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THERMAL INSULATION MATERIALS FOR NON-CONVENTIONAL ENERGY

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Developed geocement-based perlite thermal insulation material is considered the most suitable for use as insulation of alternative energy facilities for energy storage. The material is characterized by the following values: density 321 kg/m^3, thermal conductivity, 0.0727 W/m K, the average coefficient of thermal resistance of 2.1 m^2 K/W, thermal cycles 145-148. This material ensures minimum heat loss in underground storage of energy when its thickness is 260 mm.

Introduction. The use of renewable energy sources is a way to succeed sustainable development of human activity. Towards this, the European Council has approved the so-called 20-20-20 goals, which determine the EU-27 strategic energy policy until 2020. Reaching a minimum 20% share of renewable energies in total EU consumption is included to these goals.

In order to use the energy obtained from renewable natural resources in practical applications, such as the energy effective buildings, several problems concerning the ways to gain and store it have to be considered. The major problem of using in practice renewable energy sources is their intermittent nature. Thus, it is of high importance to balance the variable loads of fluctuating or not energy production, as well as to ensure its long term storing as a backup thermal energy load. A possible way to approach this problem is to construct an energy storage reservoir. The operating principle of such a facility is related with the ability of the material used, characterized by its own thermal capacity, to accumulate the low potential heat. In this case the use of economically efficient thermal insulation materials, which possess optimum functional characteristics, is of crucial importance.

The advantage of storing energy in this way is that various materials may be used as heat accumulators. The energy is getting stored through heating the certain material used as an energy storing medium. However, the majority of these materials have low thermal capacity values. In addition, the effectiveness of the accumulation process is significantly lowered due to the heat transfer from the storage medium back to the environment. In order to use in practice a heat storage facility and to increase its effectiveness, it is necessary to minimize any thermal energy losses by protecting it with a reliable insulation. This allows the storage medium to keep the absorbed low potential energy for a sufficiently long period of time.

The goal of implemented project is the development of a functional solar system with energy storage, including the development of an innovative energy transmission method. The proposed prototype is comprised of three main technological compounds: LUCIFER – input of solar energy, solar concentrator; TEMPO – energy storage; PRIMUS – use of energy (heating, electricity), and its operation is schematically shown in the picture below (Fig.1). The solar energy concentrator LUCIFER will be a specially produced Fresnel lens made of polymethylmethacrylate. The proposed structural design of the lens enables to concentrate sunbeams to focal point of several millimeters in size depending on the lens size. The aim, to achieve the smallest possible focal point at the largest possible irradiated area, is based on the intent to use an optical cable for energy transmission. The solar energy concentrator will be equipped with positioning and self-tracking devices. Additionally, in order to control extremely high temperatures, a shading device will be also fitted to the solar concentrator. Sunbeams will be transmitted by optical cables to the energy storage – the so-called energy storage TEMPO. The energy storage is calculated to store an approx. 3-month energy demand straight on site, thus covering the annual energy consumption of household. The energy storage must be made of a material with a high specific heat capacity. This material will be heated by sunbeams coming out of the optical cable [1].

