SmartEnergyCover simulation in the installation of mining farms with waste heat

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Abstract SmartEnergyCover is able to generate electricity due to nanostructured elements in the composition independently. Also it provides optimal temperature conditions by thermal energy accumulation. The cover contains heat-conducting and heat-accumulating elements in composition. There is a simulation of the practical application of SmartEnergyCover in a mining farm with waste heat.

1 Statement of the research problem

Depending on a development of modern environmental and energy situations there is a special attention for existing potential for improving energy efficiency. That question becomes relevant in Russia and European countries. The EPBD directive requires that self-regulating devices must be installed to control the indoor temperature at all new constructions and in heat systems of modernized buildings [1]. In addition, using of recycling of waste heat remains a very effective direction.

The author of the article was approached by a company engaged in mining on an industrial scale with the request to create the system and its thermally analyze to obtain the specified parameters and remove the waste heat load with increasing of the overall efficiency of the mining system.

Now this is a very fashionable and profitable direction. These are mining trusses, during the operation of them you can get a significant amount of waste heat when operating technical units. When electrical energy is supplied in the process of equipment operation, a very large amount of heat is released due to the second law of thermodynamics. In this technological process for obtaining e-currency, heat generation leads to a significant decrease in process efficiency. Forced cooling of the system makes possible to place much equipment in a small area, what increases the efficiency of the entire system. Cooling maintains stable overclocking of power systems’ digital equipment. On an industrial scale, when the owner has large areas for getting bitcoins, the excess take the form of a powerful source of additional heat. In this case using of forced cooling allows to lengthen significantly the service life of electronics and electrical devices, and also the fault tolerance of the system increases as a whole. Under the conditions of the considered heat exchange in a single unit, it is necessary to divert 1400 W of thermal energy from a unit volume of equipment and 20 kW from the system as a whole. In the case of overheating in such systems, there is a mass of negative situations, such as frequency and output reduction, reduced equipment life and just reduced comfort.

For cooling purposes, air heating systems or heat dissipation are mainly used in other ways, such as immersion cooling. The essence of the method is that a part of the equipment is placed in a vessel with a liquid-cooler (coolant), having the dielectric properties. Non-conducting mineral oil, which is inert with respect to metals and other substances, has a specific heat capacity of 3.2 kJ / kg and a
density that’s comparable to the density of water, is used as the heat carrier liquid. But such systems should work year-round, while heating is required only during the cold season. During the warm period of the year, it is necessary to think about the receiver of waste heat with good work efficiency.

In addition, heat exchange systems with air coolant are significantly inferior in efficiency to systems with a liquid coolant due to the fact that the heat capacity of air is four times less than water and 2-3 times for antifreeze and other heat-transfer mediums of heat-exchange systems. Therefore, it became necessary to create a heat removal system with a liquid coolant, which is not an electrical conductor and has a good heat capacity. With this method of heat removal, it’s possible use single or dual circuit systems. Phase transition processes will be effective in such systems for leveling the heat load and automation processes’ partial replacing. In residential systems, noiseless operation of individual parts and an overall functionality become relevant.

2 Theoretical description of the process

From the point of view of thermal analysis in this case, heat transfer is composed of heat conduction and convection. The radiation component was not taken into account, considering that the process was completely isolated from the environment and radiation losses were minimal. The process is a two or more contour system with the presence of heat exchange with secondary consumers, with the opportunity to connect to the winter garden for heating greenhouses and flowers, for the primary heating circuit and even forced cooling from the environment. The main task in this case is to get the maximum amount of heat from mining farms and equipment with optimal cooling and heat storage. This process was modeled.

Thermal conductivity is the process of thermal energy proliferation with the direct contact of individual particles of a body that have different temperatures. In the general case, the process of heat transfer by thermal conductivity is characterized by a change in temperature both in space and time.

For a point with coordinates \((x, y, z)\) with temperature \(t\) at time \(\tau\), which is given by the function \(t(x, y, z, \tau)\). For each fixed value \(\tau\), the function \(t\) defines a scalar field, called the temperature field. The combination of body points that have the same temperature at a given time is called an isothermal surface in this field. The temperature gradient is a vector directed along the normal to the isothermal surface in the direction of increasing temperature and numerically equal to the derivative of temperature in this direction, that is

\[
\text{grad } t = (\frac{\partial t}{\partial n}) \cdot n,
\]

where \(n\) - is the unit vector normal to the isothermal surface and directed in the direction of temperature increasing;

\((\frac{\partial t}{\partial n})\) - is the derivative of temperature along the \(n\).

