GEOTHERMAL SMALL POWER PLANTS ON THE BASIS OF APPLICATION OF TOTAL FLOW ENERGY CONVERSION

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Abstract

The brief description of test facility and results of total flow system investigations are presented in this paper. Their objective was to get the power from both steam and liquid expansion in the Laval nozzle. The applications of this technology conversion at Pauzhetka steam water and Paratunka liquid dominant geothermal fields is the first in world. The thermodynamic analysis of flash power systems and direct contact binary power systems, that realize the total flow concept was performed in this study. The results of field tests of jet pumps, were manufactured for reinjection of waste geothermal brin'es and the equipment for intensification of flow rate liquid dominant geothermal wells with using the light boiling medium (n-butane) is also presented. The rotory separator turbine and biphase turbine power plants with capacity 500 kW were developed on the basis of these investigations of total flow concept.

INTRODUCTION

The largest portions of high-temperature geothermal fields will be used up to the end of this century with the existing conversion technology, and it is very unlikely to wait for the discovery of new high-grade fields because of their high value.

A number of high-temperature geothermal fields constitutes only a small part from that for the fields of middle and low temperature with predominant liquid. Their use with existing conversion technology for producing the electric energy is difficult by following reasons:

-the use of trditional one-circuit system with flashers is ineffective due to small amount of steam generated in residental heat carrier (HC);

-the use of binary system with low-boiling secondary working medium (WM) is connected with introduction of surface-type heat- exchanger in the technological conversion scheme that results in the reduced potential of used HC due to the final temperature difference in heat-exchanger and its work in the conditions of corrosion and salt deposits.

Additionally geothermal wells produce high energy streams with large flow-rates, from which only thermal energy of steam is used in the process of conversion (for example, single flash system), while the thermal and kinetic energy liquid stream is insufficienty used.

The search for technical solutions that use the full potential of middle and low-temperaturees of geothermal HC is the very important technical problem. One solution for solving the problem is the method of geothermal energy conversion used for the first time in Russia the conversion of total energy from the HL flow- the heat energy of steam, water and the the excessive pressure of geothermal field /1/. Another solution is the use of energy of liquid effluented from flasher (or steam water mixture (SWM) from the well to operate a condensing injector for the reinjection of waste brines after separator /2/.

1. EXPERIMENTAL INVESTIGATION REALIZING THE CONCEPT OF MORE FULL USE OF GEOTHERMAL HC ENERGY

1.1. The method of total flow conversion was firswt realized at Pauzhetka's steam-hydrothermal field (peninsula Kamchatka) in 1969 at the experimental plant with the pelton type turbine (Fig.1a). In this experiment the two-phase SWM from the well was put through a nozzle, where it was accelerated, and its potential energy was transformed into SWM kinetic energy. The high-speed SWM flow was sent to a hydraulic turbine. which is used together with generator for the production of electric energy. The completed experiment confirmed the successful conversion of steam and hot water and guaranti- . fied the input of HC liquid component in the specific output of electric energy. The effect of blade profile on the turbine efficiency is shown in Fig.1b.

1.2. The experimental investigations and the introduction of injectors of different types and sizes were carried out also at Pauzhetka's field but only in 1981-1984. They were mounted and worked at two different wells (RE2 and K16) equipped with separators. After successfull investigation of several configurations of injectors, the large highly productive injectors were manufactured and used for pumping the hot water downstream of the separator. The cold fresh water from local small rivers was used for creating the vacuum in mixing injector's chamber. The injectors had the central or peripheral distributed input of cold water after SWM nozzle. The hot water discharged from separators was delivered through the second stage in the mixing chamber. This second stage was used also for the start-up of operation. The WM at the inlet of SWM nozzle was the SWM directly from the geothermal well or could be the hot water (in the state of saturation) from the separators. All working parameters, main sizes and weight of large injectors were the following: their length - 1.5-3.5 m; diameter - 0.3 m; their mass 150-350 kg: productivity 20-60 tonne/hour; mass steam content after well 0.01-0.15; pressures: mixture before pump 0.1-025 MPa, fluid before both injector stages 0.05-0.1 MPa; in mixing chamber 10-20 kPa; after pump 0.25-0.8 MPa; fluid temperatures, in ^oC initial in first stage 4-20, at second stage 10-95, at jet pump outlet 40-95. The flow-rates of cold G water through injector was in 2-4 times more, than the flow-rate in its SWM nozzle. The flow-rate of hot water through the second stage (from separator) was approximetely equal to G. The arrangement of the experimental injector system and its construction with typical static pressure distribution curve are presented in Figs.2a and 2b.

