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INFLUENCE OF AIR GAP ON INSULATING PROPERTIES OF COMPOSITE COATINGS ON PIPES FOR HOT MEDIA TRANSPORT

The shrinking resources of fossil fuels and the growing pollution of the environment have caused people to begin to search for possibilities of reducing energy losses. Vast possibilities in this area lie in industrial transport, called short distance transport, as well as in civil engineering. European Union authorities set limits for the emission of harmful pollutants and energy losses. That is why the laboratories of many research centres conduct research on composite insulating materials taking into account a nanotechnology and air gaps. The paper presents the results of research on steel pipelines used in the transport of hot media, insulated with PUR shaped materials covered with a composite coating with a polymer resin matrix containing an air gap between PUR and the pipe. Such a solution makes it possible to employ the reflective properties of selected materials, which, thanks to reflection of the heat flux, returns it to the source. An air gap with the thickness of 10 mm under the conditions of the conducted research, allows the heat losses of an steel industrial pipeline to be reduced by 7.6%.

Keywords: composite coating, thermal insulation, air gap, energy losses, industrial pipelines, short distance transport

WPŁYW SZCZELINY POWIETRZNEJ NA WŁAŚCIWOŚCI IZOLACYJNE POWŁOK KOMPOZYTOWYCH PRZEZNACZONYCH NA RURY DO TRANSPORTU GORĄCYCH MEDIÓW

Kurczące się zasoby kopalnych surowców energetycznych oraz zwiększające się zanieczyszczenie środowiska sprawiły, że ludzie zaczęli szukać możliwości zmniejszenia strat energetycznych. Bardzo duże możliwości w tym zakresie tkwią w transporcie przemysłowym, nazywanym transportem krótkiego zasięgu, oraz w budownictwie. Organy Unii Europejskiej wprowadzają limity emisji szkodliwych zanieczyszczeń oraz strat energetycznych. Dlatego w laboratoriach wielu ośrodków naukowych są prowadzone badania kompozytowych materiałów izolacyjnych z uwzględnieniem nanotechnologii oraz szczelin powietrznych. W artykule przedstawiono wyniki badań stosowanych w transporcie gorących mediów izolowanych kształtkami PUR rur stalowych ze szczeliną powietrzną między rurą a PUR. Takie rozwiązanie pozwala wykorzystać zdolności refleksyjne wybranych materiałów, które dzięki odbijaniu strumienia ciepła zawracają go do źródła. Szczelina powietrzna o grubości 10 mm w warunkach przeprowadzonych badań pozwala zmniejszyć o 7,6% straty ciepła rurociągu przemysłowego.

Keywords: powłoka kompozytowa, izolacja cieplna, szczelina powietrzna, straty energii, przemysłowe rurociągi

INTRODUCTION

The shrinkage of non-renewable energy sources on the Earth and the warming of the climate cause people to look for every possibility to limit energy consumption, and first of all energy wastes. One of these possibilities is to reduce energy losses (wastes) by the thermo-modernization of technical means, for example, buildings and pipelines for hot media transport. Buildings are additionally insulated with mineral wool, foamed polystyrene (white and grey) and polyurethane (PUR). Materials engineering has reached a temporary technical limit of reducing the thermal conductivity of insulating materials. A reduction in the thermal conductivity coefficient (λ) of foamed polystyrene or a polyurethane by 0.002 W/mK, is the goal of many manufacturers. Intensive research to find other ways to reduce the thermal conductivity of employed insulating materials are conducted in many scientific and industrial laboratories. Recently, studies and examinations of hybrid insulting panels have been carried out, i.e. plates of foamed polystyrene or polyurethane separated by reflective foils and an air gap with a thickness of 24 mm [1, 2]. Research on insulating materials with an air gap conducted in buildings in hot climates in Africa and Asia [2, 3] and climate in Europe [4] for roofing systems [4, 5] and walls [6].

In industry branches using pipe lines for the transport of hot media, many methods for reducing heat losses are applied. One of those is the manufacture and direct delivery to the end user of pre-insulated pipes, for example, pipes for hot water transport insulated with polyurethane coated with polyethylene as protection against damage.

Composite materials with a polymer matrix have found their application as insulating materials. They can be delivered as a pipe fitting (material shaped according to the place of application) and as a water soluble, semi-liquid coating material for application on pipes by means of painting or spraying methods [7, 8]. These coating materials have good insulating properties due to the presence of ceramic microspheres in which there is lower than atmospheric pressure. A thermal flux passing into a ceramic microsphere will be reflected due to the low level of vacuum and the microsphere wall. The thermal properties of such composite coatings depend on the properties of the matrix and microspheres, and on their volumetric fractions. The more microspheres with a lower thermal conductivity, the lower the conductivity of the composite is. Usually, coatings with 80-90% ceramic spheres are available. These coatings possess good reflexivity as well.

