Energy-saving technologies at oilfield facilities

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Abstract. The article presents the results of the analysis of energy generation and consumption systems at the oil field facilities. The assessment of the state of the energy supply systems of the facility was carried out. The research presents the results of thermal imaging control of heat generation and transmission losses through the external fences of buildings. The generalized characteristics of the energy efficiency of the surveyed object are considered. The article analyses the directions of energy-saving, taking into account the peculiarities of the climatic features of the location of oil fields. The research justifies the relevance of using energy-saving technologies.

1. Introduction

Oil is one of the most important raw materials that ensure the well-being of many countries, including Russia. More than 500 million tons of oil are produced annually in our country. However, the main oil fields are located in the Arctic zone north of 66°33’ s.w. The development of such deposits is complicated by harsh climatic conditions, problems of cargo delivery, remoteness from existing energy systems.

Currently, taking into account the features of the field and a specific well in terms of the characteristics of the oil reservoir, the pumping method of oil production is chosen. Booster pumping stations and separation units are provided for the preparation of oil for transportation. All equipment for the production, preparation of commercial oil and the system of main oil pipelines requires significant resources of electrical and thermal energy. The analysis of the energy consumption of one of the deposits in the territory of the Nenets Autonomous Okrug (NAO) of the Arkhangelsk Region shows that up to 95% of the generated electricity is used to provide technological and household consumers (Fig.1). Among the technological consumers, it should be noted the mechanized oil production equipment, the reservoir pressure maintenance system (RPMS), electric heating of technological pipelines, the equipment for the oil pumping station, water production [1].

Electricity generation is provided by diesel power stations (DPS). A significant amount of diesel fuel is also spent on the production of thermal energy, taking into account the low temperature for calculating heating (-39°C) and, accordingly, the duration of the heating period of 289 days. About 7,000 tons of diesel fuel are consumed per year. Figure 2 shows the share distribution of diesel fuel by consumption directions. It can be seen from the figure data that the main consumption is electricity generation at the DPS, seasonal consumption for motor transport is 5% and thermal energy generation is 4%.

Both during generation and energy consumption, there are significant losses. For example, the efficiency of the gas turbine units used does not exceed 32%. Technical losses in electrical networks due, first of all, to uneven electricity consumption include up to 37% load losses (in power transformers
and power transmission lines) and up to 62% idling losses (power transformers, reactive power compensators, through line insulation). It is known that the limit value of the reactive power coefficient ($\tan \phi$) for consumers connected to networks with a voltage of 6 kV is 0.4. However, the actual data for about ¼ of feeders show a significant excess, which leads to an increase in electricity losses in electric networks and an increase in electric energy costs.

An analysis of the efficiency of 6/0.4 kV power transformers at the enterprise shows that the load range of transformers was from 1.4 % to 66 % of the rated power. The average load level for 6 kV transformers was 29.7%. With a decrease in a load of transformers of less than 20% of the rated power, a significant increase in the amount of reactive power consumed by power transformers is observed.

The heat supply system of the enterprise is designed for the heating and hot water supply of buildings and facilities. Hot water is used as a heat carrier. Local heating, ventilation and hot water supply systems are connected to the heating networks according to an independent scheme. The heat supply of the facilities is carried out from its source of thermal energy – a hot water boiler house and local electric heating devices. Electric heating devices are installed in the premises of buildings at objects remote from the boiler room. The devices are equipped with a power regulator. The main fuel at the boiler house is diesel fuel. The laying of heating networks is aboveground. The thermal insulation design of heat pipelines on the platforms consists of a layer of mineral wool and a cover layer of galvanized iron.

To assess the loss of thermal energy through the elements of the boiler unit, as well as the enclosing structures of administrative and residential buildings and shift residential buildings, thermal imaging of buildings and facilities was performed. The results of a thermal imaging survey of the external surfaces of boiler units revealed a number of exceedances of the standard temperature values (Fig. 3). This excess leads to an increase in heat losses to the environment. Figure 4 shows the results of a thermal imaging survey of the enclosing structures of the unit for rotational accommodation (URA).
The analysis of the obtained results showed that there are heat losses due to the incompactness of doors and windows. At the same time, the research data show a significant excess of indoor air temperature in the cold period of the year up to 26°C. Increased consumption of thermal energy also leads to overspending of diesel fuel.

Difficulties in the diesel fuel delivery, the requirements of state regulatory documents in the field of improving the energy efficiency of technological processes and solving environmental problems led to the search for alternative methods of generating heat and electric energy during the development of oil fields.