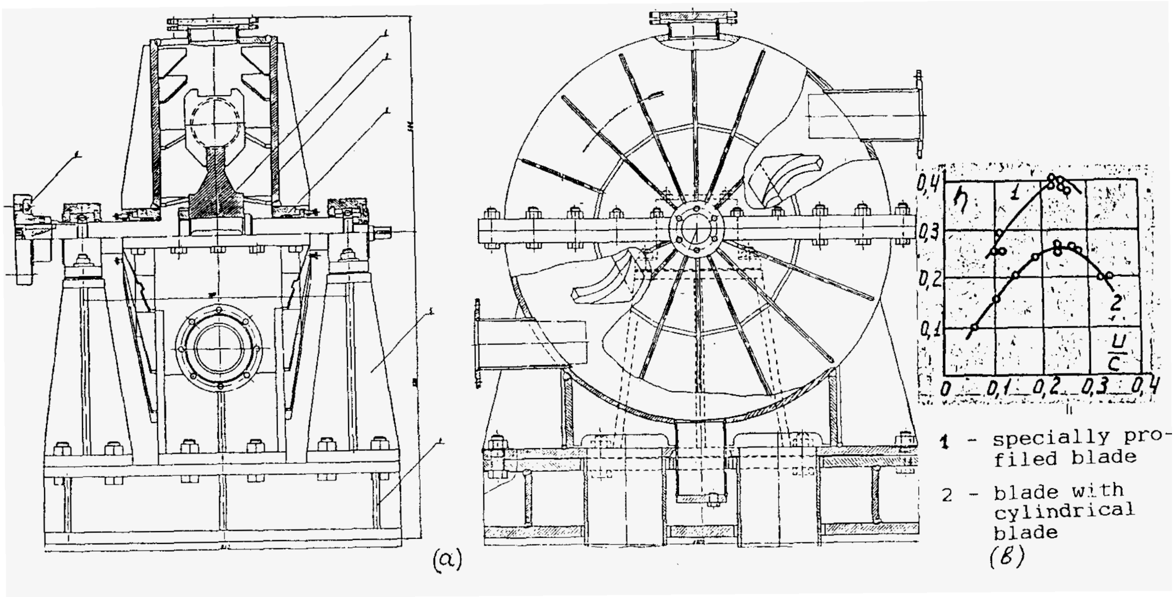


Fig.1. Experimental turbine of Pelton-type (a) and the deoendence of its efficiency η on u/c (b) for different velocity profiles of blades: 1-turbine rotor, 2-casing; 3-seal, 4-foundation frame, 5-thrust bearing,, 6-coupling

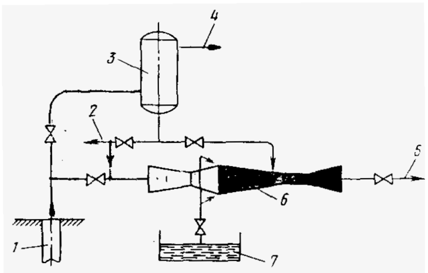


Fig.2a. Diagram of geothermal plant with jet pump mounted at Kamchtka: 1-geothermal well: 2-drain; 3-separator: 4-steam to qeothermal power plant: 5-to consumer: 6-injector (jet pump); 7-fresh water source

