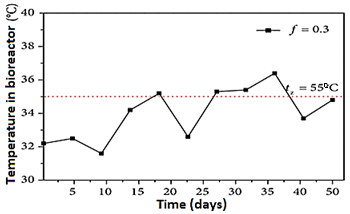
The proposed solar heat pump system is constructed to maintain anaerobic fermentation in a biogas reactor at 550C during winter. As shown by the equation ([1](https://www.hindawi.com/journals/ijp/2020/8821687/#EEq3)), the minimum length of the sewer two-pipe heat exchanger is defined by the heat transfer coefficients of the heat exchanger. Therefore, according to the equations ([2](https://www.hindawi.com/journals/ijp/2020/8821687/#EEq3))–([4](https://www.hindawi.com/journals/ijp/2020/8821687/#EEq3)), the calculated value is 291.4 W·m-1·0C-1. The annual heat load and heat loss of the installation s determined as 1.01 kW.

The conditions for using two regimes are researched. Regime 1 can be used in solar energy resource areas, where the amount of thermal energy given off by the manure substrate is greater than that given off by solar radiation for the solar heat pump installation. Conversely, regime 2 can be used in areas rich in solar energy resources, where the amount of thermal energy given off by the manure substrate is less than that from solar radiation for the solar heat pump heating system. The solar fractions for regimes 1 and 2 are 0.3 and 0.55, respectively. Thus, as shown in the figure 2 , the standard deviations are 349.8 m (regime 1) and 177.5 m (regime 2) for Fig.[2](https://www.hindawi.com/journals/ijp/2020/8821687/fig12/#a), and the standard deviations are 33.4 m-2 (regime 1) and 41.2 m-2 (regime 2) for Fig.[2](https://www.hindawi.com/journals/ijp/2020/8821687/fig12/#b). If the solar fraction of generated heat by proposed installation <0.3, regime 1 is more suitable, and for the solar fraction >0.55, regime 2 is more suitable. In addition, it is useful to regulate the temperature of anaerobic fermentation when the solar fraction is between 0.3 and 0.55



**Fig.2.** The ratio of the solar collector area to the minimum length of the heat exchanger for utilizing heat of manure from livestock’s farm in different regimes

Figure [3](https://www.hindawi.com/journals/ijp/2020/8821687/fig13/) is shown the temperature of the substrate in the biogas installation from February 22, 2023 to March 10, 2023. As shown in the figure [3](https://www.hindawi.com/journals/ijp/2020/8821687/fig13/), the temperature in biogas reactor stabilized at around 55°C, indicating that the solar heat pump system is working well and the biogas installation reactor is providing stable digestion and biogas production.



**Fig.3.** Average daily fermentation temperature in the biogas installation reactor by using solar heat pump installation

**CONCLUSIONS**

The conversion of low-potential thermal energy obtained from manure in livestock’s farm flows, exhaust gases, etc. using heat pumps and the subsequent use of the resulting high-potential heat for district heating purposes. It makes possible to use secondary sources of thermal energy from waste and thus reduce the consumption of fossil fuels.

Problems of safe operation of ranges for a burial place of a firm livestock waste are considered. Danger at storage of waste on ranges, in particular, is connected with the uncontrollable issue of biogas connected with biological decomposition of organic substance. Production process of extraction and biogas recycling will allow to solve this problem. Complex problems of effective recycling of biogas as fuel for the purpose of central heating and reception of electric energy are considered. Application of heat pumps allows to raise the general power efficiency of the technological scheme. Alternative ways of increase of power efficiency of technology of recycling of energy of biogas are considered also. In order to improve the traditional biogas heating system. Results are shown that solar heat pump system is effective for dynamic anaerobic fermentation system in biogas installation reactor.

According to the proportion of solar energy in different regions, two operating regimes were defined: regime 1 for areas with medium solar energy resources and regime 2 for areas with large solar energy resources. Based on thermodynamic calculations and experimental studies, the parameters *Ac* and or the two regimes were calculated.

The conditions for increasing the energy efficiency of the considered technology when using heat pump units for district heating purposes are determined. The use of alternative energy sources obtained from waste or low-potential sources of secondary heat energy allows for a reduction in the consumption of fossil organic fuels. It should have a positive impact on the dynamics of anthropogenic environmental loads.

