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Thermography evaluation of a bioreactor's heat loss to surrounding environment

The thermal losses of a bioreactor have to be compensated for fermentation process maintaining (the temperature first of all). In order to decrease consume heat by the bioreactor and to make up thermal losses a heat insulation has been performed. In this paper a noncontact and nondestructive thermography qualification of the thermal losses and evaluation of the heat insulation's quality for an anaerobic bioreactor is offered. By using software Researcher a thermography analysis for three different cases (without compensated heat losses; with one layer of thermal insulation; with two layers thermal insulation) is carried out. The received results show the advantages of the used approach for qualification of different kind of heat insulations.

Keywords: *thermography, heat losses, anaerobic bioreactor.*

Introduction

Thermography, or obtaining thermal images, is a method that allows remote and destructive study of the phenomena related to the spatial distribution of heat in the studied objects and its change during the time [1]. In recent years infrared thermography has made a reputation in the function of a powerful diagnostic tool for predictable maintenance of installations in various engineering fields.

The modern infrared cameras are beginning to be used in technology as appropriate addition to the other research methods [2]. By the infrared cameras it becomes easy to quickly, accurately and profitably reveal energy loss caused by poorly installed insulation and most importantly, makes it visible. Another area of application of infrared cameras is in the localization of holes and cracks in pipelines. This thermographic localization of damages gives opportunity to find the damaged areas without all the tube to be pulled out since as small as the jet fluid comes out of the tube, it causes change of the wall or isolation temperature, which is very easy to be detected by an infrared camera. Even distribution of temperature inside creates a prerequisite for testing the distribution of temperature on the outside of fireplaces and furnaces, as it explains the heat dissipation of temperature. In locations with layered sediments in

fireplaces and furnaces lower temperatures are observed by an infrared camera. The wear of insulating materials is explaining the places with higher temperature. Data is obtained showing that it can be made a differential conclusion for the remaining life of a detail. Thus the in time change of the detail that has started damaging may be planned. The use of infrared cameras, shooting in real time, is very good as a means of maintenance, inspection and documentation of energy losses and quality control of insulation.

In this article an approach for applying a thermography approach to characterize the compensation of heat loss in anaerobic bioreactor, using insulation with high reflection is proposed.

Representation of the thermography approach

Obtaining of biogas (methane) from organic products achieves primarily two tasks:

obtaining of biogas (methane) as a renewable energy source; ecological effect (transformation of organic matter into simpler and steady compounds by particular microorganisms cultured in the absence of oxygen).

There are two main temperature regimes for obtaining biogas - mesophilic and thermophilic.

In mesophilic mode the temperature of the substrate in the bioreactor is maintained (organic matter + water + mesophilic microorganisms) in the range of $34 \div 35$ °C.

In thermophilic mode the analogous thermophilic temperature in the bioreactor is 55 °C. During the operation the substrate is mixed. His average stay in the bioreactor is 20 days. Usually bioreactors operate in a continuous cycle (year-round) and daily portion of fresh substrate is fed as the same amount of exhausted mass is removed.

The experimental fermenter is a cylinder with height $h = 935$ mm and a diameter $d = 435$ mm. He has a water jacket on the cylindrical part to heat the substrate. It is made of stainless steel with a thickness of 5 mm and thermal conductivity $\lambda = 45$ W / m.K. The fermenter is expected to be filled with a substrate at about 75-80% of its volume. As the steel is a strong heat conductor it can be considered that the walls of the biogas (upper) part of the fermenter will have nearly the same temperature as the bottom, which is filled with substrate. An insulation of the fermenter made by

mineral wool with thermal conductivity $\lambda = 0,035 \text{ W / m.K}$ is stipulated.

The yield of biogas from the fermenter for a twenty-four-hour period is 78 dm^3 with an energy value of 6 kWh/m^3 [1].

For our latitudes, especially during the winter period, maintaining the temperature of the fermenter leads to heat loss of the same, i.e. the heat from the fermenter dissipates in the surrounding area. This heat is exchanged mostly by convection and radiation from outer surface of the fermenter to the environment. To maintain the fermentation process (especially its temperature) the heat losses have to be covered. This is normally done by an external heat source. For the experimental bioreactor that is made by electric heaters.

In order to reduce the consumption of heat by the bioreactor to offset heat loss, it is insulated (fig. 1). The thermal insulation is mineral wool 40 mm thick and aluminum foil. The same is placed in two layers, i.e. 80 mm. This results in lower surface temperature of the outer surface of the bioreactor and thus lower heat losses to the environment.