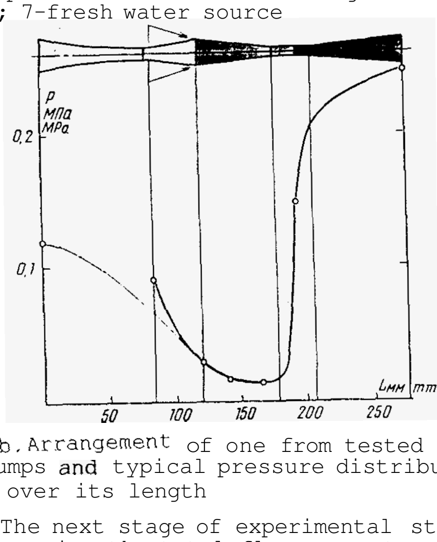


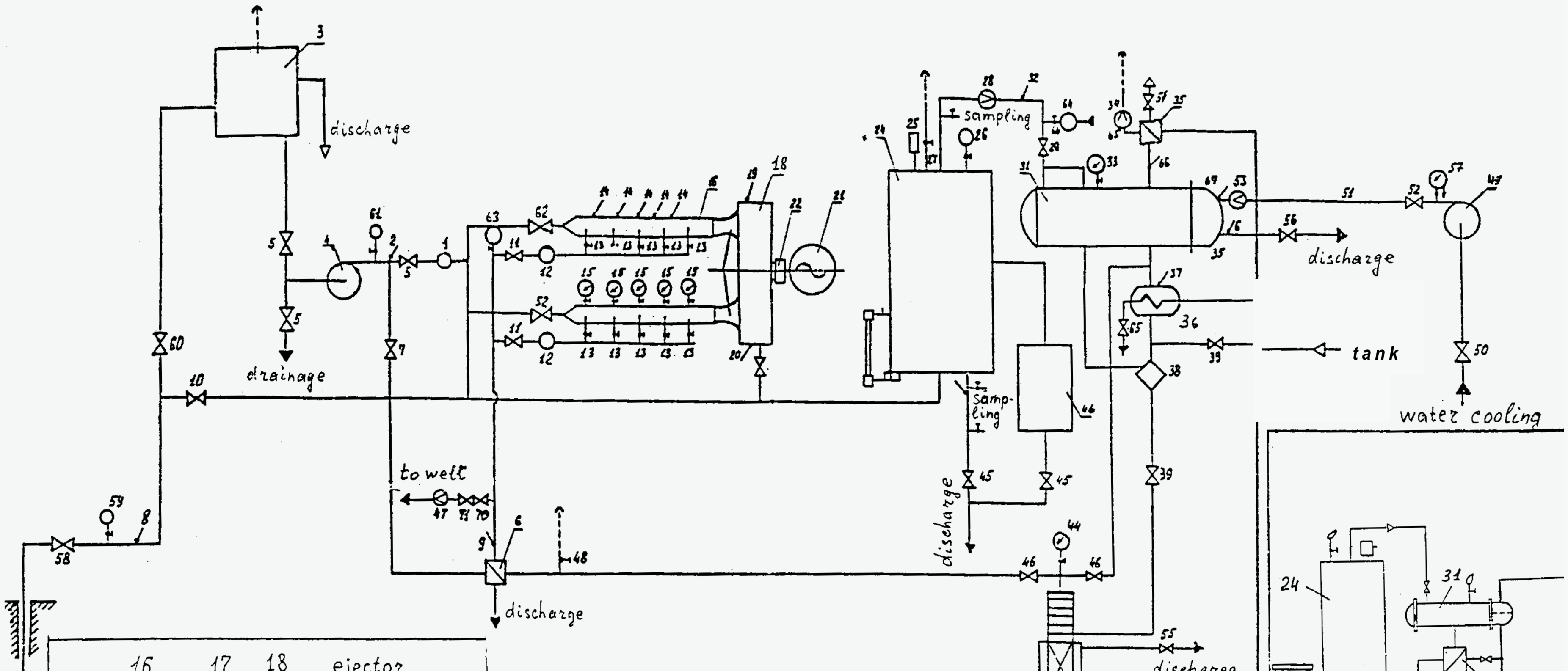
Fig.2b. Arrangement of one from tested jet pumps and typical pressure distribution curve over its length

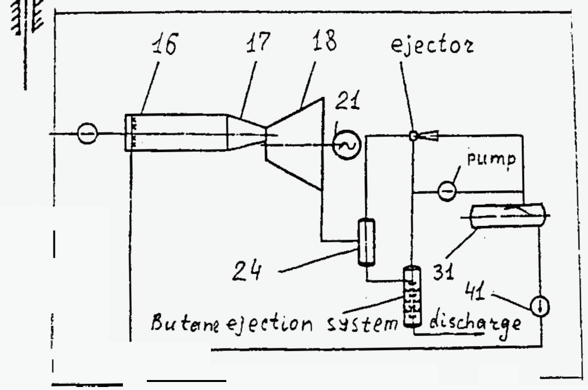
1.3. The next stage of experimental study for using the total flow concept for conversion of geothermal energy in electricity /2/ was completed in 1972-75 to Paratunka's geothermal field with HC temperature up to 100 C by using binary system and mixing natural HC with n-buthane. The power plant (capacity 50 kW) was installed for the study of turbine impeller specially designed and tested previously at Pauzhetka field with SWM (Fig.1a). The technical arrangement of experimental power plant, and the simplified principal thermal diagram are shown in Figure 3. The experimental plant tests allowed to find the operating parameters of the main and auxiliary equipment-separator, turbine, condenser, pumps etc.

