Eco-Energetics: technologies, environment, law and economy
ISSN 2657-5922 2018, Vol. 1, s. 89–96
Annual DOI 10.24426/eco-energetics.v1i0.35

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Waste heat from CHP in biogas plant utilization for local central heating

Abstract
The effective utilization of waste heat it is great challenge for highly efficient co-generation based on biogas. The possibility for highly efficient co-generation using biogas is analyzed. The system generating 500 kWe and 700 kWh, where main heat receiver would be village or small city region with central heating system and heat storage system is considered. Both home heating and hot water supply is discussed.

Keywords: biogas, co-generation, heat utilization, heat storage, low temperature district heating.

1. Introduction

Effective utilization of waste heat state great challenge for highly efficient co-generation based on biogas. Among the proposed solution best known are related to district heating systems, heat transfer to nearby companies, drying of agriculture products, use of heat for pellet production as well as growing vegetables, mushrooms or fishes.

De Jong (2011) has described a CHP plant using biogas as fuel and supplying renewable heat to Polderwijk, a new housing area in Zeewolde, NL. The biogas is transported to CHP unit by the biogas pipeline with diameter 250 mm (5600 m long) from biogas plant on dairy-farm located on the outskirts of the residential area. There are another CHP plant (250 kW) which produce heat and power on farm and provide electricity and heat for the local demands of digester and farm. The plant in Polderwijk is equipped with an engine of 1060 kW electric power, producing around 7 GWh electricity annually with efficiency 41%. It produce also heat (1270 kW) at average temperature of 90°C.

Dzene and Slotina (2013) discussed the issue of heat utilization in 3 case studies: the Ekorima, the Agro Iecava and the Bio Ziedi biogas plants. The CHP system in the first one (Ekorina) produces 7,500 MWh_e and 8,500 MWh_t yearly. The surplus heat 7,200 MWh_t is used for drying wood. From Agro Iecava plant the biogas is transported by pipeline to Iecava village and waste heat is used for heating households using 8,190 MWh_t. As a result the heat tariff for residents was reduced by 17%. There were plans to use the heat during summer for drying. In Bio Ziedi biogas plants there are plans for heating a cannery and aquaculture.

Wirth and Hartmann (2013) pointed to much faster progress for electricity than heat utilization (although in years 2008 to 2012 the electric energy from CHP grew in Germany more that 150%, heat use increased less than 38%. The heat utilization for own needs in the small plants (up to 70 kW_e) reaches level 57.2% but falls to 18.3% for plants of 1 MW_e power.

Wegner (2015) and Ritz (2015) discussed the issue of heat utilization and a broad variety of bottlenecks, including issues of awareness, capacity, social acceptance, legal and political questions. Table 1 presents potential methods of heat utilization for heating human and agricultural houses, drying, cooling and additional electricity production (e.g. in ORC or Kalina cycles).

Table 1. The methods of waste heat utilization from CHP in biogas plants

Option	Heating	Drying	Cooling	Electricity production
Uses	• District heating • Heating of stables • Heating of green-houses • Heating for aqu-aculture • Heat transport in containers • Other heating options	• Drying wood, woodchips, and pellets • Drying agricultu-ral products • Drying digestate and sewage sludge	• District cooling • Cooling of buil-dings • Cooling of stables • Acclimatization of food storage buil-dings • Process cooling	• Additional elec-tricity production with CRC, ORC or Kalina techno-logies

Source: *Sustainable Heat Use of Biogas Plants. A Handbook 2nd edition*, D. Ritz, 2015. Received from: http://www.biogasheat.org/wp-content/uploads/2015/03/Handbook-2ed_2015-02-20-cleanversion.pdf; also *Sustainable Heat Use of Biogas Plants. Questions & Answers*, I. Wagner, 2015. Received from: http://www.biogasheat.org/wp-content/uploads/2015/03/BiogasHeat-Questions-and-Answers-Brochure.pdf.

Jasiulewicz and Gostomczyk (2016) have discussed the issue related to location of biogas installation and CHP unit. They discussed various variants, including (i) common location at the outskirts of the village or the city, (ii) transport of the biogas from the farm to the CHP plant in housing area in order to separate the potential odor source from the densely populated area where electricity and heat are utilized, (iii) biogas enrichment and injection to the gas grid, which transport the biomethane to its utilization site as well as (iv) enrichment to biomethane, compression and liquefying it in order to use it as transportation fuel. These solutions increase energy efficiency and economy of investments.

