Analyses of the thermal characteristics of construction details at the biogas station plant

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Abstract

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This paper presents analyses of the thermal characteristics of construction details at the biogas station plant, in order to investigate the impact of the thermal bridges on the energy consumption. Thermal bridges in the building's envelope remain a weak spot in the constructions. Heat losses of biogas plant constructions are a negative phenomenon and cause wasting of energy. If we eliminate thermal bridges in constructions we can achieve a reduction of general heat losses and save a certain amount of heat energy for utilization. Correct structural design of construction details has impact on general environmental and economic characteristics of biogas plant.

Keywords: buildings; thermal bridges; thermal losses; energy consumption

Biogas is a promising renewable fuel, which can be produced from a variety of organic raw materials and used for various energy services. For example ten percent of Swedish biogas production is currently upgraded and used as vehicle fuel in buses, distribution tracks and passenger cars and the remaining biogas is mainly used for heat or combined heat and power (Lantz et al. 2007). Another use of biogas in practice is as non–traditional source of energy in drying techniques (Vitázek, Tirol 2011). Some authors state that biogas is a renewable energy with high increase developed in last few decades (Moravec et al. 2011). The author also states that it is a big opportunity for economic stabilization of rural areas and agricultural sector. Biogas is produced through microorganisms that degrade organic materials in anaerobic environment. The feedstock can consist of various types of organic materials, mainly biodegradable waste from municipal sphere, farm wastes from livestock production and specialized energy crops production such as maize. Pastorek et al. (2004) state that biogas contains 50–75% of methane, 25–50% of carbon dioxide and adulterants of minor gas such as hydrogen sulphide. Besides biogas production, anaerobic digestion also transforms the added feedstock into digestate that can be used as fertiliser in crop production (Börjesson, Berglund 2003). Biogas is produced in special technological construction called biogas plant. The conceptions of biogas plants are very various and depend mainly on the type of technological process and processed feedstock. The most biogas plants in the Czech Republic are designed as farm biogas plants to processing biological materials such as maize silage and slurry. These biogas plants with continual process are intended for processing of liquid biological materials with 3–14% of dry matter. The main parts of biogas plant construction consist of mechanical pretreatment, feeding and transportation technological equipment and anaerobic reactors (fermenters). Other technological equipment is specified for mixing and heating of fermenters and for accumulation, cleaning and utilization of biogas (Pastorek et al. 2004). Most of farm biogas plants run in the mesophile mode at temperature 25–35°C (Schulz, Eder 2004). Very important is correct structural design of biogas plant. The design of constructions has to be in harmony with requirements of legislation. The most important legislation in energy parameters of construction is the European Directive 2010/31/EC on the Energy Performance of Buildings. Most of farm biogas plants in the Czech Republic have a technology with combined heat and power production. These biogas plants have heat utilization such as drying of materials or heating of buildings. Larbi (2005) and Déqué et al. (2001) state that envelope thermal insulation is the most effective measure for reduction of thermal losses and for improvement of the buildings energy efficiency. The authors also state that there are the problems of thermal bridges, appearing for example at the junction between two separately insulated elements, or between a vertical and a horizontal element. National regulations in energy performance of buildings specify various requirements for the insulation of the various buildings elements according to specific thermo physical characteristics. National regulations specified calculations procedures, based on various standards, varying from simple one-dimensional considerations steady state to more sophisticated two-dimensional dynamic models.

Thermal imaging system is a standard tool for identification of thermal losses of objects. This system is the most often used for identification of thermal bridges in buildings. However many papers deal with the use of thermal imaging system for non-traditional applications. These include the use of thermal imaging system in drying technique (Vitázek, Tirol 2008) or use system for calculation of heat losses of boilers for combustion biomass (Vítěz, Trávníček 2011). The goal of the paper is evaluation of the thermal characteristics of construction details at the biogas station plant with a view to thermal bridges. In one part of the paper there is calculation of the heat flux and thermal power according to equation by Wilkes-Peterson (Bašta 2000).

MATERIAL AND METHODS

The analysed biogas plant is located at Znojmo region, Czech Republic. This biogas plant represents farm biogas plant which is situated close to the livestock production. It was built in the year 2007. The biogas plant is in interconnection with livestock production (pigs breeding). The feedstock consists of slurry from livestock (daily production 27 m^3) production and maize silage from plant production, sugar extraction residue and grains from processing of agricultural production. The technology of biogas plant was supplied by the Weltec BioPower Corporation (Vechta, Germany). The technology of biogas plant consists of two concurrently exploited reactors (unit reaction volume 1,500 m^3). The spaces of reactors are circular-cylindrical and were constructed from rustless sheet metals. The basements of reactors are from monolithic steel concrete. In upside of reactors there are gas-holders (storage volume 400 m^3). Each of the reactors is equipped with solid substrate dosing feeder (volume 16 m^3), two slurry tanks (volume 70 and 90 m^3) and central pumping unit. For the stocking of digestate there are two open-air storage tanks from monolithic steel concrete (storage volume 4,000 and 3,000 m^3). Combined heat and power technology for biogas utilization comprises three cogeneration units featuring the installed power capacity of 2 × 175 kW and 1 × 180 kW. The cogeneration units are placed in an independent steel container. The general electric output is 495 kW. The general heat output is 203 kW. There is a possibility to control the electric output from biogas plant between 90–495 kW. The cogeneration technology was supplied by TEDOM a.s., Třebíč, Czech Republic.

