Use of microbial fuel cells and solar collectors in the multifunctional energy container

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Abstract. The results of studies of a multifunctional energy container are given. The use of microbial-fuel cells for generating electricity, as well as flat liquid solar collectors for generating thermal energy, has been investigated in the energy container.

For energy supply and sewage treatment of villages, cottage settlements and even separate buildings it is necessary to build additional energy and sewage treatment plants, with associated complex design work. In most cases, after deterioration or obsolescence of these stations, it is necessary to carry out major repairs and reconstruction or conservation, followed by the construction of new stations. It is also impossible to move them with reusing in case of a decrease in the number of subscribers of these stations or their complete disappearance for some circumstances. Not to mention the fact that the use of traditional energy often has environmental consequences [1-2]. This is especially concerns the recreational areas, like The Baikal Nature Territory in the Irkutsk region.

Development and reconstruction of urban infrastructure is impossible without the reconstruction and modernization of life support systems [3]. At the same time, the reconstruction and technical re-equipment of power supply, heating and hot water supply systems is one of the most difficult engineering tasks. The use of renewable energy sources can solve many of the above problems [4-11], but even they alone cannot solve the problems of mobility and dependence on external factors [12].
The complex mobile independent power stations [13-14], described in this article, will allow to solve these problems.

**Microbial fuel cells construction**

There were made a research of microbial-fuel cells in the energy container during the work process.

For the microbial fuel cells assembly a transparent plexiglass (3 mm of thick) was used. Components were cut out according to specified dimensions and then they were joined using adhesive “COSMOFEN CA – 500.200” (“Weiss” Germany). The basis of this is ethylcyanoacrylate. The adhesive is quick-drying (5-20 seconds) and gives a very hard colorless seam. The following ion selective membranes were located between the aerobic and anaerobic parts of the microbial fuel cells:

- MF-4SK (Plastpolymer OJSC, Russian Federation) (Fig. 1) - technical characteristics are presented in the table (Table 1.).

![Figure 1. Ion selective membrane MF-4SK (Plastpolymer OJSC, Russian Federation).](image)

| Indicator's name                  | Actual value                                                                 |
|----------------------------------|-----------------------------------------------------------------------------|
| Appearance                       | A film with a smooth surface, transparent or matte, colorless or with yellowish color. |
| Thickness, (mm)                  | 0.230±0,025                                                                |
| Strength, (kg/sm²) not less      | 170                                                                         |
| Volume resistivity, (Om/sm²) not more | 13,6                                                                      |
| Hydrogen ion exchange capacity, (mg-ekv/g) | 0,89                                                                      |

During of microbial fuel cells research with the main medium or base media, model wastewater was used (GOST R 50595-93), the composition of
which is presented in Table 2. The media were sterilized by autoclaving for 40 minutes at pressure of 1 atm.

Table 2. The model wastewater composition (GOST R 50595-93)

| Wastewater component          | Mass concentration, mg/dm$^3$ |
|-------------------------------|-------------------------------|
| Sodium carbonate              | 50                            |
| Sodium acetate                | 50*                           |
| Potassium phosphate monosubstituted | 25                      |
| Ammonium phosphate disubstituted | 25                      |
| Calcium chloride              | 7.5                           |
| Magnesium sulfate             | 5*                            |
| Peptone                       | 100-150                       |

Note: * - Seen in terms of anhydrous salts

Setting up the experiments in microbial fuel cells

Before setting up the experiments using microbial fuel cells (Fig. 2) [15-19], the chambers were checked for leaks, after which they were thoroughly sterilized. Sterilization was carried out as follows: 3% hydrogen peroxide was poured into the microbial fuel cell, held until the membranes returned to their original color, then washed with distilled water and placed under direct ultraviolet radiation for 20 minutes, the source of which was the bactericidal lamp PURITEC HNS G5 8 W ("OSRAM" Italy).

![Figure 2. Microbial fuel cell.](image)

The 3% hydrogen peroxide was also used to sterilize the electrodes, in which they were soaked for 20 minutes, after which they were washed in sterile distilled water for a three times.

