INCREASE OF GEOTHERMAL POWER PLANT EFFICIENCY BY UTILIZING LOW ENVIRONMENTAL TEMPERATURES

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KEY WORDS

Geothermal, power plant, environment.

ABSTRACT

Possibilities of increasing the efficiency of geothermal and nuclear power plants by utilizing low environmental temperatures are described in this paper.
It is shown that replacement of the traditional working fluid in heat-power cycle – water – with ammonia-water mixture (Kalina cycle) or with another agent, non-frozen at condensation temperatures of down to - 30…- 40 °C, allows significant increasing in the capacity of geothermal power plants within most part of the year.
The paper gives the idea of additional difficulties, connected with implementation of low temperature heat-power cycles (varying mode, application of air condensers) and underlines that they are insignificant if compared to positive technological and economic benefits.

1. INTRODUCTION

In winter low environmental temperatures are typical both to a number of northern countries and to the most territory of Russia.
In general this circumstance negatively affects the economy, in particular the economy of those countries.
At the same time views on the nature, magnitude and consequences of affects caused by low temperatures differ significantly, ranging from extremely pessimistic to mildly optimistic.
Supporters of the first view - pessimists – pay major attention to difficulties in power engineering, agriculture, transportation, construction as well as in everyday life, which are conditioned by low environmental temperatures in winter time. Referring to this fact, several authors even give rise to far going pessimistic views regarding the future of our country and its place in the world economy [4].
As for optimists, not sharing such skeptical views on «the future of Russia», they, not denying difficulties caused by climate conditions on the most territory of our country, believe that these difficulties can be overcome to a great extent by implementing appropriate economic policy together with use of modern scientific achievements. This could be considered acceptable in general, but realization of such plans requires detailed analysis.
In this respect it is useful to consider some variants of low environmental temperatures utilization in the national economy, looking at it from the energy position and abstracting oneself from global political and economic projections, which rarely come true.
To do this it is necessary, at least briefly, to examine, if one can say so, positive features of subzero temperatures [2].
These features are used, for example, in the technology of storage, transportation and refrigerated processing of food and bioproducts, as well as where products of low temperature air separation are used.
Still there exists another significant reserve of energy efficiency increase, which is based on low environmental temperature utilization in winter time in thermal power engineering – the key field of the national economy.

2. THERMAL POWER ENGINEERING AND THE COLD

The idea of a new, «cold», trend in development of thermal power engineering is related to direct use of scientific base and experience, cumulated both in the field of energy and in respect to the refrigerated technique.

Until recently the main barrier to use low temperature technique in thermal power engineering was the traditional utilization of water as the only possible working fluid at power plants. Advantages of water are well known both in thermodynamic and economic aspects.

There were some attempts to deploy other working fluids in thermal power engineering (here steam power plants are considered, not internal-combustion engines or gas-turbine units), for example, until recently some working fluids, which are utilized in the refrigerated technique, have been treated by most specialists as exotics, although were discussed in literature from time to time [3, 6].

Increase of thermal efficiency ratio of steam-power cycle can be achieved, as is known from the thermodynamics, by two ways only, in case all other conditions are equal. The first way – increase of temperature level for heat supply both in the steam cycle and by means of "superstructures" - from magnetogasdynamic generators to steam turbines. Gas-turbine variant turned out to be most acceptable and allowed increasing the thermal efficiency ratio of power plants up to 60 %.

However it is becoming more difficult and expensive to go «higher», since in compliance with the laws of the thermodynamics each degree of temperature increase leads to lower and lower energy effect. This is visually demonstrated on the chart in coordinates $\tau_e = (T - T_{oc})/T$ (exergy temperature) - T [2] (pic.1).

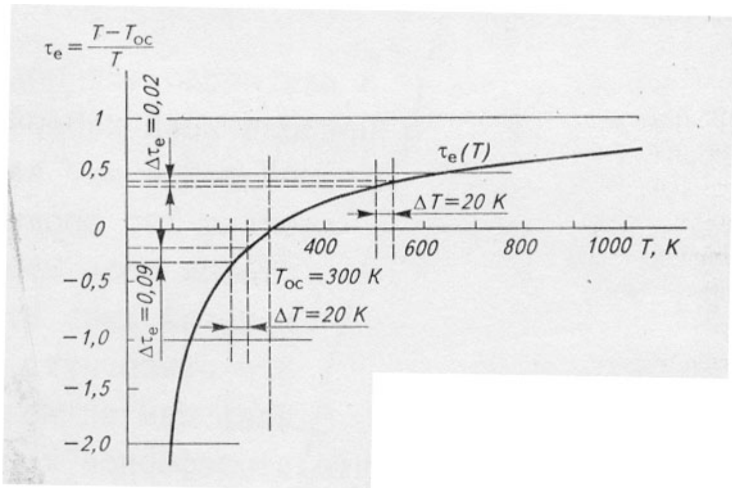

Fig. 1. Dependence of Karno factor τ_e on temperature

Equal change of temperature ΔT resulted in much greater change of Karno factor τ_e (and therefore, of thermal efficiency ratio of the cycle) at low temperatures.

