The Assessment of Thermal Insulation of Bioreactors for an Aerobic Biostabilization of Waste

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Abstract. The aim of the study was to analyze and assess the thermal insulation of three walls (the side wall, the front wall with a hook and the back wall – the door) of a bioreactor for an aerobic biostabilization of waste (built in accordance with the DIN 30722 standard) for 3 different variants of thermal insulation applied. It should be noted that currently there are no requirements in the literature regarding the design of a thermal insulating layer of bioreactors in municipal solid waste treatment installations in Poland. The side wall of the bioreactor and the front wall (with a hook) appeared to have the best thermal insulation while the back wall (the door of the bioreactor) showed the worst insulation. This was confirmed by photographs (thermograms) taken using a thermal imaging camera. The highest observed temperatures were recorded on the door of the bioreactor, on which many thermal bridges were also visible. The lowest mean temperatures on the surface of the bioreactor walls were obtained using foam insulation (variant 1), however, it was found that the differences between the temperatures of the analyzed elements in particular variants were not statistically significant.

Keywords: Aerobic biostabilization · Heat transfer · Thermography

1 Introduction

Installations for mechanical and biological treatment (MBT) of mixed municipal solid waste have been the basic form of municipal waste management in Poland since 1 July 2013. In the MBT plant, the oversize fraction with a grain size >80 mm (which can be used e.g. in cement plants as an alternative fuel) and undersize fraction with a grain size below 80 mm (directed to the biological part of the MBT plant for biological drying, aerobic stabilization or methane fermentation) are generated [5, 6, 9]. One of the most popular biological waste treatment methods in the MBT plant is aerobic biostabilization. This is a process of biological treatment of organic waste, carried out under

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aerobic conditions [1, 7, 10]. The processes of aerobic biostabilization and bio-drying are the best way for decomposition of organic matter contained in the waste (as a result of the activity of various groups of microorganisms), which is accompanied by an increase in temperature [1, 4, 7, 8, 19]. High temperature kept in the range of 50–60 °C is advantageous for aerobic bacteria, the activity of which is then the highest. This causes the process to proceed dynamically and the product of the stabilization process, which is the stabilizer, can be obtained in a shorter time. Jędrczak [9] states that all biological waste treatment processes should be carried out in specially designed bioreactors, which allows controlling the process.

The aim of the study was to assess the thermal insulation of 3 different elements (walls) of bioreactors with container construction designed for aerobic biostabilization of waste. The research was carried out for three different construction variants of isolated bioreactors for aerobic stabilization of waste in real conditions in the MBT plant in Kraków (Poland). Proper selection of solutions for thermal insulation of bioreactors is indispensable to ensure the lowest possible heat loss through the bioreactor walls. The waste deposit cooling (inter alia due to the heat loss through the wall of the bioreactor) results in the process being slowed down.

So far no similar studies have been carried out for bioreactors for biostabilization of waste. This is a novelty of the tests carried out. Teleszewski and Żukowski [18] give the results of research on the thermal insulation of bioreactors for the production of biogas in Polish conditions.

2 Materials and Methods

The bioreactor for aerobic biostabilization of waste is a closing construction of working volume of 33 m^3 with a hook and special skids which enable its loading on a hook lift. The bioreactor was built in accordance with the DIN 30722 standard with a wall thickness of 4 mm. The walls, roof and bottom of the bioreactors were additionally insulated with a layer of polystyrene foam, insulating foam and external metal sheet depending on the type of construction (variant). The bioreactors have openings for delivery and removal of process air, as well as an opening for getting rid of leachate. The bioreactors are airtight, so that there is no possibility of uncontrolled contact of the process air with the atmosphere. The analysis covered three walls of bioreactors, i.e. the side wall, the front wall with a hook and the back wall (the door of the bioreactor). The research was carried out for three variants of insulation of bioreactor walls:

1. insulation with insulating foam (60 mm) and 1 mm external metal sheet;
2. insulation with polystyrene foam (40 mm) and 1 mm external metal sheet;
3. insulation with polystyrene foam (20 mm) and external metal sheet 2 mm.

In order to determine the substitute heat transfer coefficient, the thermal resistance of individual elements was calculated for the side wall, front wall with a hook and the back wall (door) of the bioreactor. The thermal insulation of the partitions depends on the size of the heat transfer coefficient through the partition. It is the reverse of the total thermal resistance, which consists of the thermal conductivity coefficient of the material from which the partition is made and the thickness of this partition, as well as resistance to heat penetration on both sides of the partition (internal and external).

Each construction material is characterized by a different heat conduction coefficient, therefore it is possible to determine whether a given material is a good thermal insulator or not. The lower the coefficient value, the better the insulation level. Heat transfer coefficient indicates the amount of heat that permeates within 1 h through 1 m^2 of a flat partition with the difference of air temperature on both sides of it equal to 1 °C (1 K). In order to determine the heat transfer coefficient of the bioreactor walls, the PN-EN ISO 6946 standard was used.

