Autonomous power supply complex for oil leakage detection system in pipelines

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Abstract. In this article an autonomous power supply complex for oil leakage detection system is proposed for pipelines using the units of thermoelectric generators as a power source. Laboratory experimental studies were conducted as well as obtained operating energy characteristics of the complex. A sufficient number of the units of thermoelectric generators for uninterrupted power supply of the data collection point of the oil leak detection system has been defined.

1. Introduction
At present, the total length of trunk pipelines on the territory of Russia is more than 55000 km and the field pipelines length is over 400000 km. At the same time, placing in commission of new oil fields requires further development of the oil and gas transportation systems and the length of oil pipelines will increase [1]. According to the Ministry of Energy of Russia Federation, about 10–20 thousand accidents occur and are officially registered annually at the enterprises of the Russian fuel and energy complex. At the same time, about 14000 oil spills are recorded annually in the United States [2-4]. Accidents are caused by the deterioration of fixed industrial assets (in particular, pipeline transport), paraffin deposits on the walls of pipes, also illegal activities of third parties [5–7]. Therefore, ensuring the safe and reliable operation of oil pipelines is a high-priority task, especially in the Arctic region. To deal with this issue, a number of oil leakage detection systems (LDS) based on continuous monitoring methods are used.

The recommended distance between the data collection points of oil LDS located the pipeline is 20 km [8]. However, oil pipelines are often placed in hard-to-reach regions and are far removed from the centralized electricity supply. Therefore, there is a problem of power-efficient provision of electricity to LDS data collection points, namely for pressure sensors, rate-of-flow meters and other equipment necessary for the stable operation of systems and information transmission.

The methods of power supply of objects of the mineral resources sector are follows:

- the centralized electricity supply networks with overhead (OHTL) or underground power transmission lines;
- the area network with diesel generators of electric power;
- the autonomous networks using local renewable energy sources, for instance, windfarms or photovoltaic installations [9–11].

These methods of power supply require significant investment under the construction stage, have considerable drawbacks during the organization of energy supply of oil LDS. Using centralized networks long-distance transmission circuits are required what directly affects the reliability of power supply for the consumers [12, 13]. In the case of the area network, the permanent high fuel costs
(procurement, delivery, storage) and the maintenance expenses of diesel generators are required. The efficiency of windfarms or photovoltaic panels depends on the energy potential of renewable energy sources at their location. Moreover, autonomous generation is poorly predictable and very uneven. [14-17]. Thus, the development of a reliable and economically feasible method of power supply to low-power consumers is an essential task.

The aim of the research is to solve the issue of uninterruptible autonomous power supply systems for detecting oil leaks in pipelines by developing an electro generating complex based on units of thermoelectric generators (UTEG).

2. Schematic structure of the autonomous power supply complex
There are a large number of modern devices, methods and diagnostic systems for leaks detection. Each method has its own advantages and disadvantages. According to the article’s authors, the best option is a stationary, static, parametric, constantly working system with indirect measurement of the pumped medium parameters. Also this system should have combined capabilities in terms of physical phenomena. Considering that the average power consumption of the lower (pressure sensors, flow meters) and middle (controller) levels of such LDSs is less than 5 W [8], the proposed energy supply method is a UTEG-based power source (Figure 1).

![Figure 1. The oil LDS elements.](image)

Installing UTEG on an oil pipeline with temperature above 40°C allows to achieve the required temperature difference between the hot and cold sides of the unit for electricity generation. The UTEG is most efficient in the winter when the average ambient temperature is -20°C and the temperature of the pipeline reaches 60°C. Until now, the low efficiency coefficient of converting thermal flux into the electrical energy, from 3 to 8%, remains a significant limitation of the thermoelectric conversion advantages. However, when it is impossible or uneconomic to bring centralized electricity supply networks for light loads, the UTEG becomes indispensable.

Taking into account the climatic features of use and technical characteristics, a schematic structure of the autonomous power supply complex of LDS based on UTEG was developed (Figure 2).
Figure 2. Schematic structure of the autonomous power supply complex.

Presented structure allows to transmit information from sensors in continuous mode or at certain intervals of time. While the wireless controller is in standby mode, energy accumulates on the battery. Thus, the flexibility of the system is achieved and the direct dependence of capitalized expenses on the required frequency of data updating and specific operating conditions is established.

3. Simulation

3.1. Experimental research

UTEG existing on the market are designed for large temperature differences (250–300°C). Accordingly, technical characteristics are also indicated for these operating modes. To study the characteristics of modules in another range of temperature differences (up to 120°C), an experimental installation was developed, including:

- the laboratory autotransformer;
- the UTEG circuit resistor (load);
- the UTEG;
- the radiator located on the cold side of the UTEG;
- the container with dry ice;
- the heat source (heating resistors);
- the heat distribution plate located on the UTEG hot side;
- the temperature sensors located on the cold and hot side of the UTEG.

The thermal flux was generated by the energy released from the two resistors that were placed on the heat distribution plate. This plate was in contact with one of the UTEG sides while the other side of the UTEG was cooled by a radiator. The temperature magnitude and its change were recorded using electronic sensors for both the hot and cold sides of the UTEG. Under these conditions, generated by the UTEG the open-circuit voltage and the operating current when a load with different resistance was connected to the circuit were determined. To simulate operating modes at negative temperatures, the side with the radiator was placed in a dry ice container that allowed to recreate negative temperatures down to -40°C. As a result of the studies, the linear current-voltage characteristic of the UTEG was obtained at the developed installation when average value of the internal resistance was $R_{in}=12$ Ohm.

In Figure 3 and 4, there are the dependences of the voltage generated during open-circuit mode and under load ($R_{load}=R_{in}=12$ Ohm) on temperature difference ($\Delta T$) between the hot ($T_{hot}$) and cold ($T_{cold}$) sides of the UTEG.
3.2. Processing of experimental results

Analysis of the obtained data (Figure 5) showed that the UTEG worked with the same efficiency in all temperature ranges.
The obtained results suggested that the UTEG could be used for autonomous power supply of the oil LDS in a pipeline for different climatic conditions.

Taking into account the average power consumption of the LDS equipment less than 5 W, a serial connection of 8 UTEG (with a total area of 128 cm$^2$) with a 35°C minimum temperature difference between the sides of the UTEG allows one data collection point to be fully supplied with power.

4. Conclusions
The developed electric generating complex with thermoelectric generating units for autonomous electric power supply of oil leakage detection systems can be installed on trunk and field oil pipelines of any diameter. This complex solves not only the problem of energy-efficient power supply of leak detection systems but also reduces the search time for an accident site on oil pipelines owing to the possibility of more frequent placement of these systems as well as its location on hard-to-reach regions. As a result, it reduces both the negative impact on the environment and the financial expenses of enterprises to breakdown elimination.

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