The essence of this experiment consisted of geothermal water (with temperature 85-90 C) mixer with lightly-boiling liquid (n-buthane). The latter was heated in the cocurrent flow with geothermal fluid and was evaporated forming the two-phase flow with geothermal HC. The resulting two-phase gas-water mixture was accelerated in the Laval nozzle and increased its kinetic energy, which then operated in the Pelton-type turbine (PT). The main test elements for the study were the turbine. the two-phase nozzle and the mixture device. The efficiency of total flow system is mainly determined by their efficient work, that depends in turn on the correct arrangemen of heat-mass transfer and energy conversion processes.

Another version of total flow method is two-stage (cascade) arrangement, that allow more efficient. use of the HC potential. Here the residential HC flows into the tube-mixer of high pressure stream(n-buthane in liquid). The mixtureis accelerated due to the considerable change in specific volume of WM flashing and expansing in the Laval nozzle. The mixture kinetic energy is used in the hydro-steam turbine, then the mixture is separated from geothermal HC in the separator. Then WM is directed to condensor, while the geothermal HC at still high temperature is directed to the low pressure tube-mixer and is mixed with WM. The mixture is additionally accelerated in the second Laval nozzle and also enters the hydro-steam turbine. The advantage of two-stage arrangement over the single-stage scheme is the increase by using heat energy,

1.4. One of the important experimental results was the development and investigation of new technology for intensifying the productive well discharge. The expenses for drilling the wells constitute considerable part (50%) in the capital costs for construction of GeoPPs. Due to it, there is a necessity in intensification of well output by means of using the gaslift created by introduction of

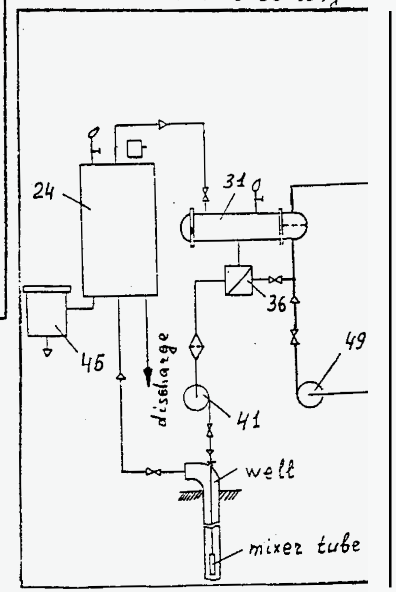




β) Thermal diagram of experimental power installation

a)

Technical arrangement of the experimental 50 kW installation
Measurements: flow-rate - 1,12,28,47,53,65; temperature - 2, 8,9,14,19,20,32,37,66,67,68; pressure - 15,26,33,44,57,59,61,63;
Equipment: gate valve- 5,7,20,11,13,23,29,39,40,43,45,52,56, 58,60,62; valve - 27,34,48,54,55,64,69,70; storage tank - 3: pump - 4.41.49: condenser - 34; regenerative heater - 6; pipe-mixer - 16; nozzle -17: turbine -18; reduction gear - 22: volume separator - 24: cooler - 35.42: condensate collector - 36 float regulation - 46: generator - 21: auxiliary elements (filters,valves etc.) - 38.25.30.51.71.



-c> scheme of intensification of water flow-rate from geothermal well with light-boiling liquid

Fig.3

low-biling WM at a certain depth in the well. This technology was tested and its arrangement presented in Fig.3c. In correspondence with it, n-buthane was injected in the liquid state at a different depth of well. The n-buthane was eveporated with the direct contact and increased rate of thermal water from well. The flow-rate increased 1.5-2.5 times depending on the depth of injection, the pressure at the well mouth and the well construction. In general, the experiment confirmed the possibility of using the schemes with low-boiling WM for realization of full-flow concept.