The best way to reduce the level of environmental pollution is attempt to employ a component of environment, i.e. an air gap, as an insulating material.

At the Silesian University of Technology, an attempt to check the influence of an air gap between a hot steel pipe and insulating shaped parts made of polyurethane and shaped parts coated with a composite insulating material having high reflection (TSR = 0.92) was performed. This paper describes the conditions and results of thermal flux losses in hot oil transport in pipes by using an insulating shaped panel consisting of PUR coated with an insulating coating and an air gap. The presence of the air gap allowed the very high reflectance of the composite material (TSR = 0.92) to be exploited, which would be not possible by direct contact between the steel pipe and the insulation due to the dominance of conductivity.

a)
b)
c)


Fig. 1. Shaped insulating material: a) PUR, b) PUR with matrix material coating, c) PUR with composite coating

Rys. 1. Kształtki izolacyjne: a) PUR, b) PUR pokryty materiałem osnowy, c) PUR pokryty kompozytem

MATERIALS AND METHODS

To verify the influence of the air gap on the thermal conductivity of polyurethane (PUR, $\lambda_{20} = 0.023$ W/mK), shaped PUR pieces coated with a composite layer (Fig. 1a) were used. The inner surface of the shaped pieces was coated with a matrix material (matrix coating – MC) only (Fig. 1b) and with a composite coating (CC) with this matrix (Fig. 1c).

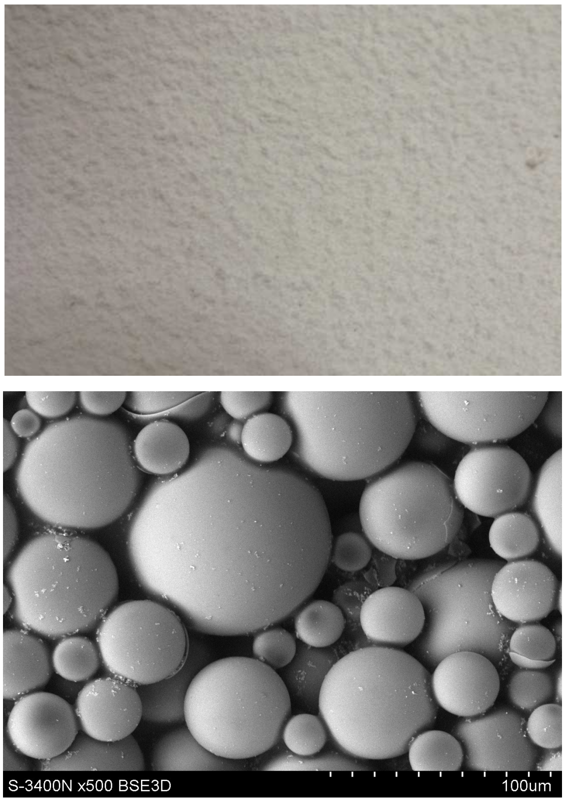
a)
b)


Fig. 2. View of inner surface of shaped insulation with composite coating: a) macrophotograph 8x, b) SEM – ceramic microspheres on resin matrix are visible

Rys. 2. Widok wewnętrznej powierzchni kształtki izolacyjnej z powłoką kompozytową: a) makrofotografia x8, b) SEM – widoczne mikrosfery ceramiczne na tle osnowy

The matrix of the composite coating (10% mass) is made of an acrylic resin with an addition of aluminium and titanium oxides. As the reinforcing phase (90% mass), which increases the heat resistivity, expanded whole ceramic microspheres (soda lime borosilicate glass) 3M (Fig. 2) with the average diameter of $d_{av} =$ $= 15$ μm ($\sigma_d = 5.96$ μm) were used. A heat flux entering the spheres will be reflected, which decrease the heat conductivity [5].

The thermal conductivity of the examined composite material depends on the employed measuring method and device. Using a standardized hot plate device $\lambda_{20} = 0.052$, $\lambda_{80} = 0.057$ W/mK were measured [8]. Using the comparative method (comparison to PUR), depending on the coating thickness, $\lambda_{80} = 0.0032$ W/mK for thickness = 24 mm and $\lambda_{80} = 0.0053$ W/mK for 48 mm thickness were measured [9].

A pipe apparatus was used as the test stand according to the EN 12897:2006 standard [9-12] (Fig. 3). The heating element (8) was placed in the axis of a steel pipe (d = 100 mm, L = 1000 mm) (6) filled with silicon oil. The heat flux from the heater passes through the oil and the wall of the pipe. An air gap with a thickness of 10 mm is between the pipe wall and insulating shaped piece.