Thus, increase of temperature by 20 K at even not so high temperatures (for example, between 500 and 520 K) leads to change of Karno factor τ_e from 0.4 to 0.42 (i.e. by 0.02). The same change (drop) of temperature at low temperatures (for example, between 260 and 240 K) changes τ_e from -0.13 to -0.22 (i.e. by 0.9 in absolute meaning, which is several times higher).

In this situation extension of heat-power cycle "downward" is considered to be most appropriate. Here in compliance with the laws of the thermodynamics «each degree is more and more expensive» and the thermal efficiency ratio is increasing much quicker at its extension «downward», than at its extension «upward».

For our country, where the environmental temperature in most regions is kept on the level much lower than 0 ^{o}C, such extension of the cycle's limits can provide most significant effect.
The same considerations, only «with the reversed mark», are related to the refrigerated technique: decrease of temperature of heat supply in the refrigeration cycle can provide significant energy savings.
However there arise many questions, the answers to which will influence the choice – whether to develop low temperature trend or not, and if the answer is positive, then in which way? Which role the refrigerated technique, which is "used to" low temperatures, can play here?
To answer these questions with enough certainty, they need to be discusses in various aspects both from the thermodynamic and practical (engineering) points of view.

3. THERMODYNAMIC ASPECT OF THE PROBLEM

From elementary thermodynamic correlations, relevant to the second law of the thermodynamics, it is followed that decrease of temperature of the heat receiver (in our case – environmental temperature T_{oc}) at the predetermined temperature of the heat-releaser (in our case – hating medium) leads (in the direct cycle and with all other equal conditions) to increase of the amount of work received by ΔW_{hot}. (In the reversed cycle the same decrease of environmental temperature (with all other equal conditions) leads to reduction of work required by ΔW_{cold}). At the same time the thermal energy efficiency of heat-power cycle will increase in the same way as the refrigeration efficiency factor of the reversed cycle.
Table 1 shows the received work W for an ideal case - direct Karno cycle (the amount of delivered heat Q = 1.0 Дж).
For real thermal power plants W will naturally be significantly lower. However relative meanings of W remained nearly the same, with only insignificant deviations.

Table 1.Work of heat-power (direct) Karno cycle at various temperatures of heat source $T_г$ and heat receiver T_{oc}

$T_г$, K	Received work W (Дж) of the cycle at the environmental temperature T_{oc}, K						
	300	290	280	270	260	250	240
1500	0,80	0,81	0,81	0,82	0,83	0,83	0,84
1200	0,75	0,76	0,77	0,78	0,78	0,79	0,80
1000	0,70	0,71	0,72	0,73	0,74	0,75	0,76
800	0,62	0,64	0,65	0,66	0,68	0,69	0,70
600	0,50	0,52	0,53	0,55	0,57	0,58	0,60

Table I shows that in all cases – both for high temperatures of heat delivery $T_г$, (1000... 1500 K), and relatively low (400...600 K) – the received work increases significantly when T_{oc} decreases. It is important that the largest increase is observed in cycles with lower level of $T_г$. Thus, if for the cycle with $T_г$ = 1500 K the increase of the received work at T_{oc} = 240 K in comparison to T_{oc}=300 K is ~5%, and at T_{oc} = 250 K - ~ 4 %, then in the cycle with $T_г$ = 1000 K increase of work with the same change of T_{oc} is much higher: ~8 и 7 %.
The largest increase of the thermal efficiency factor (~ 16 %) can be observed at relatively low temperature $T_г$ = 600 K. These figures make us think of some practical opportunities to apply such cycles in the thermodynamics.
Practical utilization of low environmental temperatures requires solution of a number of serious engineering issues. If to put aside the conservatism, which is inevitable in such situation, then we are left with real difficulties, connected with two main questions: selection of a working fluid of a new heat-power cycle and equipment operation in varying mode, which is determined by changes in environmental temperature. The experience of refrigerated technique application

proved to be useful while answering first two questions.

