Use of geothermal energy from abandoned oil wells

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Abstract. Abandoned oil wells, low-rate oil wells can be used as low-temperature geothermal resources. Geothermal power generation from abandoned wells is a new way to utilize geothermal energy. The paper presents a model for using geothermal energy from abandoned wells. The paper analyzes the use of freon as a main working fluid.

1. Introduction
It is known that the Earth’s depths have huge thermal energy resources. Nuclear, gravitational and other processes determine the accumulation of enormous thermal resources. The main sources of thermal energy are as follows:
- spontaneous decomposition of radioactive elements (elements with a half-life less than the period of the Earth’s formation disintegrated upon initial heating of the planetary substance, while the decay of long-lived elements is going on);
- gravitational differentiation of the Earth’s substance and its separation accompanied by formation of a dense core and a less dense shell;
- tectonic processes causing vertical and horizontal displacement of large blocks of the earth's crust and its elastic deformations;
- physical and chemical processes in the Earth’s depths.
Continuous generation of intraterrestrial heat compensates for its external losses, serves as a source of accumulation of deep thermal energy and determines renewable resources.
The sources of geothermal energy can be divided into 5 types:
- deposits of geothermal dry steam. They are relatively easy to develop, but quite rare. However, 50% of all geothermal power plants use heat from these sources.
- sources of wet steam (a mixture of hot water and steam). They are more common. When developing them, it is necessary to prevent corrosion of equipment of a geothermal power plants and environmental pollution (removal of condensate due to its high degree of salinity).
- deposits of geothermal water (contain hot water or steam and water). They are geothermal reservoirs which are formed by filling underground cavities with water from precipitation heated by closely located magma.
- dry hot rocks heated by magma (at a depth of 2 km or more). Their energy reserves are the largest ones (petrothermal energy).

The more comprehensive classification of subsoil thermal energy sources is as follows:

- steam-hydrothermal resources (thermal resources used since ancient times as self-flowing sources of steam or liquid). These resources are available and easy to study but they are locally located, require cleaning before using them and can pollute the environment (thermal, chemical). About 70% of the global energy potential of steam-hydrothermal sources accounts for deposits with fluid temperatures below 130 °C. A significant part of these geothermal resources is explored.

- petrothermal resources (in developed countries, this type is referred to as HotDryRock). A relatively new direction based on the use of thermal energy contained in the hard rocks of the Earth – in the crust. Compared to steam hydrothermal resources, this thermal energy is found anywhere in the world, regardless of its geographic location. The disadvantage is hard extraction which becomes easier due to the development of drilling technologies.

The authors suggest using a new geothermal source – thermal energy of oil wells which are at the final stage of operation or abandoned.

A lot of studies deal with the problem of using abandoned wells. In [1], oil wells are modeled as a source of geothermal energy for generating electricity. Isobutane is chosen as a working fluid that is heated from geothermal energy and drives a turbine to generate electricity.

In [2], the problem of geothermal power generation from abandoned oil wells is dealt with. It develops a mathematical model accounting for masses, energy, and momentum conservation equations for fluid flows in the well. Isobutane is chosen as a working fluid. One more approach is described in [3]. The authors suggest using water as a well fluid. The wellbore is used as a heat exchanger which enables generation of electricity through the binary cycle unit. The research analyzes the results for more than 2500 wells in Texas where this technology is used.

The authors of [4] propose a numerical model of energy production from abandoned oil wells in Iran. The mathematical model accounts for geometrical parameters of the casing wells and exact temperature gradients. The simulation results were optimized for the flow rate of the input and output fluid and temperatures.

The use of the Rankine organic cycle in abandoned wells shows the efficiency of the studies [5]. The authors analyze different liquids for different temperature gradients. Well depths and their temperature gradients are classified. Based on this classification, working fluids are selected.

In [6], the authors suggest using freon as a working fluid. Modern binary turbines allow for using low-grade heat of the medium. These technologies are used by RASER operating in Alaska.

The design of wells is described in [7]. Depending on the formation structure, various well construction designs are developed. The authors of [8-10] developed a new approach to the selection of resource-attractive wells. They developed a mathematical model which is determined by the temperature gradient, well depth, bottom and coolant temperatures. Depending on the depth and temperature gradients, these nomograms determine injection rates. Based on these nomograms, it is possible to predict what thermal power can be obtained from a certain well at a given coolant injection rate.

2. Methods and technology

2.1. Power generation technology using heat of abandoned oil wells

The article provides calculations for a single well with a heat output of 1000 kW.

The unit consists of three contour (Figure 1):
- the glycol contour for selecting low-potential energy from the well;
- the main freon contour for converting low-potential energy into high-potential energy for further power generation;
- the auxiliary freon contour for condensation of freon of the main circuit.