2. SINGLE AND TWO-STAGE FLASH SYSTEMS WITH USING TOTAL FLOW CONCEPT

The thermodynamic and thermal calculations of GeoPP scheme using the total flow concept and traditional approach were carried out. The following GeoPP schemes (Fig.4) were calculated: 1-single-stage flashing system: 11-two-stage flashing system: NI-single stage system with rotary separator turbine: 1Y-single-stage system with PT: Y-two-stage system with rotary separator turbine (RST), YI-two-stage system with PT instead of second flasher.

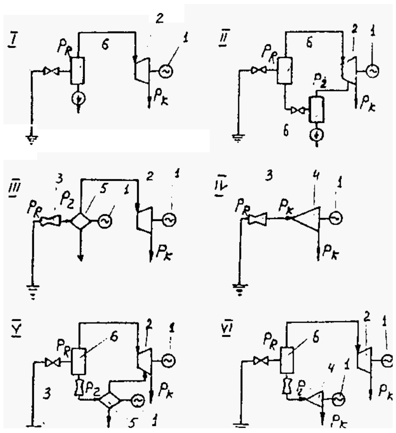


Fig.4. Calculated schemes of GeoPPs: 1-generator; 2-steam turbine: 3-nozzle; 4-PT turbine: 5-RST: 6-flasher

The calculations were performed with initial SWM enthalpy from 640 to 1200 kJ/kg in the range of initial temperatures T from 110 to 230 C. The calculated results are presented in Fig.5a,b,c with the following other data: the condensation pressure-0.01 MPa; the pressure in the second flasher and RST-0.11 MPa (in the scheme HI with 1210 kJ/kg this pressure was o.21 MPa). The phase velocity slip in nozzle was taken as 0.9, the nozzle efficiency-0.81; the hydraulic turbine efficiency-0.9: the PT efficiency-0.8: the steam turbine efficiency - 0.85(1+X)/2, where X is steam quality after turbine. The completed calculations showed, that the configurations Y1 and IY were most efficient with the low initial SWM enthalpies (600 kJ/kg); though the scheme IY gave the less specific output, it may be more preferable, since it is much simpler. With 800 kJ/kg the schema: YI, Y, IY had the largest specific output. The scheme IY could be more preferable because of its simplicity in spite of the less specific output. With SWM enthalpy 1210 kJ/kg the largest specific output was received by using the configurations Y and YI. Thus, for all calculated SWM enyhalpies, the GeoPP schemes realizing the total flow concept had an advantage in comparison with the traditional GePPs with the single and two flashing system!:.

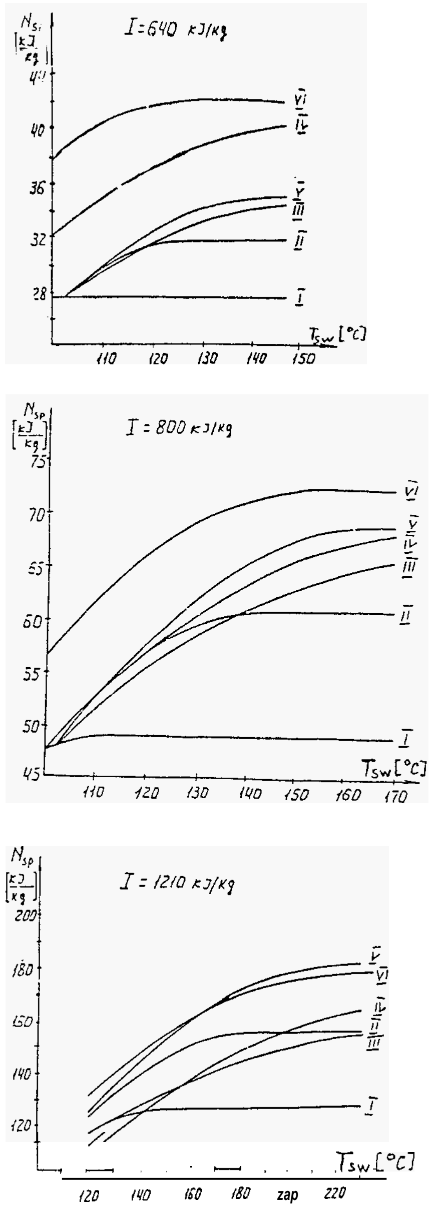


Fig.5. Dependence of specific output on the initial SWM temperature for different enthalpies