The assessment of thermal insulation of bioreactors for aerobic stabilization of waste was undertaken employing the FLIR ThermaCAM E300 thermal imaging camera. The images were digitally processed using the ThermaCAM ™ FLIR QuickReport 1.2 software. Thermography deals with the detection, recording, processing and visualization of infrared radiation, which is invisible to the human eye, emitted by each object, as a result of which it receives a digital image (thermogram) representing the temperature distribution on the surface of the object in question [11, 15, 17, 20]. All bodies that is solid, liquid and gas, whose temperature is higher than 0 K (−273.15 °C), emit thermal radiation called infrared radiation. The measured thermal energy of the object depends on the spectral, thermal and physical properties of the material [13, 14, 16, 18, 20].

Thermography is a method that enables to visualize the temperature distribution on the surface of a given element. The measurement takes into account the influence of the environment, which can distort the thermal image of the thermogram [2, 3, 12–14]. The execution of thermograms of the external walls of buildings and their analysis allows non-invasive identification of defects in the insulation layer, as well as the occurrence of manufacturing errors, mold or moisture [11].

The photos of bioreactors were taken between the 3rd and 4th day of the aerobic biostabilization process of waste. The tests were carried out from December 2017 to February 2018. The air temperature on the measurement days was 0 ± 3 °C and the temperature inside the bioreactors 60 ± 5 °C. Most often the sky was overcast, but with no rain, snow or wind. Solar radiation did not significantly affect measurement errors. The surfaces of bioreactors were carefully cleaned of all kinds of contaminants. 81 photos were taken during the measurements. For each variant, 27 thermograms illustrating bioreactors for aerobic biostabilization of waste were executed. In each variant, three different bioreactors were analyzed. The bioreactors were structurally new (production date: March 2016).

3 Results and Discussion

Table 1 presents the data that enabled calculation of a substitute heat transfer coefficient for individual construction elements of the bioreactor presented in Table 2. The calculations assumed heat transfer coefficients from the internal side of the bioreactor at the level of 0.066 (m^2 K) W^{-1} and from the external side of 0.04 (m^2 K) W^{-1} [17]. The lowest thermal resistance was demonstrated for variant 1 (foam insulation (60 mm) and external metal sheet (1 mm)). The highest thermal resistance was noted for the side wall for variant 1, the resistance amounted to 2.87 (m^2 K) W^{-1}, while the lowest resistance was observed for the back wall (variant 3): 0.8 (m^2 K) W^{-1}. The lowest heat transfer coefficient and hence the highest thermal insulation was discerned for the side wall of the bioreactor in variant 1 (Table 2), for which the heat transfer coefficient equaled to 0.35 W $(m^2 K)^{-1}$, while the lowest thermal insulation was noted for the back wall (the door of the bioreactor) in variant 3: 1.25 W $(m^2 K)^{-1}$.

Table 1. Heat transfer coefficients for individual types of layers forming the bioreactor structure

Type of material	Heat transfer coefficient W $(m^2 K)^{-1}$	Layer thickness (m)
Metal sheet (construction steel)	58	0.001
Metal sheet (construction steel)	58	0.002
Polystyrene foam	0.043	0.02
Polystyrene foam	0.043	0.04
Insulating foam	0.025	0.06

Table 2. Heat transfer coefficients of individual structural elements of the bioreactor

Type of structure	Unit	Variant 1	Variant 2	Variant 3
Side wall	W $(m^2 K)^{-1}$	0.35	0.48	0.79
Front wall with a hook	W $(m^2 K)^{-1}$	0.38	0.55	0.97
Back wall (door)	W $(m^2 K)^{-1}$	0.42	0.62	1.25

Figure 1 shows the temperature distribution on the side wall surface of one of the analyzed bioreactors (variant 1). The marked pixels Sp1 and Sp2 indicate the temperatures of the process air discharge conduit from the bioreactor. The Ar1 area indicates the range of temperature values on the side wall of the bioreactor. With the use of the Li1 and Li2 lines, the temperatures on the ribs (structure) of the bioreactor, whose temperature in the lower part was higher than the rest of the wall of the bioreactor, were visualized. A similar situation with a bioreactor ribbing which is well visible on the thermogram is shown in Fig. 2 (the thermogram of the bioreactor whose thermal insulation was made of polystyrene foam with a thickness of 20 mm and metal sheet thickness of 2 mm (variant 3). Figure 2 shows that the door of the bioreactor had a much higher temperature than the side wall, which was due to the very high value of the heat transfer coefficient (1.25 W $(m^2 K)^{-1}$).

