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Increase of the Operation Efficacy of Geothermal Power Stations

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ABSTRACT

The exhaustion of the mineral resources, environmental problems, and appearance of new, more perfect technologies necessitate the development of unconventional raw materials, one of which is geothermal. With growth of thermodynamic parametres of heat-carriers the chemical activity and energy of deduction of mineral connections by geothermal steam increases while passing through the rocks. Therefore, if low-temperature heat-carriers containing chemical compounds can be defined by their balneal properties, it is necessary to consider middle and high-temperature heat-carriers with a high content of chemical compounds as "liquid ores". A complex approach is required to more efficiently utilize geothermal resources, including their mineral components.

1. INTRODUCTION

The exhaustion of mineral resources, environmental problems and appearance of new, more perfect technologies necessitate the development of unconventional raw materials, one of which is geothermal. Practical use of geothermal resources is possible in the presence of certain characteristics, namely the reserves, favorable thermodynamic parameters of the geothermal fluid, and profitability.

The power parameters of the geothermal fluid define their technological use: geothermal fluids with temperatures up to 100°C are characterized as low-temperature heat-carriers, those with temperatures of 100-300°C are medium-temperature heat-carriers, and those with temperatures above 300°C are high-temperature heat-carriers. The chemical activity of heat-carriers increases with their thermodynamic parameters.

Therefore, the chemical compounds found in low-temperature heat-carriers usually have balneological properties. Medium and high-temperature heat-carriers have a higher content of chemical compounds, so it is necessary to consider them as "liquid ores" The high concentrations of the chemical compounds containing active ions like NH_4^+, F^-, Cl^-, SO_3^{2-}, and SO_4^{2-} in these liquid ores causes corrosion of equipment, particularly in turbines, creating a barrier to the efficient utilization of this resource.

So, separating these compounds from heat-carriers is necessary to increase the profitability of these energo-technological processes for optimal utilization.

2. THEORY

According to various research, the content of chemical compounds in geothermal fluids depends not only on their deposition, but also on the temperature. In one geological area, the lithology is consistent with resource temperature. Most high-temperature zones are composed of bismuth, cobalt, molybdenum prevail; zinc, vanadium, copper prevail in most medium -temperature zones; and most low-temperature zones contain basically lead, arsenic, and mercury.

In some countries, active research concerning the extraction of the chemical compounds from geothermal fluids is being conducted. For example, the extraction of boron in the deposit Lardarello in Italy has been of interest for many years.

It is possible to consider geothermal fluids not only as "liquid ore ", but also as an acid solution-reagent for use in hydrometallurgical processes. The analysis of the physical and chemical properties of existing geothermal fluids in various deposits around the world has allowed for their classification based on their energy and chemical properties. This is presented in Table 1.

Table 1: Classification of geothermal fluids

phase	pH	temperature°C	mineralization
fluid	pH < 7	≤ 100	> 600
	pH = 7	≤ 100	< 50
	pH > 7	≤ 100	50-600
Steam-water mixture	pH < 7	< 120	50-3600
	pH = 7	120 - 180	< 50
	pH > 7	> 180	>600
steam	pH < 7	< 250	600-6000
	pH = 7	250-600	< 50
	pH > 7	> 250	> 3600

The following physical and chemical parameters were included in the classification of these fluids: fluid phase, acidity, temperature, and mineralization. The analysis of the possible conditions of geothermal heat-carriers enables to the characterization of these fluids by their physical and chemical properties.

Firstly, the content of chemical compounds in geothermal compounds is directly proportional to the fluid temperature. This is explained by the increase in chemical activity and the energy of confinement of mineral deposits with the thermodynamic parameters of the geothermal fluid (Mjazin, Belova et al 2002).

However, the presence of the chemical compounds in the geothermal heat-carrier leads to serious problems when using classical power generation equipment like corrosion and scurf in the pipelines and a decrease in the efficiency of the power plant as a whole. Therefore, the creation of effective separation equipment to remove corrosive compounds is a problem relevant to geothermal development. This has two potential benefits: it will allow an increase in plant efficiency and produce a solution containing chemical compounds useful in ecological and chemical-technological matters.