3. SINGLE AND TWO STAGE DIRECT CONTACT BINARY SYSTEMS WITH USING TOTAL FLOW CONCEPT

The basis for thermodynamic analysis of such schemes can be formed by means of the technology described above.The results of this concept was realized in 1975 with PT on water-buthane mixture. in 1981 this technology was demonstrated in East Mesai direct contact binary system using a contact counterflow isobuthane heatexchanger and in 1982 at the VS-power plant with RST tested in Milford /6/. There are two ways to maximize the full use of energy and to increase of specific output: 1) the use of schemes that use two-stage boiling with high and low pressures; 2) the use of total flow concept, i.e.the use of RST or PT.

Low-potential thermal energy conversion in electric energy were considered (Fig.6): a) scheme DC-1 for conversion with the contact counterflow preheater and boiler under one pressure; b) the scheme DC-2 - for conversion with the contact counterflow preheaters and the boilers with two different (high and low) pressures: c) the scheme DCTP-1 - for conversion with contact counterflow preheater, steam turbine and RST under one evaporating pressure d)two-stage scheme DCTF-2 for conversion with steam turbine, 2 RST with two pressures.

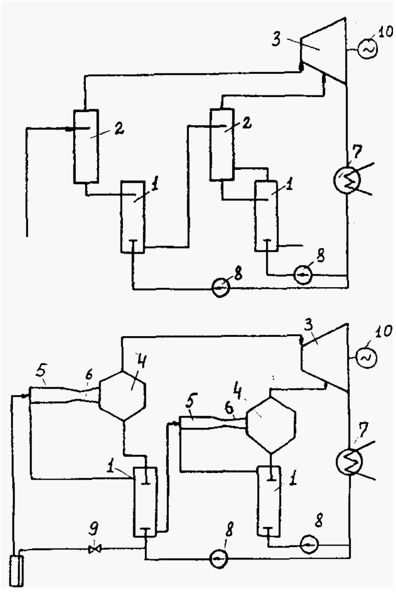


Fig.6. Direct contact binary system (a) and direct contact bynary system with rotary separator turbine DCTT-2 (b): 1-preheater: 2- boiler ; 3-turbine: 4-RST: 5-tube-mixer: 6-nozzle; 7-condensor: 8-pump: 9-valve: 10-generator

For determination of the optimum thermodynamic parameters, an analysis of 60 cycles in the range of HC temperatures 80-100°C was carried out. It included the determination of parameters of different states in the cycle points, that used two secondary WM-buthane and isobuthane. The temperatures, pressures, flow-rates, enthalpies, enthropies specific volumes in these points were calculated for the condensation temperature -20°C. During optimization. the quality of low-boiling WM was changed, and the specific output was calculated.The results are given in Table and Fig.7 for the conditions, when n-buthane was injected in tube-mixer of 1 cascade.

Scheme	DC-1	DCTT-1	DC-2	DCTT-2
Maximum specific output,kJ/kg	13.43	14.13	15.91	20.64
%	100	105	118	152

As seen from the Table, if the maximum specific output 13.4 kJ/kg and these parameters of HC in scheme DC-1 is 100%. the RST introduction in scheme DCTT-1 will increase this quantity by 5.5%. The use of cascade scheme DC-2 gives the specific output increase by 18%. The largest output is achieved in cascade scheme DCTT-1 with RST and constitutes 20.64 kJ/kg, i.e. by 50% more, than in scheme without RST. The corresponding results are presented in Figs. 7 and 8.

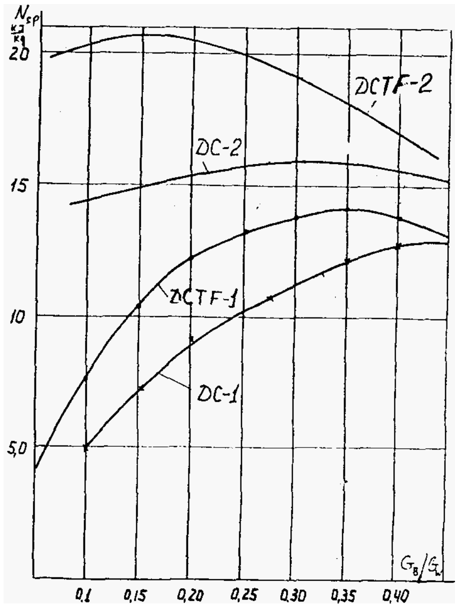


Fig.7. Dependence of maximum specific output on the n-buthane quantity, G_8 T_{HC} - 90°C