Fig.1. Accomplishment of heat insulation of the bioreactor to compensate the heat losses

The heat losses from the surface of the equipment to the environment are determined by the formula

$$Q = \alpha(t_m - t_a)S, \quad (1)$$

where α – heat transfer coefficient of the surface, $\text{W/(m}^2\text{°C)}$; t_m – average surface temperature, $^{\circ}\text{C}$; t_a – temperature of the air in the environment, $^{\circ}\text{C}$; S – surface area, m^2 .

The determination of heat loss requires determination of all components of the equation and is implemented in the course of comprehensive study involving both thermograms and contact measurements.

The results from the infrared images are the thermograms of the object surface from which the average surface temperatures are determined. The air temperature in the environment is measured by thermometer. To determine the coefficient of heat transfer from the surface the density of heat flow through the surface at certain points - the base stations is measured.

The heat transfer coefficient is calculated from the experimentally obtained data

$$\alpha = q/(t - t_a), \quad (2)$$

where q – density of heat flow, W/m^2 ; t – surface temperature in the test point, $^{\circ}\text{C}$.

The presented approach can be used to determine the heat loss for any kind of equipment and to assess the quality of thermal insulation.

For this study it is used thermal camera type ThermaCAM SC640 of FLIR with non-cooling microbolometric matrix of 640×480 pixels [3]. FireWire configuration is used for communication between the infrared camera and the computer. For processing and analysis of thermal images the software Researcher is used. Using OLE, it is possible ThermaCAM TM Researcher to be managed remotely.

For accurate temperature measurement the effects of several different sources of radiation must be compensated. This is done automatically by the camera in real time.

Since the material, used for insulation of anaerobic bioreactor, is mineral wool with aluminum foil, additional measures determined by the following features had to be taken.

It is known that polished metal surfaces have low absorbability and thus have little radiation in the infrared range, at about 5% of the emissivity of black body. Therefore, glow emitted by such a metal surface is weak and produces only weak infrared images. It is even worse when there is presence of grease, oil stains or slightly oxidized zones, which can alter the value of surface emissivity at about 5, 10 or 20% of that of black body (an oxidized surface shows higher radiation). This produces visible hot spots in the infrared images that can be interpreted as falsely damaged areas.

Moreover, the high reflection of metal surfaces determines a problem of parasitic reflection, this is when radiation is emitted by warm bodies and are reflected on the metal surface which acts as a mirror in the infrared spectrum.

This reflected image is superimposed on the image radiated by the inspected metal surface, conditioning the establishment of parasitic hotspots, which would further complicate the thermographic interpretation. Therefore, extreme caution is required in determining the placement of the material that has a reflective surface. Another requirement is the radiation to vary depending on the viewing angle.

A common approach to solving the radiation problem is to cover metal surfaces with high - emitting paste before the inspection. These "black pastes" with a constant and high emissivity in the

infrared band have a property to reflect less. Therefore, if it is applied to surfaces with lower emission, interference caused by neighboring warm bodies can be cleared and thermographic inspection may become possible.

In conducting thermographic measurements there were used two different approaches to solve the radiation problem. For the assessment of pre-selected areas from the bioreactor surface there was used insulation tape 3M with known coefficient of emission. The second approach is connected to the capabilities of the software used for processing the infrared images. Temperatures are analyzed in the software environment of Flir ThermaCAM Researcher. This software allows different emissivity values to be reported for selected points or areas of the thermogram but not as homogeneous emissivity map of the object.

Moreover the thermograms, reflecting the dynamics of the heat flow, are handled as a package of frames. Emissivity map can be created both for the entire image and the selected area. The software changes the emissivity values from 1 to 0.01 and remembers the temperature for each emissivity value. After that interpolation of the emissivity is done. Finally, it can be generated emissivity map for each pixel of the image and can be saved a file such as bitmap file. The process of generating emissivity map is quite complex because of the calculation of the unknown temperatures in the ThermaCAM Researcher.

Three sessions of pictures in 4 hours were made by means of the infrared camera.

I session - no thermal insulation, moisture in the room is 53%, temperature in the reactor is 35°C, ambient temperature is 19°C;

II session - with one layer of insulation (40 mm), moisture in the room is 46%, temperature in the reactor is 33°C, and ambient temperature is 17°C;

III session - with two layers of insulation (80 mm), moisture in the room is 44%, temperature in the reactor is 35.6°C and ambient temperature is 26°C.

During the analysis of the thermograms the temperature profiles are mainly used because they are useful when it is necessary to illustrate the temperature difference across or along a single object in the image.

The easiest way to determine temperature distribution within a field or a line of the image is to look at the histogram that shows how the line or area is covered by a given temperature range.

To be able to see and compare two histograms at the same time a double histogram mode is used. It will then be possible to choose two analysis tools

to be displayed simultaneously. Fig. 2 and Fig.3 show thermograms, the distribution of the surface temperature and thermal histogram, respectively, for insulated and uninsulated bioreactor for the same internal temperature of reactor.