4. SELECTION OF THE WORKING FLUID OF A NEW HEAT-POWER CYCLE

Among numerous working fluids, suggested for water replacement in heat-power cycles, the first place was gradually occupied by cooling agents, utilized in low temperature cycles and being well known: firstky - R12, and then - ammonia.
By now a great experience has been gained regarding utilization of non-water working fluids in the thermal power engineering; the priority here belongs to our country.
As early as 1955 Rozenfeld L.M. offered to use binary water-ammonia cycle in heat-power installations [6], and in 1967 the first pilot thermal power plant was put into operation in Kamchatka, which operates on R12. However the main trend in «non-water» thermal power engineering became water-ammonia trend, which is based on Kalina cycle («cycles» to be more correct)*, developed by him with active support from the well-known American scientist and specialist in the field of the thermodynamics –M. Traibus.
The choice of the mixture NH_3 + H_2O, which was based on the experience and traditions of refrigerated technique, turned out to be very effective. Both ammonia and water-ammonia mixture are well investigated. Ammonia occupies the second place after water in respect to heat conversion; ammonia is widely used not only in refrigerated technique, but also in chemical technology. Rumors, which circulate among power engineering specialists regarding danger connected with ammonia utilization, are (to say mildly) exaggerated. There is no problem here, since in heat-power systems ammonia is used in mixture with water. Ammonia is cheap and available, does not cause corrosion of iron and its alloy, and is dissolved in water in any concentration. And the last, but not the least important fact is that in water-ammonia heat-power cycle (even at low temperatures, which can be faced on practice) pressure of two-phase mixture exceeds atmosphere pressure. The value of this fact is hard to overestimate both from constructional and operational points of view.
3 MW experimental power plant, constructed by Kalina and operating on water-ammonia working fluid, demonstrates high efficiency of this cycle both in thermodynamic and exploitation respects [7, 9].
The only negative result - impossibility to raise the cycle upper range temperature higher than such limits as 550-600 ^{o}C due to inevitable dissociation of ammonia into hydrogen and nitrogen. All hopes, that ammonia in mixture with water will not start dissociating at such temperature, did not come true.
As for temperatures being lower than the dissociation point, then water-ammonia Kalina cycle successfully operates at four installations – in USA, Japan and Iceland. It is planed to build other power plants with capacities more than 100 MW.
Various variants of Kalina cycle, both already implemented and still being designed, have similar parameters: as usual they work at condensation temperatures which are significantly higher 0 ^{o}C.
In the upper range of the cycle, points of temperature increase, as was earlier defined, are determined by the beginning of ammonia dissociation process, therefore such cycles can be mainly used as «Bottom Cycles» at nuclear and geothermal power plants.
At the same time it is important that they, as was mentioned earlier, can be successfully applied also at much lower environmental temperatures, right down to those typical to strong Siberian frosts. Besides in winter time the thermal efficiency ratio increases significantly, there remains some extra pressure in the condenser; therefore all difficulties related to vacuum and big steam specific volumes will be no longer vital [8].

* A.I. Kalina graduated from Odessa Institute of refrigerated industry. In 70s he immigrated to USA, where he established the firm “Exergy Inc.”. This firm successfully works on creation of water-ammonia cycles of power plants [7, 9].

Of course, transition to a new working fluid – water-ammonia mixture - connected with the possibility of constructing thermal power plants, effectively operating and providing extra electricity in winter time, requires serious design and experimental activities. Inevitably some specific difficulties of practical engineering nature will appear, to overcome them one will need to make additional efforts.

5. DIFFICULTIES RELATED TO PRACTICAL UTILIZATION OF LOW ENVIRONMENTAL TEMPERATURES

The first difficulty is the varying mode of power plant operation due to inevitable changes of environmental temperature – both seasonal, and comparatively short-term, determined by meteorological factors. Consequently we face a number of tasks, relevant to operation of turbine and heat-exchange equipment in the varying mode and creation of appropriate control systems.

As for seasonal changes of environmental temperature, the process of regulation is becoming easier since such changes occur within quite a long period of time, but the change of temperature is not usually big in case of short-term weather changes.

The second difficulty is the transition to air condensers. Here the task is becoming easier since there is a great experience of successful creation and application of air condensers both in the refrigerated technique, and in the thermal power engineering (for example, at the Mutnovsky thermal power plant in Kamchatka) [5].

Of course, to overcome difficulties one shall make certain efforts and require professional expertise. However in general such difficulties lie within possibilities of modern technique. The experience of creation and exploitation of technical systems with similar parameters, which has been gained in the field of power engineering and refrigerated technique, will undoubtedly help to solve such difficulties.

Positive moments of environmental temperature utilization, which are presented by the nature for power engineering development, are quite obvious. Further discussion can be devoted only to technical issues, scope of works and economic evaluation of those advantages, which such discussion can provide in each separate case.

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