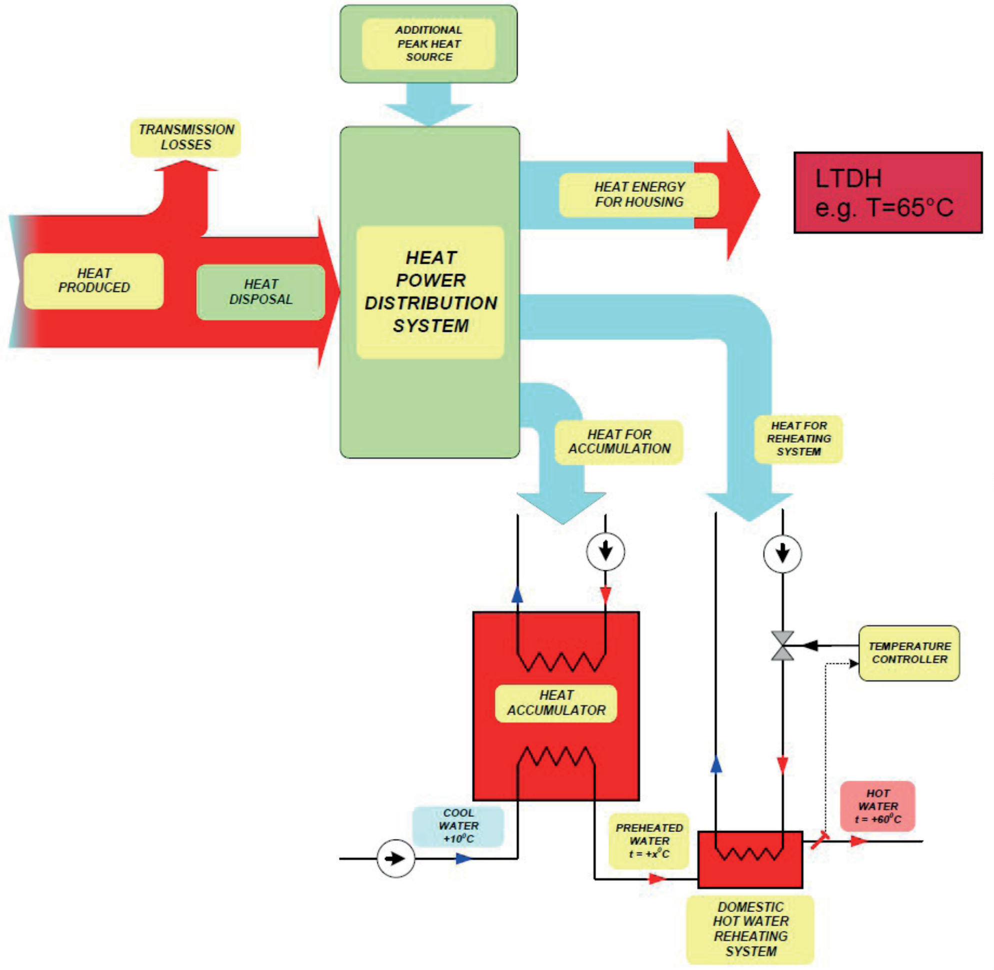

Fig. 1. Scheme of energy supply in the village

The role of district heating (especially Low Temperature DH) in decarbonization of future EU energy system was discussed by Connolly et al. (2014) and Lend et al. (2014). The DH systems will allow utilization waste heat from industrial and waste-to-energy systems, use of geothermal and solar thermal heat. The technologies converting solid biomass into bio(syn)gas as well as liquid biofuels will also play important role in future "smart energy systems". These smart energy systems will be characterized by high degree integration between district heating, cooling, electricity and transport fuel, leading to possible synergies among them.

In this paper possibility for high efficient co-generation with biogas installation 500 kW_e/700 kWh, where main heat receiver would be village or small city region with central heating system is discussed. Local, distributed CHP energy systems are considered nowadays the most efficient and ecological, especially taking into account possible biomass utilization and logistic problems related to low mass density (Popczyk, 2010; Gula et al. 2012). Taking into account large losses in conventional centralized energetics (averaged efficiency of polish power system amounts at ~33%) the local co-generation systems are really beneficial. Even more, whenever there is any demand for heat, one should consider to build CHP system, which has much higher efficiency then conventional systems, with separated generation of heat and electricity.

The paper aims at determination of systems characteristics, which enable high efficiency CHP-systems with power of 500 kW_e and 700 kWh using biogas from local plant. Additionally, a PCM (phase changing material) tank as energy storage is applied (Garg, 1985).