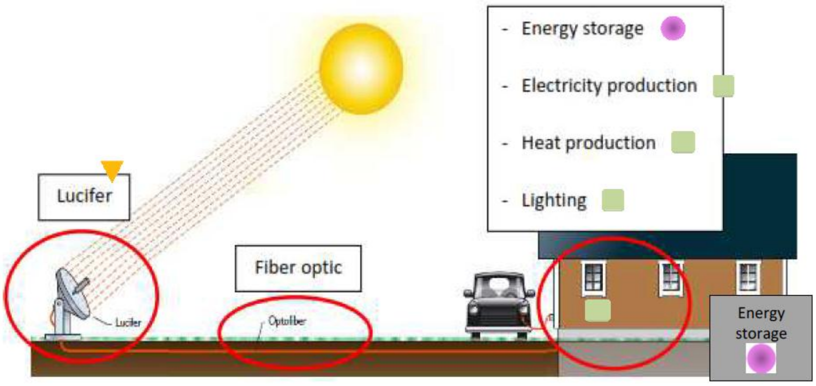

Fig.1: Principal scheme of the system

Energy from the energy storage will be used for warming of water and for heating as such. Energy will also drive a technical appliance PRIMUS to generate electricity. A standard available engine will be used and only its modification will be the concern of the project. The objective of the project is that technical appliances will obtain the energy required for electric power generation directly from the energy storage. The device size depends on its required capacity that increases with the amount of installed optical lenses concentrating sun radiation.

The reliability of a thermal storage facility can be increased by using suitable thermal insulation, which will minimize any heat loss from the storage itself or from the possible heat energy transport equipment. And in the same protects technical appliances transforming energy from overheating. The selection of the thermal insulating material depends on the storage mechanism that is supposed to be used in a certain building. Nevertheless, it should always ensure effective insulation, long lifetime, easy and affordable repairing and maintenance, last but not lowest possible price. There are certain limits for parts of energy storage which require different property from insulating materials, for example relatively high compressive strength, different thermal resistance, maximum thickness. And also the production cost plays very important role. Thermo insulation of energy storage in described project was designed as a sandwich structure of four layers with different composition in various parts of energy storage.

The aim of the present work is to develop thermal insulating materials, which are based on geocement and which could be used as insulation for energy storage facilities. Geocement is distinguished from other binders, because it is ecologically friendly and is characterized by long-term durability [2-5].

Experimental

Materials. For the development of the insulating materials, a geocement, formulated as $Na_2O{\cdot}Al_2O_3{\cdot}6SiO_2{\cdot}20H_2O$ [4], was used. The ratios of its structural oxides are as follows: $Na_2O/Al_2O_3=1$, $SiO_2/Al_2O_3=6$ and $H_2O/Al_2O_3=20$. Geocement was prepared, using a finely grinded metakaolin. Sodium silicate solution (silicate modulus $M_s=3.0$; density $\rho=1430\pm10$ kg/m^3) was used as a liquid phase to produce geocement, while rotten-stone was used as a correcting additive. The main constituent of rotten-stone is opal-like amorphous micro silica ($SiO_2{\cdot}mH_2O$). Expanded perlite (maximum particle sizes of 0.14-2.5 mm and 2.5 mm) were also used. A hardener was added to the mixture in order to increase the strength of the final product. Ground granulated blast furnace slag with a specific surface of 480 m^2/kg (Blaine method) was used as a hardener. In Table, the composition of each of the thermal insulating materials produced is presented.

Table.

Compositions of thermal insulating materials

Components	Developed thermal insulating materials	
	No 1	No 2
Geocement, wt. [%]	46.15	53.85
Fillers:		
Expanded perlite (max. size 2.5 mm), wt. [%]	46.15	–
Expanded perlite (max. size 0.14-2.5 mm), wt. [%]	–	46.15
Hardening agent, wt. [%]	7.7	–

The specimens (plates of 125×125×40 mm) were prepared using the semi-dry compression method by applying 0.1 MPa/cm^2 specific pressure on the mixture of 15% humidity. After the compression process, the thermal insulating specimens formed, were dried at 373 K for 24 h and then exposed to the temperature of 923 K.

Test. After heat treatment, the average density of each of the heat-insulating materials produced was determined. Their average coefficients of thermal conductivity were measured using the method of hot plate. Calculation of the optimal thickness for each insulation material was Terenchuk S.A. in accordance with formulas (1)-(4) and the data shown in Fig. 1. For this purpose, steel surface energy storage tank supposed being in contact with the insulating material.

The heat transfer coefficient (α) from the external surface of the thermal insulating layer to the environment is:

$$\alpha = 9.74 + \lambda(T_1 - T_{env}),\ [\mathrm{W/m^2 \cdot K}] \quad (1)$$

where T_1: is the temperature of the external surface of the insulating material, [K] and T_{env}: is the temperature of the environment, [K].

