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Investigation of a binary power plant using different single-component working fluids☆

G.V. Tomarov*, A.A. Shipkov, E.V. Sorokina

LLS "Geotherm-EM", 24 Lefortovsky val, Moscow, 111250, Russia

ARTICLE INFO

Article history:
Received 2 February 2015
Accepted 8 February 2015
Available online xxx
Dates refer to the original article's editorial history.

Keywords:
Geothermal fluid
Geothermal power plant
Binary cycle power plant
Organic working fluid
Combined power plant
Hydrogen–oxygen steam generator

ABSTRACT

The tendencies of the development of geothermal energy technologies on the base of utilizing geothermal fluid of different temperature are studied. It is shown that in recent years there are an increasing number of countries where the growth of installed capacity of geothermal power plants is mainly due to the construction of power units with a binary cycle. It allows to expand the resource base of geothermal energy through the development of low-temperature geothermal sources, the total capacity of which exceeds the one of high-temperature resources. It is noted that the low-temperature geothermal sources are widely available and in fact can be utilized almost anywhere in the world. The analysis of the scale and geography of the application binary energy technologies for the development of geothermal resources are shown. The features of the use of organic working fluids in binary power plants are described. The basic principles of the optimal working fluid selection for binary plant are explained. The results of numerical modeling of the working fluid selection on the performance of binary power plants are presented. It is shown, that use of the hydrogen-oxygen steam generator in combined power plants can increase the effectiveness of geothermal utilization.

Introduction

The modern geothermal energetics is characterized by increasing interest to the binary power technologies, which allow dilating its resource base essentially at the expense of involving low-temperature sources in electrogeneration. In a binary power station the process of heat transfer from geothermal fluid to other low-boiling fluid which is an organic working fluid of the second closed loop is provided.

The geothermics advancement rested initially on the development of geothermal high-temperature resources, mainly in the form of over-heated steam. Later on, geothermal moist steam or water-steam mixture became the basic primary source for Geothermal Power Plant (GPP). Nowadays the development of geothermal power in many countries is carried out at the cost of the low-temperature fluid's heat utilization, as well as waste geothermal brine of operating GPPs in terms of the binary power plants' usage.

Use of low-boiling organic working fluids in the second circuit of binary power station allows utilizing fluid's heat at temperatures from 80 °C to 250 °C. The GPPs, built in Russia (overall 12 power units with total capacity of more than 80 MW) use geothermal fluid in the form of water-steam

☆ This paper is the English version of the paper reviewed and published in Russian in International Scientific Journal for Alternative Energy and Ecology "ISJAEE", issue 185, number 21, date 10.11.2014.

* *Corresponding author*.
E-mail address: geotherm@gmail.com (G.V. Tomarov).

http://dx.doi.org/10.1016/j.ijhydene.2016.09.165

Nomenclature

G	flow rate, kg/s, m^3/h
GPP	geothermal power plant
N	capacity, power, MW
P	pressure, MPa
TLV	threshold limit value
U.S.	United States
WGC	world geothermal congress

Greek letters

Δ	difference of values
$\sum$	sum, total
η	efficiency, %

Superscripts and subscripts

au	auxiliaries
el	electrical
ev	at the evaporator exit
exp	expansion
geo	geothermal fluid
n	net
out	out, in condenser
wf	working fluid
H_2	hydrogen
O_2	oxygen
RC-318	octafluorocyclobutane
R-134a	tetrafluoroethane
R-152a	1,1-difluoroethane

mixture by pumping liquid phase (geothermal brine) back into the seam. Appliance of binary power stations, capable of utilizing this waste fluid's heat, should provide increase in capacity of domestic GPPs by 20–25% without circle flood.

Features of use of low-boiling organic working fluids in binary power stations

The first geothermal power plant in the world with a binary cycle was built at Russian Kamchatka in 1967 (Paratunskaya GPP) [1]. Freon was used as organic working fluid in the second circuit. It was heated up by geothermal water at temperature close to 90 °C and was used in the form of steam in a turbogenerator for electric power development.

The total installed capacity of geothermal stations with binary cycle in 25 countries is 1790 MW, including 873 MW in U.S., 265 MW in New Zealand and 219 MW in Philippines, according to WGC-2015 [2]. The pilot geothermal power plant with binary cycle having a capacity of 2.5 MW was developed and built in Russia at Paratunskaya GPP for heat utilizing of the waste geothermal fluid of the operating GPP [3,4].

Today binary power plants with geothermal fluid of different temperature levels are maintained. Fig. 1 shows information on the number of binary power plants, utilizing geothermal fluid of different potential. The overwhelming majority of operating binary power plants utilizes geothermal fluid heat at temperature range within 100 °C–200 °C.

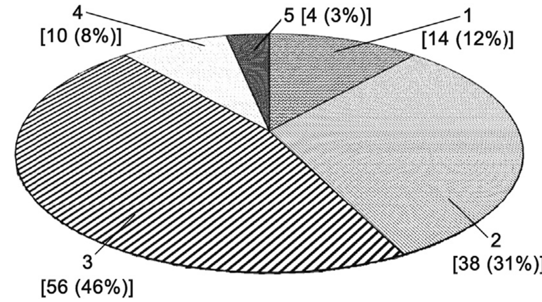

Fig. 1 – Information on the number of binary power plants, utilizing geothermal fluid of different potential: 1 – less than 100 °C; 2 – 100–150 °C; 3 – 150–200 °C; 4 – 200–250 °C; 5 – more than 250 °C.

Selection of organic working fluid is one of the most complex and responsible problem during the development and construction of binary power plants. The physicochemical properties of organic working fluid alongside with geothermal fluid's features (which depend on GPP location) make essential impact on the optimum thermal schema, design and technical characteristics of the binary power station's equipment.

While selecting low-boiling organic working fluid, it is necessary to assure that it is stable, nonflammable, nonexplosive, non-toxic, inert to applied constructional materials and soft for the environment. The effective selection of the organic working fluid is hindered by the fact that one requirement often contradicts another. Almost all of the binary power plants actually utilize hydrocarbons today (Fig. 2) [5].

Having different good thermodynamic and thermal features, rather cheap hydrocarbons (pentane, isobutane, isopentane, etc.) are fire and explosion dangerous and can be used in outdoor powerhouse only that is unacceptable for Russia and for regions with negative winter temperatures.

Comparative characteristics of binary power plants, utilizing different organic working fluids

In justifying the selection of low-boiled organic working fluid of binary power plants designed for operation in Kamchatka and in other regions of Russia with negative winter temperatures, the complex of settlement researches covering the

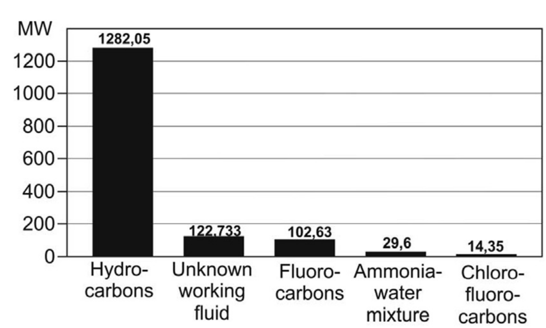

Fig. 2 – Information about the total installed capacity of binary power plants and their working fluids.

Please cite this article in press as: Tomarov GV, et al., Investigation of a binary power plant using different single-component working fluids, International Journal of Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.09.165