The necessary components were poured into the chambers (for example a model wastewater, substrate and microbiological preparation), after which
they were sparged with argon for 5 minutes and the electrode was immediately twisted to create anaerobic conditions. If it is required to inoculate microbiological preparations or substrates after a certain the microbial fuel cell operation time, a syringe was used for making the injections through the plug 4C. To make the sampling for determining TMC or chemical analysis, a syringe was used. The needle was previously pretreated with alcohol, also the cork was wiped outside.

During the research, it was found that the electricity produced by the microbial fuel cells can be used for autonomous operation of various sensors that are not required by high voltage, or for lighting the rooms in which no work associated with visual load is performed. Such areas can be illuminated using LED strips or lamps. One element, under certain conditions, is capable of producing energy at 0,5 V.

**Use of solar collectors**

Also the multifunctional energy container has a solar collector, called Solar Unit 1 (SUN 1) [20-21] (Figure 3), or a modified model called SUN 2 (Figure 4) or SUN 3 model (Figure 5) [22-23].

![Figure 3. The prototype of solar collector SUN 1.](image)

Analysis of various models of flat solar collectors and experience in their application have shown that most of them are ineffective in regions with a cold climate. At the same time, solar activity in most of these regions has a high level. The main reason for this is the orientation of collectors producers on their use in areas with warm and temperate climates. Therefore, thermal insulation parameters of solar power plants are optimal for these regions, but in regions with cold climates, they show the worst results.

New types of flat solar collector SUN 1, SUN 2 and SUN 3 can be effectively used in areas with warm and temperate climates, as well as with climatic...
conditions equivalent to the far north, and have improved thermal insulation properties and elongated heat carrier channels.

The SUN 2 solar collector differs from the SUN 1 in some design features of the body. The body of the solar collector SUN 2 is made of aluminum and coated with anti-corrosion enamel.

The surface of the solar collector is a translucent insulation from the double-glazed unit, which has a separate body and is connected to the main collector body using coupling bolts and rubber gaskets. Double glazing will significantly reduce the overall thermal conductivity coefficient. In this case, the solar collector optical efficiency will decrease by no more than 10%.

There is the sensing surface or absorber under the glass. It is a metal sheet, covered with black enamel.

Copper tubes are meander-shaped and are attached to copper-brass tube collectors. The solar collector also has four outlet connections, which allows the use of different connection options. Empirically [24] and experimentally it was established that, ceteris paribus, such heat-receiving tubes allow to increase the heat carrier temperature at the solar collector outlet and have relatively low hydraulic resistance, which makes it possible to increase the efficiency of the solar collector by increasing the heat transfer coefficient from the pipe to the coolant, depending on the Reynolds coefficient, by increasing the flow rate of the coolant with minimal energy consumption, as well as width directly isolated fin, which also increases the efficiency of the collector, the heat carrier heating rate and solar collector efficiency.

A foil is applied on the inner walls of the SUN 2 collector, as well as on the front side of the insulation, which allows to reduce heat losses through the side and rear walls, as well as the heat absorption of the tubes is improved.

Insulation material in this device is poroplast, it was developed at the Department of Building Structures of INRTU. The thermal conductivity $\lambda$ of this material is 0.036 W/m$^2$$\cdot$°C, which is much lower than that of many known insulation material. In addition, the layer of insulation in this solar collector is larger than that of analogs. This will reduce heat loss through the rear wall of the SUN 2.

The design of the solar collector SUN 2, so as SUN 1, allows its opening, repair and replacement of its individual parts.

In the construction of SUN 1 and SUN 2, meander-shaped pipes were used, and the SUN 3 collector - spiral pipes. This form allows increasing the length of the collector tubes with a standard size of its body.
Figure 4. Solar collector SUN 2 in section: 1 - Double-glazed unit; 2 - Body; 3 - Soft rubber gaskets; 4 - Solid rubber gaskets; 5 - Coupling bolt; 6 - Radiation absorbing sheet; 7 - Copper-brass tube collectors; 8 - Tubes; 9 - Insulation; 10 - Steel sheet rear wall; 11 - Aluminum foil layer.