Almost all extracted raw materials (including geothermal fluids) consist of both inert and valuable components. For existing raw material primary processing technologies, the specific cost of the conditioned product $\mathbf{S_{cp}}$ (without taking into account the cost of construction of GOK) is expressed in Equation 1:

$$\mathbf{S_{cp} = S_{pw} + S_{oe.} + S_c + S_{dp} + S_{cp} + S_{sr}} \qquad (1)$$

where $\mathbf{S_{pw}}$ is the cost of the preliminary works, $\mathbf{S_{oe.}}$ is the cost of the ore extraction, $\mathbf{S_c}$ is the cost of breaking, crushing, receiving the concentrate, $\mathbf{S_{dp}}$ is the cost of receiving a draft product, $\mathbf{S_{cp}}$ is the cost of receiving the conditioned product, and $\mathbf{S_{sr}}$ is the cost of waste storage and recycling. Geothermal applications differ slightly, so a different expression must be used (Equation 2):

$$\mathbf{S_g = S_d + S^*_{dp} + S^*_{cp} + S_r - S_{ep}} \qquad (2)$$

where $\mathbf{S_g}$ is cost of geothermal energy production (without accounting for the construction cost of the industrial enterprise), $\mathbf{S_d}$ is the cost of drilling, $\mathbf{S^*_{dp}}$ is the cost of receiving a draft product, $\mathbf{S^*_{cp}}$ is the cost of receiving the conditioned product, $\mathbf{S_r}$ is the cost of reinjecting the waste heat-carrier, and $\mathbf{S_{ep}}$ is the cost of the received electric power.

Comparison of the Equations 1 and 2 shows that the cost of the products of traditional and geothermal technologies differ. In the Equation 1, the sum of the first three components ($\mathbf{S_{pw} + S_{oe.} + S_c}$) corresponds to the component $\mathbf{S_d}$ in the Equation 2 (the cost of drilling, value of which on 2-3 times is below.)

Values of the complexes ($\mathbf{S_{dp} + S_{cp}}$) and ($\mathbf{S^*_{dp} + S^*_{cp}}$) in Equations 1 and 2 are comparable.

It is reasonable to assume that components $\mathbf{S_{sr}}$ in Equation 1 and $\mathbf{S_r}$ in the Equation 2 are equal or at least comparable.

If geothermal resources are used comprehensively, the energy cost will decrease. At the same time, extraction of the valuable components from the heat-carrier raises its technological value due to the simultaneous reduction of corrosion in the plant equipment and utilization of chemical compounds.

The qualitative analysis of the Equations 1 and 2 creates an optimistic picture of the potential development of comprehensive use of geothermal resources. Unfortunately, there are some barriers that limit profitability:

1. The absence of corresponding infrastructure near geothermal deposits and power plants in this connection means that work should be conducted cautiously.

2. Heat-carriers in currently developed geothermal reservoirs have low concentrations of valuable raw materials.

3. The absence of the corresponding materials limits the opportunity to drill geothermal deposits with temperatures above 300°C.

4. The corresponding separation equipment does not currently exist.

JSC "Geoterm " has already begun to work toward increasing the efficiency of geothermal resource exploitation.

Mutnovsky and Verhne-Mutnovsky GeoPP have extraction wells located near the volcano Zhirovskoy, which relates to the Mutnovsky volcanic area. The area is located 70 km to the south of Petropavlovsk-Kamchatsky and is a potential example of the relation between various forms of modern volcanic and hydrothermal activity.

The complex body surrounding the volcano Mutnovsky contains non-uniform age, powerful fumarole fields, the volcano Goreliy with a caldera at the top of an ancient cone, and the destroyed volcano Zhirovskoy which houses thermo-activity in a crater with a total estimated thermal capacity of 5000 kilocalories/s.

There are many of displays of modern thermal activity within the limits of this zone (Mjazin, Belova et al 2002).

Thermal schemes of the GeoPP include the local binding of extraction wells, transportation of the water-steam mixture, binary separation of steam, the binding of a turbine unit, systems of steam condensation, systems of dissolution in a condensate of un-dissolved gases (for ecological protection), systems of fluid expansion and receiving of steam for ejector, and systems of pumping condensates and fluids.

Mutnovskye GeoPP is working on the exploitation of geothermal heat-carriers with low mineralization, as displayed in Table 2.

Table 2: Mineral composition of fluid studied by Mutnovsky GeoPP-1

pH	K^+	Na^+	NH_4^+	Ca^{2+}	Mg^{2+}
9.2	53	273	0.8	3.8	< 0.1
$Fe_{(общ)}$	Cl^-	HCO_3	SO_4^{2-}	H_4SiO_4	H_3BO_3
< 0.3	234	42	5.2	1180	96

The results of the analysis presented in Table 2 show the general mineralization near 1,5 г/½, and more than 70 % silica. Concentrations of the mineral substances in geothermal fluid are generally 10-20 %. The presence of silica makes it impossible to achieve optimum work of geothermal energy exploitation using GeoPP's technological scheme.