2. Model

Highly efficient CHP-systems with powers of 500 kW_e and 700 kWh using biogas from local plant is analyzed here. It was assumed that the village is constituted by few hundred 100 m^2, low energy-consumption, 75 kWh/(m^2 · year), houses. A family, 4 people, is leaving in each house and their domestic hot water consumption amounts 3.34 MWh/(house · year). As the heat consumption during summer falls considerably, a heat storage based on PCM (phase changing material, here paraffin with phase transition at 60°C determined by needs of engine chilling-system and low temperature district heating) is considered in order to store surplus heat for winter needs. During winter heat energy from CHP is used for house heating purposes, when domestic hot water supply is provided using heat stored in PCM tank. Figure 1 presents a scheme of energy-supply system in the village. The calculations were performed for various number of households: 350, 500 and 900.

3. Results

Figure 2 presents the process of heat accumulation in heat storage (curve "ciepło akumulowane"), which is heat surplus of CHP system (curve "ciepło dostarczone do akumulacji") over the summer demand (curve "zapotrzebowanie c.w.u.") for 350, 500 and 900 households. More than 3 GWh of heat is stored from the CHP system during summer for winter needs. Only the largest considered amount of the houses enable complete utilization of heat supply (whit ought heat pump application). In order to store all the heat, the 100–200 m^3 storage volume should be planned under every house. These can be significantly decreased when another heat utilization will be found for heat surplus during summer. The negative values observed in Figure 2 shows that there will be heat deficit just after storage initiation (in March) — this can be covered by another heat source. For 900 households only 200 MWh should be provided just at the system initiation.

Figure 3 presents temperature evolution in heat storage for various numbers of households. In March, during the system initiation, temperature in the heat storage felt below 15°C (the fall depends on the amount of heated households). Approximately 5 month later the temperature reached the value of phase change and stays at this temperature ~4 month (only for 900 houses), before it slowly decline to about 20°C in the end February. For smaller number of houses temperature stay at phase change value.