Table 3. Mean values of temperatures of analyzed structural elements of the bioreactor

Type of structure	Unit	Variant 1	Variant 2	Variant 3
Side wall	°C	16.3 ± 6.1	17.1 ± 5.4	17.2 ± 5.9
Front wall with a hook	°C	17.3 ± 5.6	17.9 ± 4.4	17.8 ± 7.1
Back wall (door)	°C	20.2 ± 4.2	21.1 ± 5.2	22.0 ± 5.4

Table 3 presents mean temperatures of individual structural elements of bioreactors calculated on the basis of the analysis of thermograms. The highest temperatures concern the door of the bioreactor, on which numerous thermal bridges were evident. The lowest mean temperatures were recorded on the surface of the bioreactor walls, the insulation of which was made of foam (variant 1), however, it was found that the differences between the temperatures of the analyzed elements in individual variants were not statistically significant. This means that when selecting insulation materials for the construction of a bioreactor, economic factor should be considered and the cheapest option chosen. In this work, thermal bridges were not assumed in the calculations.

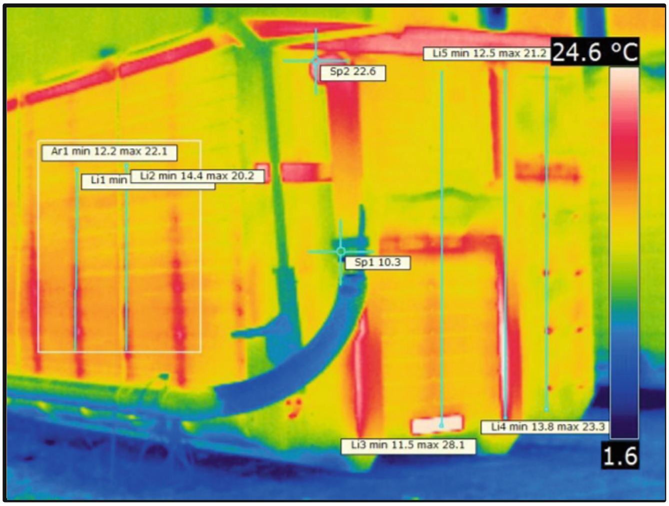

Fig. 1. Temperature distribution on the surface of the side wall and the front wall of the bioreactor (variant 1)

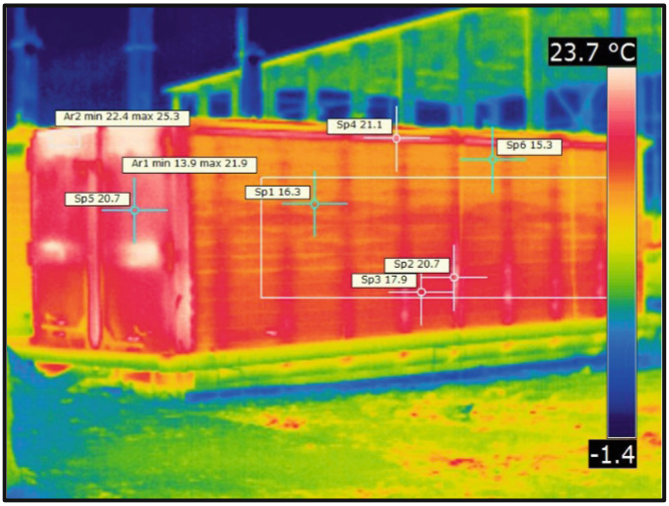

Fig. 2. Temperature distribution on the surface of the side and back walls of the bioreactor (variant 3)

Thermal bridges noticeable on thermograms were of structural and geometrical character. The main reason for the occurrence of thermal bridges involves the design or assembly errors. Structural thermal bridges are those that appear as a result of difficulties in executing the insulation due to structural solutions (in this case, the ribbing of the side walls of the bioreactors and the door of the bioreactors). In turn, geometric thermal bridges are connected with the shape of the external partitions of the bioreactor and occur in the corners of the bioreactors. In the place where the ladder was attached to the front wall, the occurrence of a point thermal bridge was noted, which had been the result of a puncture of the insulation layer by fixing bolts. The most common thermal bridges are caused by: breaking the continuity of the insulation layer, insufficient thickness of the thermal insulation layer and inhomogeneity of the partition structure, i.e. occurrence of elements that conduct heat better in the construction of the partition [18].

4 Conclusion

The paper presents an analysis of thermal insulation of walls of bioraector for a typical municipal solid waste treatment plant under the Polish climatic conditions. The simulations were made for an existing object. On the basis of the conducted research, the following conclusions were drawn:

1. Thermal insulation of bioreactors for aerobic biostabilization of waste is adequate for the process carried out in them.
2. All of the tested bioreactors had similar thermal insulation of side walls. The side wall of the bioreactor and the front wall with a hook appeared to have the best thermal insulation while the back wall (the door of the bioreactor) showed the worst insulation.
3. The analysis of the thermograms of individual structural elements of the bioreactor showed that there were thermal bridges on the surface of the walls (mainly the door of the bioreactor).

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