The geothermal water-steam mixture is separated into steam containing virtually no mineral components that goes to the turbine and liquid water in which the chemical compounds are dissolved. The fluid of higher purity is reinjected into the reservoirs, where the minerals dissolve at high temperature and are separated from the fluid after a decrease in its temperature.

The mineral sediments are dominated by silica. The fluid temperature after the separators is about 170^0C. Use of this thermal potential in binary cycles is not possible because of the heat exchangers become encrusted with firm mineral sediments which disturb the process of heat exchange and deactivate the equipment.

Extraction of the chemical compounds while preserving the high temperature is not possible because of the high solubility of the chemical compounds at this temperature other technological difficulties. Experiments have shown that the optimum temperature of extraction of the chemical compounds while avoiding technological difficulties and the formation of firm sediments is 80^0C (Latkin, Luzin, et al 2008). Therefore, an increase in the efficiency of geothermal power plants is possible during realization of the following programs:

1 – Use of thermal energy of the fluid.

For this purpose, the fluid is boiled at a temperature 800°C in a special dilator. Received steam goes to a turbine with a generator. Waste steam arrives in a mixing condenser. The received condensate is cooled in a cooling tower and is utilized as a cooling agent in the mixing condenser. In accordance with preliminary estimates, the use of the thermal energy in secondary steam will allow an increase in power capacity of plants of up to 20-25 %.

2 – Receiving the conditioned products on the basis of clearing of the secondary fluid from chemical compounds.

The secondary fluid can be separated from chemical compounds using chemical or electrochemical methods (Iler R.M. 1982). Rough silica is 15-20 % polluted with the elements specified in Table 2, which can be extracted easily by washing with acids (Latkin A.S. 2007). After drying in a laboratory atmosphere, it was possible to receive thinly dispersed silica of 998 % purity.

Silica is a commodity that is widely applicable in chemical additives, the varnish-and-paint industry, in the manufacture quality paper and rubber, and in electronics for the manufacture of silicon batteries. Depending on the cleanliness of silica, its cost varies from $2,000-20,000 per ton (Iler R.M. 1982).

The essential economic contribution to the operation efficacy will be the production of 1000 t/year of pure silica. Silica production potential from the Mutnovsky GeoPP's heat-carrier is 3000-4000 t/year.

3 – Use of thermal energy of the secondary fluid.

Cleared of chemical compounds, the secondary fluid at 80^0C can be used in a binary cycle for power production. In accordance with the preliminary estimates, the use of the thermal energy in the secondary steam will allow to increase power capacity of the power plants by 3-5 %.

Cooled fluid with concentrations of silica less than 0.1 % and temperatures from $20\text{-}25^0$C will be reinjected into the reservoir. The absence of silica and the small concentrations of chemical compounds in the reinjected water allow for the avoidance of plugging the reinjective wells by adjournment.

In connection with the possible realization of these programs, the basic technological scheme of the complex use of resources in geothermal heat-carriers is presented in Figure 1.(on the basis of existing Mutnovsky GeoPP-1). Complex use of resources of geothermal heat-carriers, according to scheme, will be executed in the following way. First, the steam-water mixture moves through the line (1) to the separator (2), where it is divided into liquid and steam. Next, the purified steam arrives at the turbine of a generator (3). Waste steam is condensed in the mixing condenser (4) and is moved by the pump (5) to the cooling tower (6), where it is cooled. This cooled condensate from the cooling tower is then introduced to the condenser as a cooling agent.