The specific thermal flow (q) is:

$$q = \alpha(T_1 - T_{env}),\ [\mathrm{W/m^2}] \qquad (2)$$

The temperature at the internal surface of the thermal insulating layer (T_2), as well as on the steel walls of the heat storage unit is:

$$T_3 - T_2 = q\left(\frac{\delta_s}{\lambda_s}\right), \qquad (3)$$

where T_3: is the temperature of the energy storage medium, [K], δ_s: is the thickness of the steel wall of the heat storage unit, [m] and λ_s: is the steel's thermal conductivity coefficient, [W/m·K].

The necessary thickness of the thermal insulating layer (δ_{th}) is:

$$\delta_{th} = \frac{\lambda_{th}}{q}(T_2 - T_1), \qquad (4)$$

where λ_{th}: is the thermal conductivity coefficient of the geocement based thermal insulating layer, [W/m·K]

The thermal resistance coefficient R, [m^2·K/W] of the system presented in Fig. 1 is given by the following well-known formula:

$$R = \frac{\delta_{th}}{\lambda_{th}}, \qquad (5)$$

In the above calculations, the following values have been selected as constant: T_{env} = 293 K is the temperature of the environment; T_1 = 318 K is the temperature of the external surface of the insulation layer; δ_s = 0.004 m is the thickness of the energy storage unit's walls; λ_s = 17.5 W/m·K is the steel's thermal conductivity coefficient.

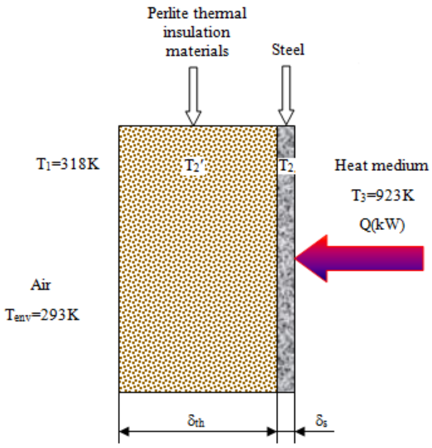

Fig. 1 Thermal design scheme to determine the thickness of the insulation layer

Thermal stability of samples glued using geocement on stainless steel plate (dimensions see above), was determined by the following procedure: samples were heated in an electric furnace at a speed of up to 403 K/min temperature 923 K; isothermal exposure was performed for 4 hours at a temperature of 923K; after isothermal exposure the samples were removed from the electric furnace and cooled in air to ambient temperature (273 K). Such a test is 1 cycle.

Results and discussion

According to the results of previous works [4], swelling or volume increase of the geocement, formulated as $Na_2O{\cdot}Al_2O_3{\cdot}6SiO_2{\cdot}20H_2O$, occurs due to the removal of the chemically bound water which is contained in heulandite type structures which are similar to zeolite. The material developed in the present study begins to swell at the temperature of 423 K, due to the initiation of the dehydration of heulandite, ussingite, sodium zeolite and other phases, followed by a medium porous structure formation. When the temperature increases, reaching 1323 K, the dehydration of the previously mentioned hydrated phases results in the formation of a finely porous glassy aluminosilicate frame of jadeite-albite composition, which is characterized by low thermal conductivity [2]. The usage of different particle size fillers allows obtaining compressed geocement thermal insulation materials with different macrostructure: coarse granulation (No 1) and medium granulation (No 2). After thermal treatment at 923 K the thermal insulation materials are characterized by average density of 376 kg/m^3 and 321 kg/m^3, respectively and by thermal conductivity coefficient of 0.0766 W/m·K and 0.0727 W/m·K, respectively.