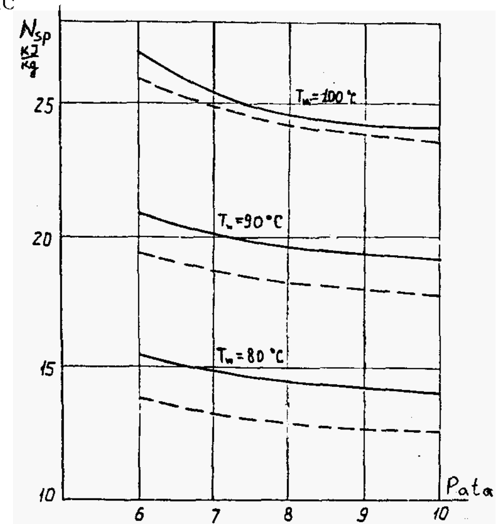


Fig.8. The dependance of maximum specific output on the pressure in RST casing, WM: 1 - n-buthane, 2 - isobutnane

CONCLUSION

Two variants of module GeoPP-500 kW, in which the concept of full flow in the scheme of expansion for the condition of Mutnovskoye geothermal field, had the construction development on the basis of performed theoretical investigations. WM was the hot liquid after GeoPP separator with 0.7 MPa and the saturation temperature 437 K. Both plant variants: 1 - with byphase axial turbine and 2 - with RST and steam turbine, and also their technical data are presented in Figs.9 and 10.

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REFERENCES

1.Trusov V.,Gaidarov C.,Zabarny G. Method and technology of geothermal power engineering 139 p., 1991, Petropavlovsk-Kamchtsky.
2. Aladiev I.,Averbach J.,Voronovicky V, Dryndrozhik E.,Vevit I.,Tetelbaum S., Strygin E.,Trusov V. The method of power plant operation-Patent USSR,no.708740,1975.
3. Aladiev I.,Baron A.,Voronovicky V.,Strygin,Tetelbaum S.,TrusovV.The powwer plant' operation. Patent USSR,no.690855,1977.
4.Kabakov V.,Aladiev I.,Dryndrozhik E. Geothermal heat- and water supply plant. Patent USA no.4.979.374, Dec.25,1990.
5.Voronovitsky V.,Gorokhov M. The use of low-boiling WM for intensification of water taker from geothermal well.In:Study and use of heat of Earth in volcanic areas,Nauka,M.1979
6.Cerini D.,Hays L. Power produuction from geothermal brine with rotary separator turbine. Proc.of 4th Geothermal Conference and Workshop, EPRI, 1980.