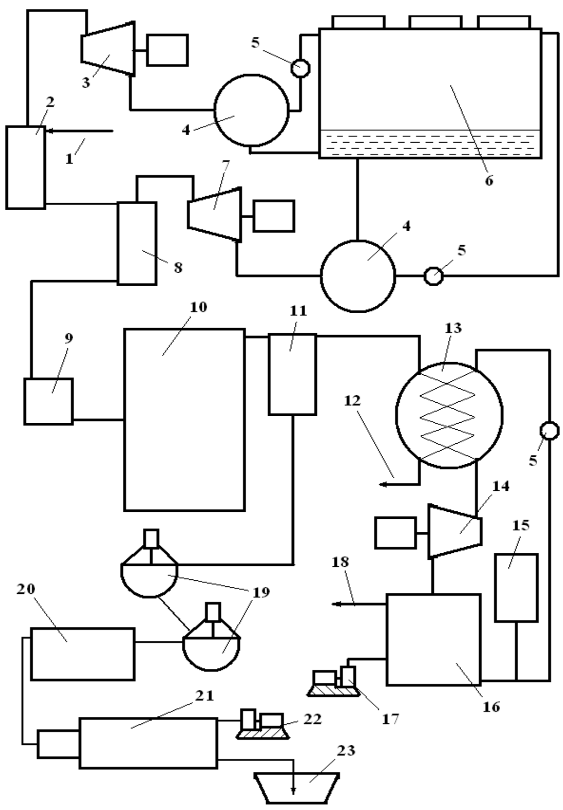

Figure 1: The basic technological scheme of the complex use of resources of geothermal heat-carriers on the basis of existing Mutnovsky GeoPP-1.

1 – an existing line of steam-water mixture supply; 2 – an existing separator; 3 – an existing generator; 4 – the existing mixing condenser; 5 - the pump; 6 – an existing cooling tower; 7 – a generator of crumpled steam; 8 – a dilator; 9 – electrodialyzer; 10 – settling tower; 11 – a thickener; 12 – a line for pumping of the waste water into the reinjection wells; 13 – the piped heat exchanger; 14 – a turbo-generator of a binary cycle; 15 – capacity with low-boiling working agent; 16 – air cooling tower; 17 – the forcing air fan; 18 – a pipe branch of air escape; 19 – reactors for clearing and washing of silica; 20 – a thickener; 21 – vacuum spray-type dryer; 22 – vacuum pump; 23 – a tank for collecting dry disperse silica

The surpluses of the condensate accumulation process are removed from the cooling tower by technological drains. Fluid from the separator (2) arrives in a dilator (8), where it is separates liquid from the secondary steam exiting the turbine of a generator (7). Waste steam is condensed in the mixing condenser (4) and moved by the pump (5) to the cooling tower (6), where it is cooled. Then, the condensate from the tower is routed to the condenser (4), where it is employed as a cooling agent. Secondary fluid from a dilator (8) arrives in the electrodialyzer (9), where there is a formation of the siliceous sol with the various chemical elements. Then, a stream of secondary fluid containing sol arrives in the settling tower (10) where there is a formation of the siliceous colloid, which is extracted with a thickener (11).

Cleared secondary fluid arrives in the binary cycle piped heat exchanger (13), where its heat is transferred to the low-boiling working agent, transforming it into vapor phase. After the heat exchanger, the fluid is is reinjected into the geothermal reservoir. The vaporous working agent moves to the binary cycle turbine generator (14). After the turbine, the agent arrives in the hermetic tubular air cooling tower (16), where it is condensed and moved by the pump back to the heat exchanger. After the thickener (11), the colloidal solution of the rough silica arrives in the reactors for the clearing and washing of silica (19).

Solutions of silica with the chemical compounds are moved to the line (12). Cleared colloid arrives in a thickener (20) and is then introduced into the vacuum spray-type dryer (21), and is collected in a tank (23) in the form of a chemically pure disperse powder that can be sold as a commodity.

Geotherm JSC is actively implementing scientific research and experimental design and development of these programs to increase the efficiency of geothermal energy exploitation and produce pure silica as a byproduct on the basis of separating chemical compounds from the secondary fluid.

3. CONCLUSIONS

1. Geothermal heat-carriers are classified on the basis of the analysis of their existing types. It is clear that heat-carriers in the middle-temperature range in the form of steam-water mixtures are currently more feasible for complex use of natural resources.

2. The conditions of GeoPP were analyzed with the purpose of modernization to increase the operation efficiency on the basis of the complex use of the resources of geothermal heat-carriers. The basic technological scheme for increasing the operation efficiency of GeoPP is offered.

REFERENCES

Mjazin V.P, Belova T.P., Latkin A.S., Rybakova O. I, Lavrov A.JU.: Geotechnological and physical and chemical estimation of mineral and nonconventional type of raw materials of the Kurilo-Kamchatka region: the Educational grant -Chita: 2002. - 120.

Latkin A.S., Luzin V.E., Parshin B.E., Morgun V. M, Basmanov O. L, Belova T.P.: «The way of extraction of silica from the hydrothermal heat-carrier» the Patent. №2322889 from 10.05.2008.

Latkin A.S.: Heat-mass exchange in the twirled streams. The monography. Publishing house RUK. Petropavlovsk-Kamchatsky, 2007, 256.

Iler R.M.: Chemistry of the silica. The world. 1982, 1198p.