The steel pipe transfers the heat to the air in the gap. The heat flux in a radiation form will be reflected (TSR = 0.92) by the composite coating more than during conduction (direct contact between the pipe and PUR) in a test stand without an air gap. After a given time, the thermodynamic steady state is reached and the temperatures are constant. Standard [10] requires constant temperatures during the 3 subsequent days. Under these conditions the energy losses are constant.

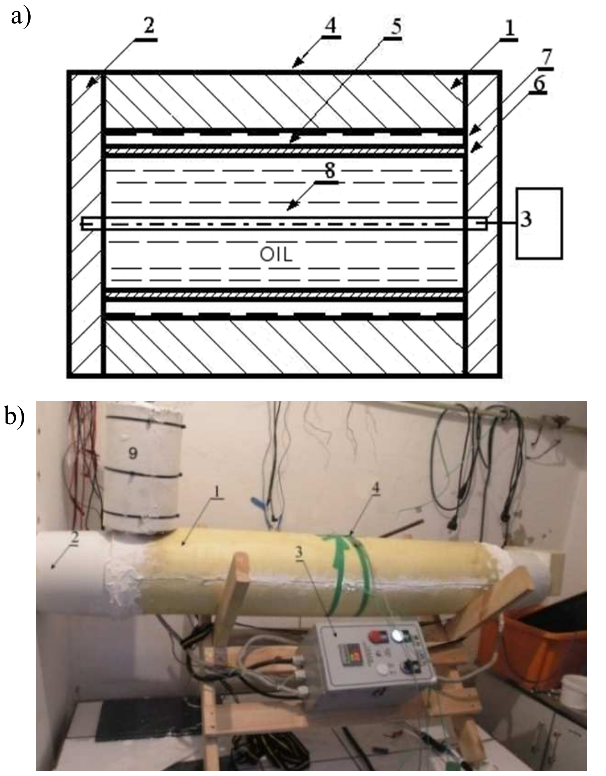


Fig. 3. Test stand: a) diagram, b) view; 1 – examined thermal insulation (place of coating application is marked with dashed line), 2 – caps on pipe ends, 3 – temperature steering device, 4 – temperature measuring point on insulation outer surface, 5 – temperature measuring point on the insulation inner surface. 6 – steel pipe, 7 – air gap 10 mm, 8 – heating element, 9 – oil tank

Rys. 3. Stanowisko do badań: a) schemat, b) widok, 1 – badana izolacja termiczna (przerywaną linią zaznaczono miejsce naniesienia powłok, 2 – kołpaki zasłaniające końce rury, 3 – układ zadawania i automatycznej regulacji temperatury, 4 – miejsce pomiaru temperatury na zewnętrznej powierzchni izolacji, 5 – miejsce pomiaru temperatury na wewnętrznej powierzchni izolacji, 6- rura stalowa, 7 – szczelina powietrzna 10 mm, 8 – element grzejny, 9 – zbiornik oleju

CONDITIONS AND COURSE OF INVESTIGATION

Examination of the insulating properties of the chosen materials conducted according to standard EN 12897:2006 [10]. The constant temperature (80°C ±1°C) of the oil in the pipe was maintained by an automatic device (3 in Fig. 3b). The constant temperature in the laboratory (20°C ±1°C), was maintained by another automatic device. During the tests, the energy consumption was recorded using a 0.5 class meter and the temperature (±1°C) at defined points (Fig. 3a) using of thermocouples for four days. The results are presented in Figure 4 and Tables 1 and 2.