**REFERENCES**

1. A. Aslani, T. Mazzuca-Sobczuk, S. Eivazi, and K. Bekhrad, “Analysis of bioenergy technologies development based on life cycle and adaptation trends,” Renewable Energy, vol. 127, P. 1076–1086, 2018.
2. T. M. Alkhamis, R. El-khazali, M. M. Kablan, and M. A. Alhusein, “Heating of a biogas reactor using a solar energy system with temperature control unit,” Solar Energy, vol. 69, no. 3, P. 239–247, 2000.
3. N. Krakat, A. Westphal, S. Schmidt, and P. Scherer, “Anaerobic digestion of renewable biomass: thermophilic temperature governs methanogen population dynamics,” Applied and Environmental Microbiology, vol. 76, no. 6, P. 1842–1850, 2010.
4. T. Zhang, Y. Tan, and X. Zhang, “Using a hybrid heating system to increase the biogas production of livestock digesters in cold areas of China: an experimental research,” Applied Thermal Engineering, vol. 103, P. 1299–1311, 2016.
5. V.V. Lozovetsky, G.S. Dugin, E.V. Malyshev. Methods of using biogas (as a renewable energy source), which is a product of landfill waste disposal. Journal "Problems of Safety and Emergencies". Moscow: VINITI. 2010. No. 1. P. 85-95.
6. Y. Liu, Y. Chen, Y. Zhou, D. Wang, Y. Wang, and D. Wang, “Experimental research on the thermal performance of PEX helical coil pipes for heating the biogas digester,” Applied Thermal Engineering, vol. 147, P. 167–176, 2019.
7. P. Guo, R. J. Ma, and N. Y. Yu, “Operation regime of solar and untreated sewage source heat pump system for heating biogas digester,” Journal of Southwest Jiaotong University, vol. 53, P. 1087–1094, 2018.
8. A. Anarbaev, M.A.Koroli. Autonomous hybrid solar-heat pump for system heat-cooling in buildings. IOP Conf. Ser.: Mater. Sci. Eng. 1030 012178 (2021)
9. A. Anarbaev, M. Koroly. Issues of application an absorption heat pumps for solar heat and cooling supply of buildings. AIP Conf. Proc. 2969, 020029 (2024)
10. R. Feng, J. Li, T. Dong, and X. Li, “Performance of a novel livestock solar heating thermostatic biogas system,” Applied Thermal Engineering, vol. 96, P. 519–526, 2016.
11. N. Curry and P. Pillay, “Integrating solar energy into an urban small-scale anaerobic digester for improved performance,” Renewable Energy, vol. 83, P. 280–293, 2015.
12. X. M. Pei, H. X. S. Di Zhang, H. G. Zhu, Y. Lei, and Z. Wang, “Collector area optimization of integrated solar and ground source heat pump system for heating biogas digester,” Transactions of the Chinese Society for Agricultural Machinery, vol. 42, P. 122–128, 2011.
13. J. Kim, H.-J. Choi, and K. C. Kim, “A combined dual hot-gas bypass defrosting method with accumulator heater for an air-to-air heat pump in cold region,” Applied Energy, vol. 147, P. 344–352, 2015.
14. A. A. M. Hassanein, L. Qiu, P. Junting, G. Yihong, F. Witarsa, and A. A. Hassanain, “Simulation and validation of a model for heating underground biogas digesters by solar energy,” Ecological Engineering, vol. 82, P. 336–344, 2015.
15. H. Shi, T. Wang, H. Zhu, Y. Li, L. Rong, and X. Pei, “Heating system of biogas digester by ground-source heat pump,” Transactions of the Chinese Society of Agricultural Engineering, vol. 26, P. 268–273, 2010.
16. S.-J. Cao, X.-R. Kong, Y. Deng, W. Zhang, L. Yang, and Z.-P. Ye, “Investigation on thermal performance of steel heat exchanger for ground source heat pump systems using full-scale experiments and numerical simulations,” Applied Thermal Engineering, vol. 115, P. 91–98, 2017.
17. G. D. Qin, P. Lou, and X. L. Wu, “Research on warming parallel system with solar energy, air source heat pump and electric heat of biogas fermentation,” Transactions of The Chinese Society of Agricultural Machinery, vol. 35, P. 187–194, 2014.
18. J. Liu, W. Li, Z. Chen, and W. Sha, “Heating regime of biogas installation in alpine region based on underground water source heat pump,” Transactions of the Chinese Society of Agricultural Engineering, vol. 29, P. 163–169, 2013.
19. H. X. Shi, D. T. Xu, H. G. Zhu, Y. L. Zhang, X. Z. Meng, and C. C. Guo, “TRNSYS simulation of integrated solar and ground source heat pump for biogas digester heating system,” Transactions of The Chinese Society of Agricultural Machinery, vol. 48, P. 288–295, 2017.

20. P. Guo, J. Zhou, R. Ma, N. Yu, and Y. Yuan, “Biogas production and heat transfer performance of a multiphase flow digester,” Energies, vol. 12, no. 10, p. 1960, 2019.