Thermal analyses were executed by the FLIR E320 thermal camera (FLIR Systems Inc., Wilsonville, USA). For thermal imaging measurement purposes the air temperature, air humidity, distance from the monitored object and material emissivity were measured. Determination of material emissivity was executed by creation of measuring points on the materials, where thermal analyses were executed. On these points temperature was measured using the OMEGA HH11 contact thermometer (OMEGA Engineering Inc., Stamford, USA), accuracy of temperature measurement: ± 0.1°C. The most significant prerequisite was to prevent fluctuation of temperature in the course of time. The aforementioned point was also monitored using the FLIR E320 thermal camera. In case that the temperature values proved to differ, the temperature in the thermal camera was calibrated by the means of setting up the emissivity value in the user interface of this device. The final emissivity value was determined at the time when the temperature values on both devices were balanced.

The air temperature and humidity were measured using the OMEGA RH81 thermo-hydrometer (OMEGA Engineering Inc., Stamford, USA) featuring the temperature measurement accuracy of ± 1°C and humidity measurement accuracy of ± 4% (at the temperature of 25°C and relative humidity within the range of 10–90%). The temperature and humidity were measured in the close vicinity of the thermal camera and measured equipments, and the arithmetic mean was subsequently calculated on the basis of these values. The reflected temperature was not measured because no heat sources were in surroundings that could influence the measurement. The measurement was realized in cloudy conditions. During temperature measuring of the storage tank conditions temporarily changed in somewhat cloudy. There could be a little deviations of measurement as a consequence of solar radiation. Solar radiation was there only for a short time and could not expressively affected measurement. This is the reason why we did not care this fact in calculation.

The thermal screening measurement was conducted at a constant distance from measured equipment. Three thermograms were created in the course of one hour. The distance of the camera from measured equipment was determined using the Leica DISTO™ A5 laser EDM device (Leica Geosystems AG, Heerbrugg, Switzerland) (measurement accuracy: ± 1.5 mm at a distance between 0.2 and 200 m). The thermal imaging measurement as such was conducted using the FLIR ThermaCAM E320 thermal camera (field of view (FOV) 25°). The average temperature of the surface was calculated using ThermaCAM QuickReport software (FLIR Systems Inc., Wilsonville, USA) in which each pixel of the video recording was allocated to one temperature value. An arithmetic mean was subsequently created on the basis of all values.

Total heat losses Q of objects were calculated according to equation:

$$Q = S \times (I + q_t) \text{ (W)} \tag{1}$$

where:
I – intensity of grey-body radiation (W/m^2)
q_t – heat losses due to convection (W/m^2)
S – outer surface of boiler (m^2)

Heat losses due to convection were calculated with the use of the convective heat transfer coefficient. This coefficient was determined according to Wilkes-Peterson (Bašta 2000):

$$\alpha_k = 3.04 \times \Delta t^{0.12} \text{ (W/m}^2\text{·K)} \tag{2}$$

Then heat loss was calculated according to the equation:

$$q_t = \alpha_k (t_1 - t_2) \tag{3}$$

where:
α_k – convective heat transfer coefficient (W/m^2·K)
t_1 – temperature of air (°C, K)
t_2 – temperature of surface (°C, K)

Heat losses due to radiation are calculated with help of the Stefan-Boltzmann law (Bašta 2000). At first total intensity of grey body radiation is calculated. Then total intensity of an environment radiation was subtracted from total intensity of grey body radiation.

The equation for calculation of heat losses due to radiation is following:

$$I = (\sigma \times \varepsilon_s \times T_s^4) - (\sigma \times \varepsilon_t \times T_t^4) \text{ (W/m}^2\text{)} \tag{5}$$

where:
ε_s – emissivity of grey-body (–)
ε_t – emissivity of environment (–)
T_s – thermodynamic temperature of grey-body (K)
T_t – thermodynamic temperature of environment (K)
σ – Stefan-Boltzmann constant (W/m^2·K^4)

RESULTS AND DISCUSSION

The first objects of thermo vision analysis were fermenters 1 and 2. These objects are designed like cylindrical tanks from rustless metal plates. There are basement constructions under these tanks designed like basement slab from steel concrete without thermal insulation. At the outside of these tanks there are five circular racks from thin-walled steel section with integrated thermal insulation from expanded Styrofoam boards (thickness 100 mm; α_k = 0.39 W/m^2·K). The claddings of fermenters are from varnished (green varnish) aluminous trapezium sheet metals. In upside of reactors there are gas-holders (storage volume 400 m^3) from dual membranes (consists of polyethylene textile with rubber coating in white colour). In Fig. 1 we can see the thermogram of details of external coatings of fermenters.