Figure 5. The prototype of solar collector SUN 3.

Testing of a flat solar collector SUN 1 and comparing it with a reference model
The purpose of this experiment was to test the solar collector SUN 1 in the climatic conditions of the Irkutsk city in different periods of the year under different weather conditions and compare it with a reference model, which was the flat solar collector "Sokol". The results of one of the experiments are shown in table 3 and Figure 6.

**Table 3. Change of the inlet and the outlet heat carrier temperature in time**

| Time, min | Inlet heat carrier temperature of the solar collector $T_{f,i}$, °C | Outlet heat carrier temperature of the solar collector $T_{f,o}$, °C | Solar activity $E_{ph}$, W/m² | Note |
|-----------|---------------------------------------------------------------|---------------------------------------------------------------|-----------------------------|------|
|           | "Sokol"            | SUN 1            | "Sokol"            | SUN 1            |                   |
| 0         | 18,3               | 18,3             | 20,0               | 19,0             | 902,6             |
| 10        | 23,0               | 23,0             | 23,8               | 24,2             | 929,0             |
| 20        | 25,5               | 25,5             | 26,2               | 26,9             | 948,9             |
| 30        | 27,3               | 27,3             | 28,0               | 28,7             | 946,1             |
| 40        | 28,0               | 28,0             | 29,0               | 29,6             | 968,8             |
| 50        | 28,2               | 28,2             | 29,4               | 30,6             | 998,7             |
| 60        | 28,6               | 28,6             | 30,2               | 31,5             | 981,6             |

**Figure 6. Change of the inlet and the outlet heat carrier temperature in time (summer period).**

From the graph in Figure 6, it is clear that, due to the mean-shaped form of the tubes, already at the 10th minute of the experiment, the outlet heat carrier...
temperature of the solar collector SUN 1 is higher than the outlet heat carrier temperature of the solar collector "Sokol". This trend is observed throughout the experiment. By the 60th minute, the outlet heat carrier temperature of the solar collector SUN 1 reached 31.5 °C and continues to grow.

For 60 minutes of the experiment, the difference between the inlet heat carrier temperatures of the collectors at 0 minute and outlet heat carrier temperatures at 60th minute was: "Sokol" - 11.9 °C, SUN 1 - 13.2 °C.

The aim of the work was to create an industrial design of a multifunctional energy container (Fig. 7), to refine the automatic control system taking into account various factors such as autonomy, current and predicted weather conditions and the use of various predefined and random scenarios of the system. Additionally, the integration of such container with emergency communication systems is assumed.

**Figure 7.** The power station draft: SP – solar panel; WT – wind turbine; IN – inverter; DG – diesel generator; MFC – microbial fuel cell; WTP – wastewater treatment plant; UVWT – ultra-violet water treatment; HP – heat pump; IB – indirect boiler; EH – electric heater; P – pump; TV – thermo-static valve; HE – heat exchanger; SC – solar collector.

**Major findings of the research**

1. The energy container is designed to provide full-fledged energy supply to both residential and industrial premises that do not have central energy supply, for example, areas of the far north, or to energy supply power of seasonal children's, student, sports, and military field camps.
2. Multifunctional energy container is an autonomous system that provides power supply of two-three-phase alternating current and heat supply of objects using wind energy, solar energy and internal combustion engine.

3. The container additionally performs water purification to the utilization-level based on energy-efficient patented wastewater treatment technologies.

4. In addition to the main renewable energy sources, such as the sun and wind, it is proposed to use microbial fuel cells.

5. A distinctive feature of the multifunctional energy container increasing the reliability and quality of energy supply, reducing the fuel consumption of a diesel generator set up to 80% by optimizing its operation in the system, and to increasing the system efficiency by controlling the operating mode of the container using an automatic control system.

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