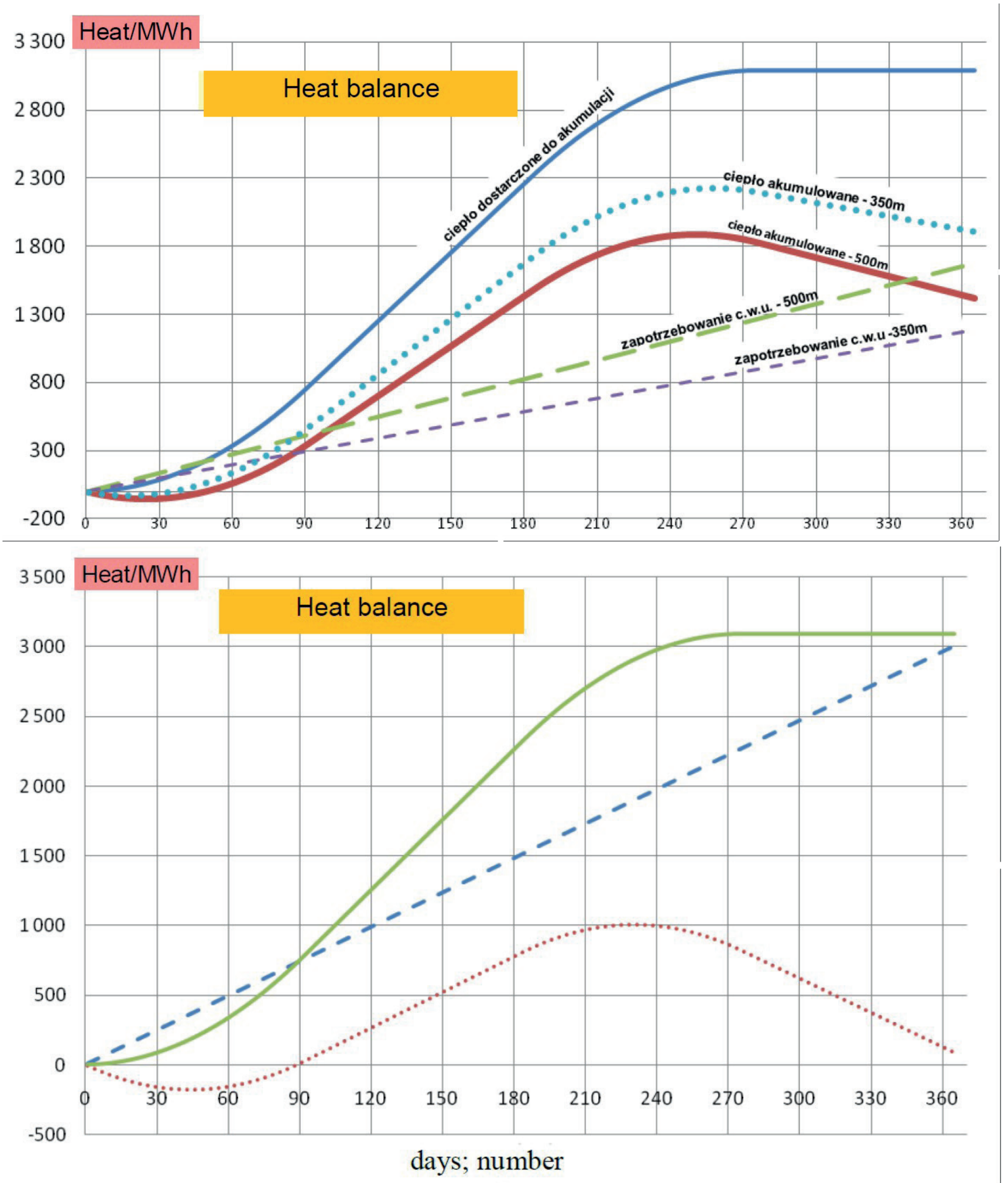

Fig. 2. Heat accumulation process in the storage for various number of households 350, 500 and 900; in each house lives 4 person family

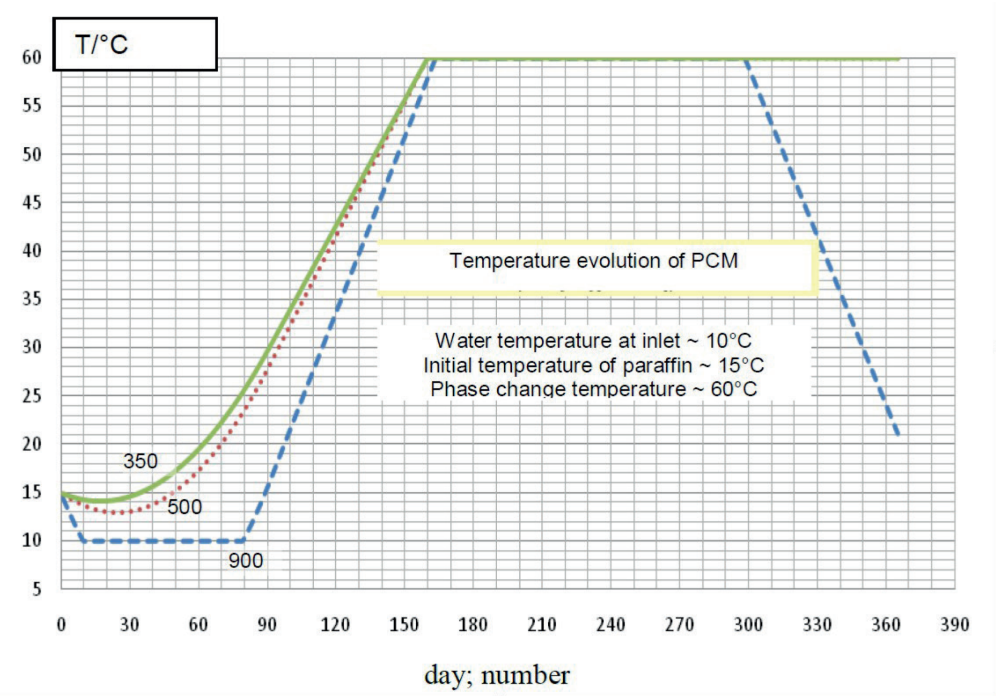

Fig. 3. PCM (paraffin) temperature evolution for various number of citizens: 350, 500 and 900

3. Conclusions

The simulations performed show that such thermodynamic system consisting: biogas installation, internal combustion engine, PCM tank and district heating can hardly provide the highly efficient CHP system. There is a solution to it, which base on additional customer for 2 GWh low temperature heat (up to 60°C). Another solution can base on heat pump application.

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Acknowledgement

This article was partly supported by the LowTEMP project co-funded by the European Union (European Regional Development Fund & European Neighborhood Instrument) in the frame of the Interreg Baltic Sea Region Programme 2014–2020.