These thermograms presented that there is evident increased heat flow at the circular steel racks. Criti-

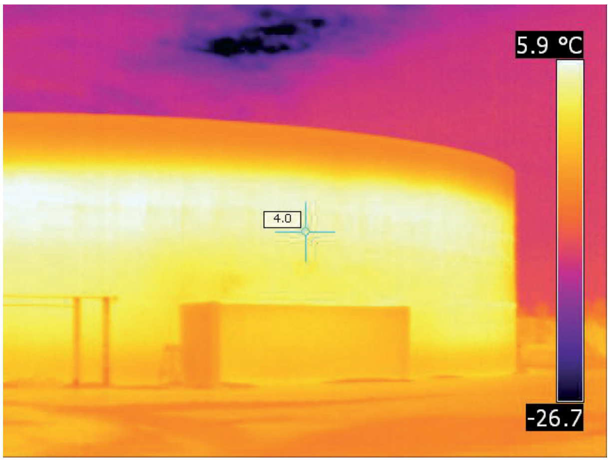

Fig. 1. Heat losses of the biogas fermenter

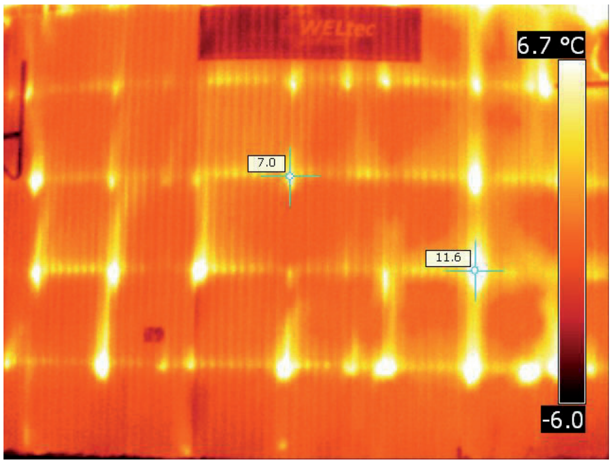

Fig. 2. Heat losses of the gas holder

cal details are at the corner crossing of the racks. The reason of existing thermal bridges is absence of thermal insulation of steel rack and its straight contact with the outdoor environment. A similar problem with thermal bridges caused by steel framework is presented by Höglund and Burstrand (1998); the authors presented innovative construction of slotted steel studs framework in external walls. Other interesting facts are reported by Al-sanea and Zedan (2012) where authors analysed the influence of horizontal and vertical joints which cut insulation layers in building walls. As appropriate solution of our case implementation of next thermal insulation of external cladding is recommended. This new thermal insulation can overlay thermal bridges at the steel rack. The other suitable solution is additional external thermal insulation of the basement slab.

The next analysed objects were constructions of the gas-holders at the fermenter 1 and 2. One of the objects is presented at the thermogram in Fig. 2.

At this thermogram it is evident that the thermal insulation of dual membranes gas-holders is poor. That is the reason of increased heat losses of this construction. There is a significant critical detail in connection of gas-holders membrane and external cladding of fermenters. Appropriate solution of this problem is replacement of membrane on behalf of material with lower thermal conductivity (e.g. membrane with integrated polyurethane layer). Alternatively it is possible to construct new roofing with thermal insulation over gas-holders.

Other analysed objects were storage tanks for digestate. These tanks are not roofed and without thermal insulation. The cladding and the basement