In a non-uniform material environment, the differential equation for the field of bulk temperature will be:

\[
\frac{\partial}{\partial x} \left( \lambda_x \frac{\partial t}{\partial x} \right) + \frac{\partial}{\partial y} \left( \lambda_y \frac{\partial t}{\partial y} \right) + \frac{\partial}{\partial z} \left( \lambda_z \frac{\partial t}{\partial z} \right) = 0
\]

(2)

where \(\lambda\), W/m*K – thermal conductivity coefficient that’s a continuous function of \(x, y\) and \(z\).

Spatial temperature fields for practical purposes are in most cases sufficient to study in separate projections, which can be represented as two-dimensional temperature fields.

If there is a source with a phase transition material, in which the front of the temperature change passes by equation (1), we can write the equations for determining of isothermal lines as

\[
\frac{\partial t}{\partial z} = a_1 \frac{\partial^2 t}{\partial x^2} + a_2 \sqrt{t}
\]

(3)
where $a_1$, m$^2$/h – is the thermal diffusivity of non-phase transition layers, $a_2$ is the thermal diffusivity parameter for a layer with a phase transition.

In this case the convective component consists of washing with a liquid-coolant of hot flat plates arranged vertically and horizontally during forced convection, since there is a pump that circulates. In this case, the heat transfer will depend on the Nusselt, Nu, Reynolds, Re and Prandtl, Pr coefficients, which characterize the flow pattern, and also contain variables such as thermal diffusivity, viscosity coefficient, thermal conductivity of the fluid, and others. From formulas [2] for the calculation of heat transfer during forced convection or with simultaneous action of free and forced convection when washing a flat plate

$$Nu = 0.664 * Re^{0.5} Pr^{0.33}$$  \hspace{1cm} (4)

$$Nu = 0.37 * Re^{0.8} Pr^{0.33}$$  \hspace{1cm} (5)

These formulas represent the general cases of flows derived from experimental observations. In each particular case, the convection coefficients are calculated individually. In this draft, the convection coefficients were adopted for the standard case of vertical and horizontal plates with the simultaneous action of free and forced convection. To equalize the heat exchange process, it was decided to apply Smart Energy Cover. In the framework of the considered simulation, the composition and size of the granules of heat-accumulating material were not the main focus, therefore, the conditions of the already performed studies were accepted earlier [3,4].

### 3 Simulation

For the installation in question, hydraulic and thermal flow modeling was performed for some specified volume cases. The purpose of the simulation was to determine the optimal configuration volume with the minimum geometric dimensions of the heat exchange region, since the cost of the coolant is relatively high. The smaller the volume at the final parameters of the coolant and the boundary conditions, the cheaper the cost of installation. The dimensions of the trusses, the number and shape of the installation, the direction of flow and the flow patterns, the required boundary temperature conditions and heating of the truss, depending on the load, were established [5,6].

When modeling, the principle of object research was used, based on the sequential change of model parameters. With the most optimal parameters changed, the model is put forward for further work. In this case, several modules are used, such as DesignModeler, which has efficient parameterization tools. To solve the problem, both linear analysis of stationary states and complex transient analysis were used.

The dimensions of the heat exchange truss were taken as follows:
The heat transfer conditions were chosen in accordance with the accepted values of heat transfer and convection with the condition of the work of the corresponding automation equipment and pumping units. In accordance with the geometry of the model, SmartEnergyCover intelligent coating in this case can be applied along the inner surface of the truss. This will align the temperature lines and a more uniform temperature distribution over all surfaces, thereby leveling the heat transfer in the volume. In addition, in this way, it becomes possible to regulate the heat flux at a given place of heat exchange, where you can choose a point heating.

SmartEnergyCover smart coating was a stable material that combines the properties of a battery and a heat conductor with the included elements based on the Peltier principle for generating electricity. Thermoelectric phenomena occur in the developed coating, which are a combination of physical phenomena based on the interrelation of the processes of heat and electric charge transfer. The essence of the process is that the temperature difference causes not only the heat flow, but also the flow of charge carriers (electric current), and the heat transfer can be carried out by electric current, and not only with the temperature difference.

Also, as in the previously simulated usage cases of SmartEnergyCover, variants of carbon structures were used in combination with phase transition materials. Carbon additives allowed us to obtain special properties of the material, successfully applicable in the working conditions of the developed coating. Such materials can be successfully used on flat surfaces [7,8,9].

Despite the form of the coating, the simulation was performed for a three-dimensional model with the option of thermal analysis of successive specified loads, as well as the heat transfer coefficient depending on the position of the point of application of the given load, since the forms of heat exchange were slightly different in the overall design.

The heat transfer coefficient, recorded in the results file for this turbulent phase with a given heat exchange, was taken with regard to the coefficient of the turbulent function for a flat wall. This was taken into account by the heat flux function near the wall surface, along with the wall temperature, as well as with the temperature of the junction to the wall (near-wall temperature). Also one of the
options was specified custom volume temperature, with the parameter "tbulk for htc = <value>". The functions of the conjugate analysis were activated by the command <fsan,on> [10].