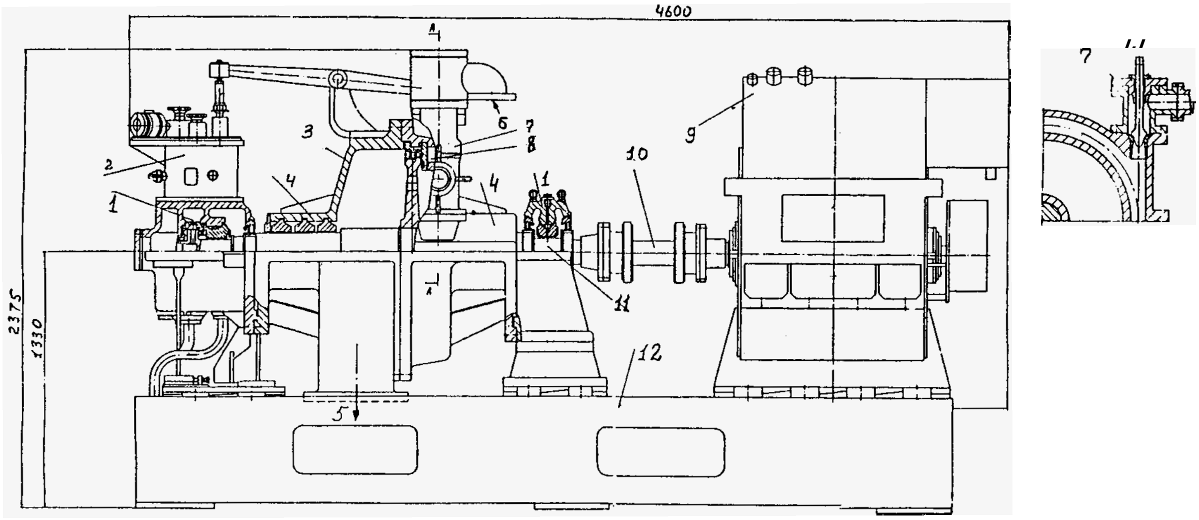

Fig.9. Biphase axial turbine
1-bearing, 2-regulating unit, 3-turbine case. 4-seal, 5-exhaust. 6-two-phase flow input, 7-valve, 8-nozzle box, 9-generator, 10-coupling, 11-rotor, 12-frame

Main technical characteristics

Initial pressure-0.7 MPa; initial temperature-437 K; Exhaust pressure-0.01 MPa; flow rate-12.2 kg/s; available heat drop-83 kJ/kg; speed-1500 r.p.m.; diameter of turbine-1000mm; velocity-78.5 m/s; velocity ratio-0.193; inner relative efficiency of turbine-0.55; inner power of turbine-435.4 kW; electric power output 400 kW

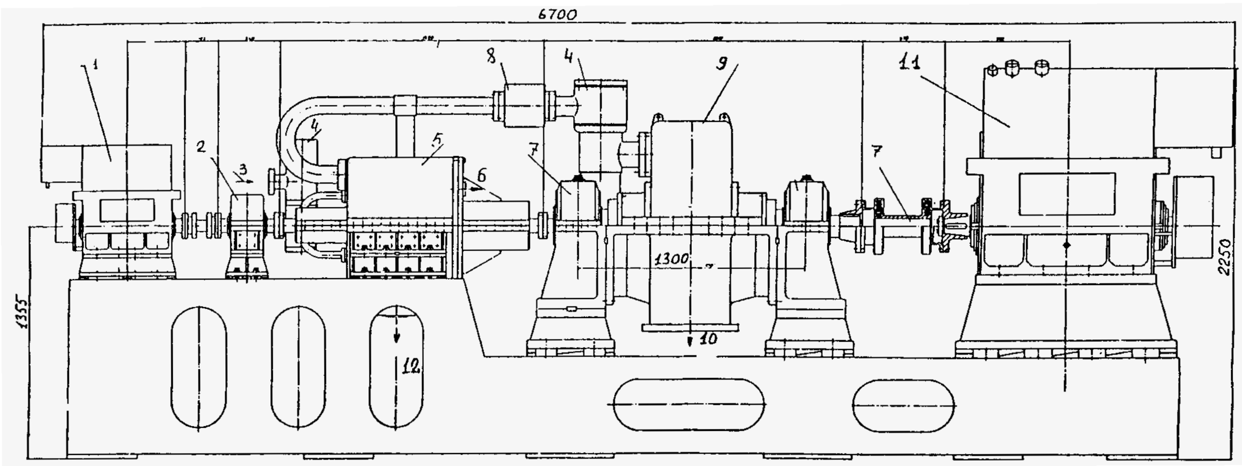

Fig.10. Steam turbine with RST
1-generator RST, 2-reduction gear, 3-two-phase flow input, 4-valve. 5-rotary separator RST, 6-water inlet. 7-bearing, 8-compensator. 9-steam turbine, 10-steam to condenser. 11-main generator, 12- drainage

Main technical characteristics

Item	nossle	separator N1	hidrawlic turbine	separator N2	diffuser	steam turbin
Initial Pressure MPa	0.7	0.1	0.1	0.1	0.1	0.1
Initial temperature °K	437	372	372	372	372	372
Flow rate kg/s	12.2	10.486	10.486	10.486	10.486	10.486
Speed r.p.m.	0	3000	1500	600	0	1500
Steam quality, (X) %	11.1					99.95
Velocity m/s	211	159	79.5	31.4	6.0	79.5
Outlet pressure MPa	0.1	0.1	0.1	0.1	0.1	0.01
Outlet power kW			131.6			411.7
Total power output kW			543.3			