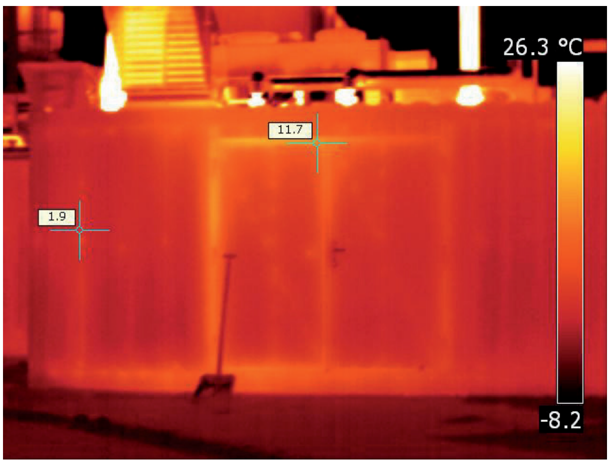

Fig. 3. Heat losses of the storage tank

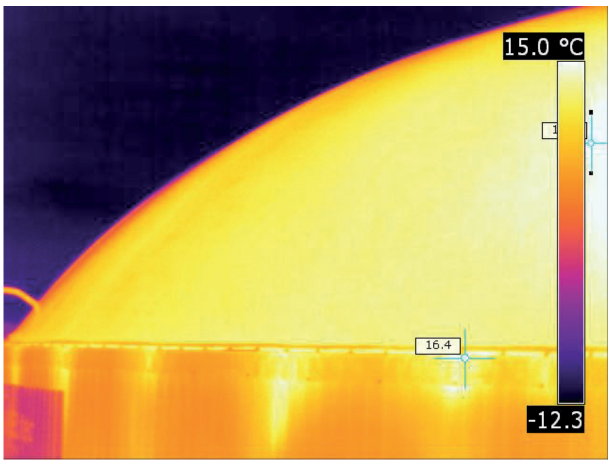

Fig. 4. Heat losses of the steel container with the cogeneration unit

Table 1. Emissivity of measured materials

Object	Material	Emissivity (–)
Fermenter 1	steel	0.87
Fermenter 2	steel	0.87
Gas holder 1	rubber	0.79
Gas holder 2	rubber	0.79
Storage tank 1	concrete	0.89
Storage tank 2	concrete	0.89
Steel container 1	steel	0.87
Steel container 2	steel	0.87

slab of these tanks are from steel concrete. Thermogram of this construction is presented in Fig. 3.

We can see that the cladding of the storage tank is heated. Higher temperature of this construction follows on heat-up from digestate. Bio-gas transformations are not controlled in those tanks. It is thus not necessary to make additional thermal insulation.

Also we performed analysis of combined heat and power object. Combined heat and power is situated in independent steel container beside of fermenters. Internal thermal insulation of container cladding is from expanded Styrofoam boards (thickness 100 mm; α_k= 0.39 W/m^2·K). Cladding of container is from varnished aluminous trapezium sheet metals. Thermogram of combined heat and power object is presented in Fig. 4.

We can see that more intense heat flow is at the points of bearing steel frame of container because there is thermal insulation of less thickness and there is a thermal bridge in horizontal and vertical joints. It is similar to the case study of slotted steel studs framework in (Höglund, Burstrand 1998). Other similar situations are described in (Juárez et al. 2012). Significantly higher surface temperature is at the exhaust tubes and silencers. Container has sufficient thermal isolative characteristics and it is not necessary to make additional thermal insulation.

In Table 1, emissivity of measured materials for next evaluation of thermograms is presented.

Values of heat fluxes and thermal power are presented in Table 2. Heat losses due to radiation were insignificant. The value of heat losses due to radiation can be thus ignored. The biggest heat losses were recorded in fermenter 1 and fermenter 2, where the value of thermal power is 8,733.1 and 8,850.2 W, respectively. When thermal losses of thermal bridges are only calculated, thermal power decreases to the value 1,631.9 and 1638.2 W, respectively. Total thermal power of biogas station objects considering heat losses is 37,745.3 W.

Table 2. Heat fluxes of various objects in biogas station (calculation by Wilkes-Peterson)

Object	Heat flux (W/m^2)	Thermal power (W)
Fermenter 1	18.0	8,733.1
Fermenter 2	18.0	8,850.2
Gas holder 1	19.5	2,144.3
Gas holder 2	19.5	1,249.0
Storage tank 1	18.9	8,888.4
Storage tank 2	18.9	7,407.0
Steel container 1	21.2	84.9
Steel container 2	21.2	88.3
Total		37,445.3

CONCLUSION

The existence of thermal bridges is significant for thermal isolation characteristics of constructions and heat losses of objects. That is the reason why consequential designing of every detail of constructions and elimination of thermal bridges is necessary. Also it is necessary to make a provision for existence of thermal bridges in calculations of thermo technological characteristics of constructions.

The results of this paper indicate that the construction details of the biogas station plant can create thermal bridges. Heat losses of the constructions are a negative phenomenon and lead to wasting of energy and degradation of materials. This paper shows that the constructions of analysed biogas plant are often not enough protected against higher heat losses. Very problematic is especially solving of structural details of building and insufficient thickness or absence of thermal insulation. Currently we can see an increase in utilization of heat energy which is produced by combined heat and power. Heat energy is exploited especially for heating up of fermenters (optimal temperature for microbial activity). There is an intensive pursuit for next utilization of heat energy at various activities (e.g. heating of stables, greenhouses and other farm buildings, drying of farm products or woods). If we eliminate thermal bridges in the constructions we can achieve a reduction of general heat losses and save amount of heat energy for utilization. A correct structural design of the construction details has impact on general environmental and economic characteristics of biogas plant.

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