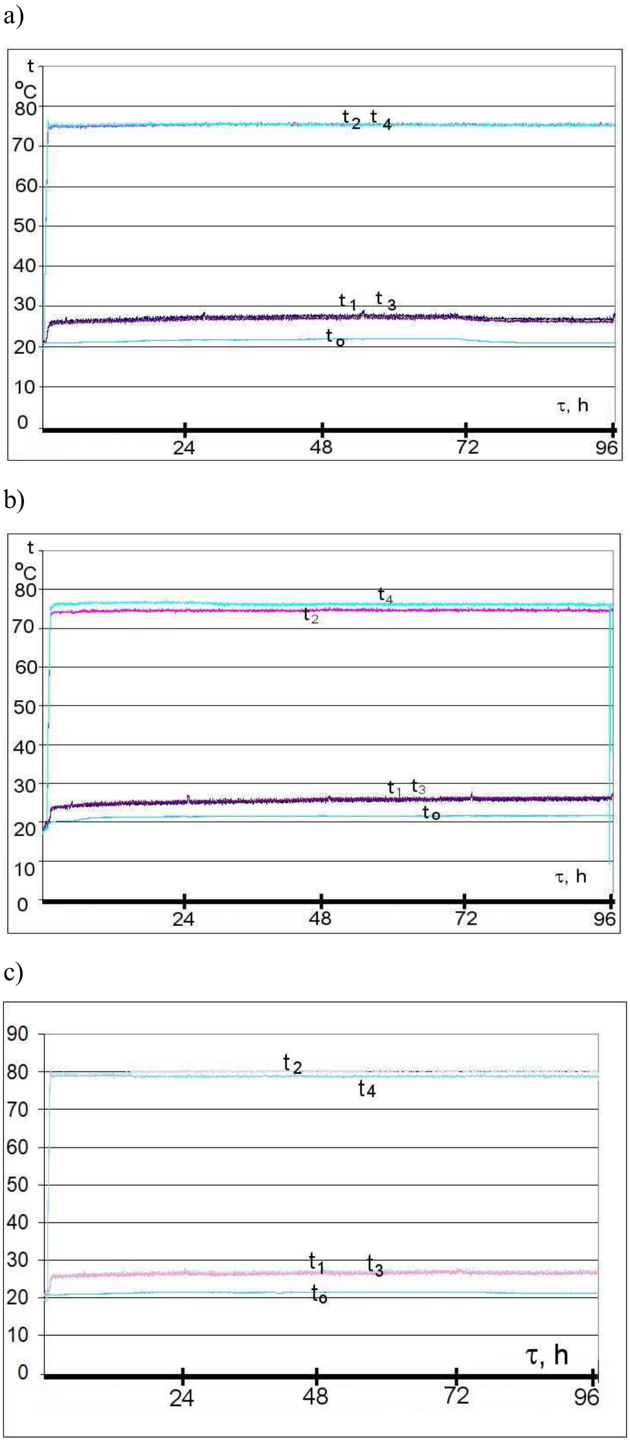


Fig. 4. Temperatures vs. heating time: a) PUR, b) PUR+MC, c) PUR+CC, t_1,t_3 – temperatures on outer surface of insulation, t_2,t_4 – temperatures on inner surface of insulation

Rys. 4. Temperatury w funkcji czasu: a) PUR, b) PUR+MC, c) PUR+CC, t_1,t_3 – tamperatury na zewnętrznej powierzchni izolacji, , t_2,t_4 – temperatury na wewnętrznej powierzchni izolacji

TABLE 1. **Temperatures at measuring points**
TABELA 1. **Temperatury w punktach pomiarowych**

Insulation	PUR		PUR+MC		PUR+CC	
Measuring point	[°C]	σ	[°C]	σ	[°C]	σ
1	27.34	0.36	26.71	0.27	25.61	0.34
3	26.80	0.39	26.50	0.28	25.88	0.33
2	75.43	0.15	74.67	0.15	80.15	0.15
4	75.43	0.18	76.17	0.16	80.84	0.18
Lab room	19.5		19,5		19.5	0.34
T_o – reference	21.58	0.35	21.32	0.10	21.56	0.11

TABLE 2. **Energy consumption**
TABELA 2. **Zużycie energii**

Energy consumption Day	PUR	PUR+MC	PUR+CC
1st	3.450	3.338	3.278
2nd	3.020	2.862	2.805
3rd	3.001	2.866	2.781
4th	3.021	2.843	2.762
Average 2th-4th day	3.014	2.857 Reduction 5.2%	2.782 Reduction 7.6%

RESULTS AND DISCUSSON

Table 2 indicates that the energy consumption when using the PUR shaped material with the reflective composite coating and an air gap is 7.6% less than by PUR without a coating. The addition of ceramic microspheres to the matrix resin causes a decrease of 2.2% in energy consumption. Both coatings, i.e. the matrix material (MC) and the composite material (CC) in the presence of a 10 mm thick air gap cause a reduction in energy consumption. This is a result of heat flux reflection from the coating surfaces, which was returned to the steel pipe. The reflection of the composite coating is greater than that of the matrix resin. This is the reason for – the approximately 2°C higher temperature on the pipe surface (Figs. 4a-c).

The presence of the air gap with the thickness of 10 mm allows the heat flux to be reflected, which reduces the energy losses by 7.4%. This small energy savings caused by the air gap with the thickness of 10 mm can bring yearly relevant advantages for industrial pipe hot medium transport because such pipelines are very long, for example for steam transport [13].

CONCLUSIONS

The application of a composite coating with the thickness of 1 mm on the inner surface of PUR shaped insulation and an air gap with the thickness of 10 mm on a steel pipeline with the diameter of 100 mm gives promising results for energy savings per year for industrial pipelines transporting hot media. These small savings can be attained without using man-made insulating material which causes pollution of the environment during its manufacture, use and disposal.

It is necessary to investigate the influence of the air gap thickness and the pipeline diameter on heat losses in order to find the optimum one for the given conditions in the industrial short and long distance transport of hot media.

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