To define a task that leads to a unique solution [11,12], we indicate sequentially information on flow variables at boundaries, mass flows, directions, thermal energy, etc. The definition of boundary conditions in this case includes: the definition of heat flow, the type of hydraulic movements and other information on the boundaries. The data required at the boundary depends on the type of boundary condition and the physical models used. If information about flow variables is unknown, then it can be taken approximately. Poorly defined boundary conditions can have a significant impact on the outcome of a solution [13-16].

Next, it needs a choice of parameters of the fluid-coolant. For multiphase flows, instead of the liquid zone, we accept the conditions that the coolant may consist of a mixture of phases. In addition, possible optional inputs, a porous area, a laminar area, fixed values that will remain constant throughout the study, as well as types of heat exchange were identified.

The porous zone and the zone with heterogeneous and mixed coefficients of the material is a special type of zone for which it was necessary to set additional parameters. The pressure loss in the flow was determined by using user inputs of resistance coefficients in the model with lumped parameters. The geometrical parameters of the flow distributors, the number of heat exchangers and the direction of flow were determined. For hydraulic modeling, input parameters were obligatory coefficients of directional viscous and inertial resistance.

When using the SmartEnergyCover, as described above, modeling for the stationary conditions of convective heat transfer revealed the following picture.

![Figure 3](image1.png)

**Figure 3.** Distribution of heat and hydraulic flows in a mining farm with the SmartEnergyCover.

This illustration shows the possibility of equalizing the temperature potential with the help of the SmartEnergyCover on a given heat exchange surface, short-term or duration-accumulated heat accumulation and its supply at a specific time on a given point or distributed area.

![Figure 4](image2.png)

**Figure 4.** The distribution of the available temperature minima and maxima of the system. Longitudinal section.
Since the SmartEnergyCover in this case worked as a heat insulator and heat accumulator, where the number of heat-conducting inclusions decreases, and the number of heat-accumulating globules increases, heat exchange was carried out mainly between the fins of the truss and the coolant. Heat transfer inclusions with a phase transition conduct the required amount of heat flux into the layers required for heat exchange, which are directly connected to the Peltier thermoelectric elements. A thermal insulation layer with inclusions of phase transition material prevents sudden temperature drops, heating and cooling of the structure, and gaps with the phase transition material ensure reliable operation of the thermoelement.

This made possible to evenly distributed heat load, stable heat transfer, regardless of the load jumps of the electronics processes and partial exclusion of automation.

**Figure 5.** The optimal increase in the length of the channel, depending on the length of the farm.

According to the results of modeling of several dimensional parameters for given sizes of trusses, the coolant volumes were selected and the percentages for optimal heat exchange were chosen, shown in Table 1.

**Table 1.** The recommended parameters of increasing of length of the heat exchange channel, depending on the length of the truss.

| Length of truss, mm | The percentage of elongation of the heat exchange channel, depending on the length of the farm |
|--------------------|------------------------------------------------------------------------------------------|
| 250                | 1,06                                                                                     |
| 260                | 1,076                                                                                    |
| 270                | 1,08                                                                                     |
| 280                | 2,0                                                                                      |

For other locations of farms in volume, for example, for their vertical loading into the refrigerant volume, which is usual for ease of repair and inspection, these parameters will differ from the data in the table, since the gravitational force of heat. Liquid transfer will affect the heat exchange process. In addition, for other quantities in a given volume of heat exchange farms, it will be necessary to determine their specific recommended parameters.
Table 2. The electric parameters.

| Power heating, W | Current, A | Voltage, B | ΔT, °C | Unit efficiency, W/(°C·kg) |
|------------------|-----------|------------|--------|---------------------------|
| 100              | 0.253     | 2.41       | 80     | 0.294                     |
|                  | 0.503     | 1.55       | 90     | 0.367                     |

Conclusions

As a result of the work, an electronic experiment was conducted for the aim of developing of methodology for determining of thermal inclusions location in the SmartEnergyCover. This needs for optimal functioning of the structure depending on the initial external boundary and working conditions. In this particular case, these are places on the inside surface of the truss or in the main supply pipes. Since the circulating fluid does not have electrical conductivity, we can use this to produce electrical potential. During heat generation from a single unit, 100 W of thermal power can be obtained from a temperature difference of 90 degrees, and 0.5 A with a voltage up to 2.5 V.

After determining of the location of isothermal lines on the surface and in the thickness of the material, we can talk about the generation of electricity. Thus, in any climatic conditions, and especially in the conditions of Siberia, we have a significant temperature differential with a waste heat and obtaining cheap electricity, the load compensation of the thermal field, the energy storage and the insulating layer at the same time.

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