2. Materials and methods
When developing energy-saving technologies for a specific object, the results of instrumental measurements are used. Thus, the assessment of the energy efficiency of centrifugal multistage pumping units for pumping commercial oil was made based on the actual values of specific energy consumption, which show excessive energy consumption compared to the passport data. To improve the energy efficiency of pumping units for the main oil transportation, it is recommended to consider the use of a frequency-controlled drive.

It is known that the viscosity of oil significantly depends on the temperature (Fig. 5 and 6). Maintaining the required temperature regime (40÷45°C) the main oil pipelines with a length of up to 30 km are provided by an induction-resistivity system (SKIN EFFECT), the power supply occurs from one end without an accompanying network. The systems are equipped with automated control systems according to a given algorithm, but the temperature sensor is installed in the common collector of the multiple-well platform, but not all pipelines can be used simultaneously. To reduce energy consumption, it is advisable to include individual sensors for each pipeline in the control scheme to avoid heating empty pipelines.

Significant potential for energy saving takes place in the reservoir pressure maintenance system (RPMS), which consists of a water intake unit, water treatment plants for injection into the oil reservoir, suction and discharge main pipelines, pumping stations. During the energy survey, it was revealed that it is necessary to develop a valve control scheme to ensure smooth regulation of water flow and, accordingly, reduce electricity consumption.

A significant number of works have been devoted to the use of associated petroleum gas (APG), for instance [3-6]. The performed analysis shows [4, 5] that the use of APG significantly reduces the emission of greenhouse gases into the atmosphere. As noted in [6], in Russia, the volume of greenhouse gas emissions due to APG flaring is about 35 billion m³/year, which is more than the total amount at the fields of Nigeria, Iraq and Iran. There are objective reasons related to the volume of oil production, the remoteness of domestic fields from settlements – potential energy consumers. In the analysed field, APG is used as fuel for process furnaces designed for circulating and additional heating of oil before transportation. However, the analysis of the results of instrumental measurements shows that the temperature of the exhaust gases is about 600°C, which also causes thermal pollution of the atmosphere.
To increase the energy efficiency of the technological process of oil heating, it is more relevant to use the high-potential energy of exhaust gases for heating water in recycling heat exchangers. The use of gas-water heat exchangers, widely used at compressor stations, would allow providing thermal energy to the shift settlement and production facilities, thus reducing the cost of diesel fuel. But at present, our own diesel-powered hot water boiler is used for heat supply, and also electric heating devices are used at remote facilities.

The boiler house also does not have a heat recovery system, while significant heat losses are associated with the ground laying of heating networks, poor insulation, and the non-compliance of the thermal technical characteristics of the enclosing structures of shift settlements (Fig.4) with modern energy-saving requirements. As a result, excessive consumption of thermal energy also leads to overspending of diesel fuel.

When using gas-fired power plants, currently the exhaust gases from a gas turbine with a temperature of about 500°C is removed without recycling, increasing thermal pollution in the atmosphere. In addition, the non-regenerative cycle has a rather low efficiency (28-32%). In order to save energy, it is proposed to use a regenerative cycle for heating cyclic air, which is also widely used in gas turbine units for driving gas superchargers at compressor stations of main gas pipelines. The use of a regenerative cycle (Fig.7) will reduce the specific fuel gas consumption by 0.01 kg/kWh, which corresponds to an increase in efficiency up to 37%. Also, the use of a gas-vapour cycle to increase the efficiency of the power generator up to 60% and reduce the temperature of the exhaust gases can become a modern direction of energy-saving when generating energy resources at an oil field.

Taking into account the modern trends in the development of energy [7-9], it is proposed to use the currently widespread cogeneration of energy [10-14]. The use of distributed energy technology makes it possible to take into account the unevenness of energy consumption, smooth out the effect of traditional calculations for peak loads, and use alternative energy sources more widely. For example, in the European Union, the contribution of cogeneration to 15% and simultaneous reduction of greenhouse gas emissions to 24% was planned for 2020. In our opinion, in Russia, the most promising option for energy-deficient areas of oil and gas field development is the use of cogeneration, including based on gas generator stations with gas-diesel engines and utilization modules, which will allow abandoning boiler houses from the drilling stage. At the same time, the use of modular technology will ensure a gradual increase in the power of energy generators and expand the possibilities of using energy resources for technological and household consumers as they transition to the industrial development of deposits.

However, the use of cogeneration nowadays still requires the delivery of diesel fuel, or the preparation of fuel gas (APG), or "crude" oil, or its highly viscous refined products for the corresponding energy generators. As one of the solutions to this problem, a well-known Stirling heat engine can be proposed, which does not require special fuel preparation and can use any source of heat, for example, solar energy.