Let us consider each contour.

1. The glycol contour consists of:
   - freon shell-and-tube (glycol / freon) evaporator 1;
- circulation pump 2;
- polyethylene pipelines (supply and return) 3;
- heat exchanger consisting of finned tubes 4;
- freon shell-and-tube (glycol / freon) condenser 5.

The glycol mixture located in a closed contour circulates between finned heat exchanger 4 and freon evaporator 1 using circulation pump 2. Low-grade heat located at the well bottom is transferred through polyethylene pipelines 3 to freon evaporator 1. The contour closes and the cycle is repeated.

2. The freon contour consists of
- freon shell-and-tube (glycol / freon) evaporator 1;
- freon compressor 6;
- turbine generator 7;
- freon shell-and-tube condenser for cooling freon 8;
- electronic thermostatic valve TSV 9.

Liquid freon enters freon shell-and-tube (glycol / freon) evaporator 1, evaporates, absorbing low-grade heat and turns into gas. Freon compressor 6 compresses freon (freon temperature and pressure increase) and goes into turbine of the turbine generator 7.

![Image](image.png)

**Figure 1.** The system for collecting heat from oil wells in the conservation state.

In the turbine, freon expands, transmits kinetic energy to the blades of the turbine and drives the rotor of the generator 7. Electrical energy is produced. Then freon enters freon shell-and-tube condenser 8 where it turns into liquid. If necessary, it is throttled using electronic thermostatic valve 9 and enters freon shell-and-tube (glycol/freon) evaporator 1. The contour closes and the cycle is repeated.

3. The freon auxiliary contour consists of
- freon shell-and-tube (freon/freon) condenser 8;
- freon compressor 10;
- freon shell-and-tube (glycol/freon) condenser 5;
- electronic thermostatic valve TSV 11.

Liquid freon enters freon shell-and-tube (freon/freon) condenser 8, evaporates, absorbing the heat of main contour freon and turns into gas. Freon compressor 10 compresses freon (freon temperature and pressure increase) and supplies it to freon shell-and-tube (glycol/freon) condenser 5 where it gives off heat to glycol, condenses and is throttled in electronic thermostatic valve 11 and enters freon shell-and-tube (freon/freon) condenser 8. The contour and the cycle repeats.

The temperature of the oil liquid which emits low-grade formation heat is monitored using sensor 12. The amount of energy produced is measured by meter 13.

2.2. Energy balance
The amount of generated electrical energy (at the turbine generator efficiency of 50 %) is 660 kW.

The amount of consumed electrical energy is as follows:
- Freon compressor (main contour, 6) – 300 kW;
- Freon compressor (auxiliary contour, 10) – 70 kW;
- Circulation pump CP (2) – 30 kW;

The total amount of consumed electrical energy is 400 kW.

The amount of electrical energy for the network is 660 - 400 = 260 kW.

2.3. Economic calculation
Expenses:
- Heat exchanger of finned tubes (4) – 500 thousand rubles;
- Polyethylene pipelines (supply and return) (3) – 4000 thousand rubles;
- The circulation pump (2) – 400 thousand rubles;
- Equipment of the freon main contour– 6000 thousand rubles;
- Equipment of the freon auxiliary contour– 1400 thousand rubles;
- Turbine generator (7) – 4000 thousand rubles;
- Automation and accounting system– 1500 thousand rubles;
- Block of sandwich panels – 1000 thousand rubles;
- Assembly works– 1000 thousand rubles;
- Installation works– 1000 thousand rubles;
- Repairs– 1000 thousand rubles;

Total: 21800 thousand rubles

Calculation of the cost of electrical energy generated for 1 year:
\[260\times 5\times 24\times 360 = 11232\] thousand rubles,
where 260 is the amount of electrical energy for the network, kW, 5 is the cost of 1 kW/h for industrial enterprises, rubles, 24 is the number of hours per day, 360 is the number of working days per year. Thus, the payback period is: 21,800 thousand rubles / 11232 thousand rubles = 1.94 years, i.e. it is 2 years.

3. Results
The article suggest using abandoned oil wells with low temperature gradients. Freon can be used as a coolant depending on geological and physical characteristics of the wells. The used of a flexible hose for freon circulation is a unique technology. Energy calculation shows that at a power consumption of 400 kW, 660 kW of electrical energy can be obtained. Economic calculations show that the payback period is 2 years.

4. Conclusion
Geothermal power generated from abandoned oil wells is a new way to use geothermal energy. The results of a five-year research on the use of abandoned wells were described in the article. Nomograms
that allow for selection of resource-attractive wells accounting for geological and physical formation parameters were constructed. The research result is a technology for using abandoned wells.

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