The results of performed calculations disclosed optimal thickness for the developed thermal insulation materials based on geocement. This optimal thickness allows lowering thermal losses of the energy storage unit during the night time. Thermal insulation layer thickness for granulation No 1 is 160 mm and for granulation No 2 is 153 mm. Besides, the temperature of the external surface of the developed materials will not exceed 338 K. From our point of view, the most prospective material is that of the granulation No 2, which ensures minimum thermal insulation thickness 153 mm, if its average density is 321 kg/m^3 and the thermal conductivity coefficient is 0.0727 W/m·K. It should be noted that in the case of underground constructions the recommendations by the Thermo Insulation Association of the Czech Republic is the thermal resistance coefficient value is 3.4 m^2·K/W. Thus, if the developed materials are supposed to be used for insulating such constructions, their thickness should be increased by approximately 1.62 times. The new thickness values are 260 mm for composition No 1 and 250 mm for composition No 3 (Fig. 2).

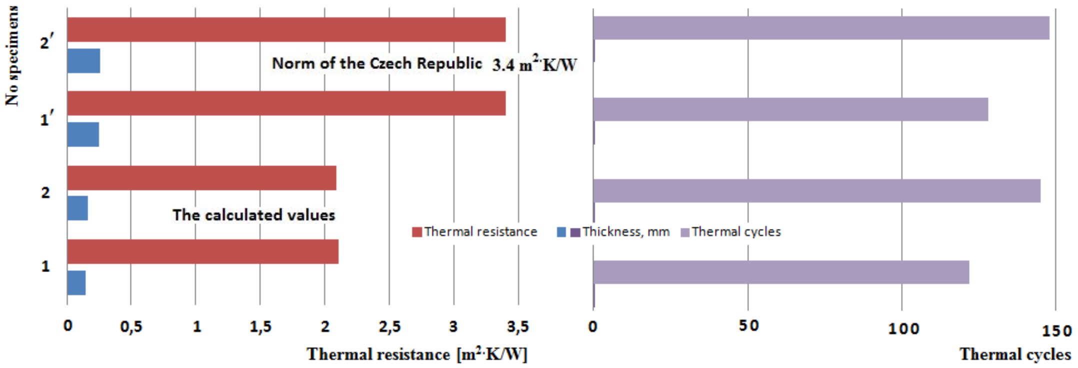

Fig. 2. Effect of thickness on the thermal resistance and heat resistance geocement-based perlite thermal insulation materials

Conclusions

In geocement-based perlite thermal insulation materials of the compositions number 2 is considered to be most suitable for use as insulation for energy storage. They are characterized by the following values: (i) density of 321 kg/m^3; (ii) the thermal conductivity of 0.0727 W/m·K; and (iii) the average coefficient of thermal resistance of 2.1 m^2 K/W; (iiii) temperature air thermal cycles is 145-148 cycles. This material provides minimal heat loss underground storage of energy when its thickness is 260 mm.

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Аннотация. Разработанный на основе геоцемента перлитосодержащий теплоизоляционный материал считается наиболее подходящим для использования в качестве изоляции объектов нетрадиционной энергетики для хранения энергии. Материал характеризуется следующими значениями: плотность 321 кг/м^3, теплопроводность 0,0727 Вт/м К, средний коэффициент термического сопротивления 2,1 м^2 К/Вт, термостойкость 145-148 циклов. Этот материал обеспечивает минимальные теплопотери при подземном хранении энергии, когда его толщина составляет 260 мм.

Анотація. Розроблений на основі геоцементу перлітовміщуючий теплоізоляційний матеріал вважається найбільш вдалим для використання в якості ізоляції об'єктів нетрадиційної енергетики для зберігання енергії. Матеріал характеризується наступними значеннями: густина 321 кг/м^3, теплопровідність 0,0727 Вт/м К, середній коефіцієнт термічного опору 2,1 м^2 К/Вт, термостійкість 145-148 циклів. Цей матеріал забезпечує мінімальні тепловтрати при підземному зберіганні енергії, коли його товщина становить 260 мм.