The thermodynamic Stirling cycle is shown in Figure 8. The work in the Stirling cycle is the difference between the work obtained in the process of isothermal expansion (heat supply $q_1$) and the work spent in the process of isothermal compression with heat removal ($q_2$). The efficiency of the cycle is determined by the energy extracted when the pressure of the working fluid changes. However, along with the positive aspects of Stirling engines - the simplicity of design, the cost-effectiveness of operation, the environmental friendliness, such indicators as dimensions and the need to create significant pressures crucially restrict its use.
Among the alternative energy sources, wind generators can be used to generate energy in oil fields, which is due to the climatic features of the regions of the northern and Arctic territories of the Russian Federation, where the average wind speed is about 4-8 m/s.

3. Results
The evaluation of the efficiency of the implemented and proposed energy-saving technologies at the analysed objects is based on the results of energy surveys.

The total electricity generation is about $150 \times 10^6$ kWh/year, with losses reaching 1.5%.

The production of thermal energy is about $4 \times 10^3$ Gcal/year, with losses of about 1%.

Diesel fuel consumption is up to 7,000 tons of fuel equivalent, APG is about $90 \times 10^3$ tons of fuel.

Figure 9 shows the data on the actual consumption of diesel fuel for the production of thermal energy and potentially possible ones when using the heat recovery system proposed above. The use of modern automation for consumers of thermal energy will provide savings of up to 60 tons of fuel, the payback period is about 6 years.

In order to save energy, it is proposed to use a thermodynamic cycle with the regeneration of thermal energy (“carnotization” of the working cycle) of a gas turbine unit (GTU). This will save about $500 \times 10^3$ kWh/year (Fig. 10).
pumping units operate with a specific energy consumption higher than the passport values, which is due to maintaining the required pressure in the main pipeline and, accordingly, reducing the pump performance. To increase the efficiency of using pumps for external oil transportation, it is recommended to consider the introduction of a frequency-controlled drive. The energy saving potential can be up to $7 \times 10^3$ kWh/year with a payback period of less than 4 years.

Similarly, for the reservoir pressure maintenance system (RPMS), the energy-saving potential is up to $3 \times 10^3$ kWh/year with a payback period of less than 10 years.

Taking into account the average annual wind speed of at least 5 m/s, the use of a wind generator on one of the multiple-well platforms was evaluated. The energy-saving potential is more than $2 \times 10^6$ kWh/year when installing 18 wind turbines. In the absence or weakening of the wind, or in the case of insufficient solar insolation, the automatic monitoring of the voltage drop on the batteries occurs, after which the automatic network connections occur. The batteries from the network are recharged through the charging rectifiers of the charging and starting device.

The assessment of the potential of energy-saving measures was carried out without taking into account the consumption of APG, which is a by-product of oil production and has no consumer value and, as a result, there is no need to reduce the consumption of this type of energy resource.

4. Discussion

The analysis of energy generation and consumption shows the presence of a potential in almost all directions — both the efficient use of fuel and the reduction of losses in distribution networks, which is also noted in [15]. First of all, the possibilities of reducing energy consumption relate to the consumption of electricity for mechanized oil production, preparation and transportation. However, some proposed energy-saving technologies should be taken into account when developing technical specifications and preparing project documentation. In particular, this is the use of regenerative cycles with the selection of appropriate equipment, cogeneration units, heating systems for technological pipelines.

The above data for the influence of oil temperature on its viscosity show that when the oil temperature increases, for example, from $0^\circ$ to $15^\circ$C the viscosity is reduced by 3 times, and the throughput of the oil pipeline increases by 21.5%. For the external transportation of oil, the heating system of pipelines in the Arctic zone is extremely important. And, the implementation of measures for comprehensive control of temperatures and the operating mode of pipelines can be carried out in the conditions of an existing pipeline. But, the transition to heating systems using antifreeze requires consideration at the project development stage.

Thus, the potential opportunities of energy-saving technologies account for about 7% of the total consumption of fuel and energy resources of the field in tons.

An important role in the development of oil and gas fields, especially in the conditions of permafrost rocks, is played by technologies related to the need for thermal stabilization [16] of these rocks to avoid deformation of production wells and potential emergencies. For example, such rocks in the Bolshezemelskaya tundra (European North-East Russia) occupy almost 95% of the territory. The depth of permafrost rocks is up to 500 m, the temperature is ($-5^\circ$C)÷($-2^\circ$C). To prevent the thawing of these rocks, for example, the thermal insulation of casing columns, seasonal cooling devices are effectively used. It is proposed to use modern heat pump technologies of year-round operation, while the utilized heat can be used in the cold period of the year for heat supply of field facilities.

5. Conclusion

The presented results of the analysis of potential energy-saving opportunities in the systems of generation and consumption of energy resources at the oil field facilities will reduce the costs of oil field development, environmental damage from thermal pollution of the atmosphere and greenhouse gas emissions.
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