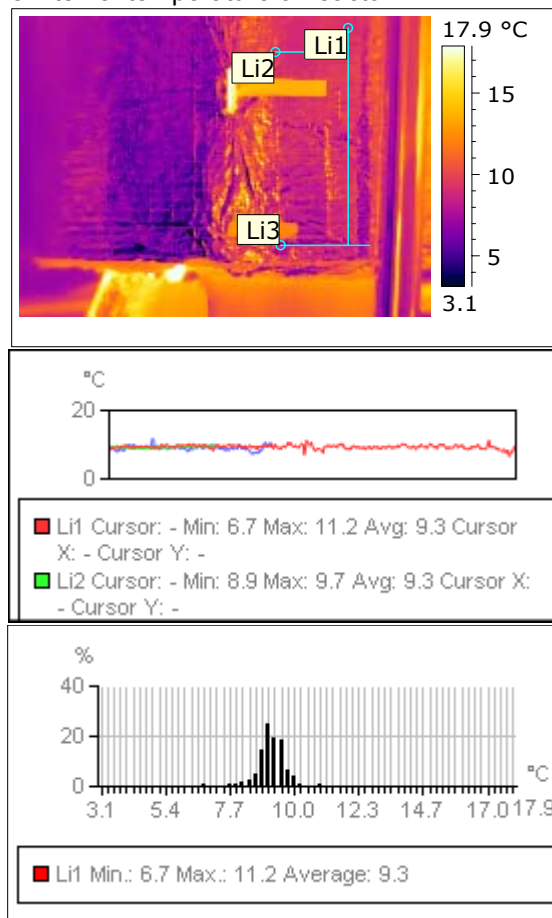


Fig.2. Distribution of surface temperature in performed double heat insulation at room temperature 26°C. The uneven surface of the foil is the reason for the crinkled profile

Conclusion

The widespread use of the opportunities, offered by infrared thermography, is a result of the reliable information for the condition of the technical equipment that it provides. The speed of inspection (i.e. the number of frames captured per second) allows this technique to be applied in real time.

From the analysis of thermograms for a particular study it can be concluded that:

- the outer surface temperature difference for insulated and uninsulated bioreactor is a maximum of 6°C for the upper and a maximum of 2°C for the bottom of the reactor;
- the temperature distribution on the surface of the bioreactor after the insulation becomes even on vertical direction;

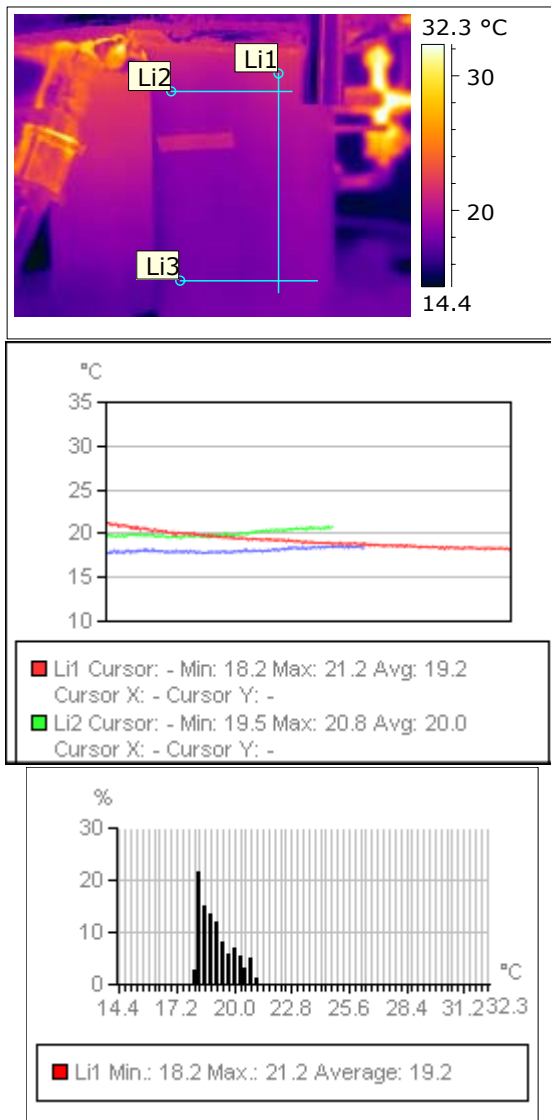


Fig.3. Distribution of surface temperature in an uninsulated bioreactor at room temperature 19°C

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- a significant surface temperature difference is noticeable after the first insulation layer of mineral wool – the efficiency is almost 2 times higher;
- when analyzing the data there are reported the temperatures in the reactor and in the room;
- measurements are made after at least 2 hours of work of the reactor.

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