Renewable and Sustainable Energy Reviews 93 (2018) 499–506

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Classification of geothermal resources in Indonesia by applying exergy concept

Saeid Mohammadzadeh Bina[a,*], Saeid Jalilinasrabady[b], Hikari Fujii[c], Nugroho Agung Pambudi[d]

[a] Graduate School of Engineering and Resource Science, Akita University, Akita, Japan
[b] Energy Resources Engineering Laboratory, Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[c] Graduate School of International Resource Sciences, Akita University, Akita, Japan
[d] Mechanical Engineering Education, Universitas Negeri Sebelas Maret, Jl. Ir. Sutami 36A, Surakarta 57126, Indonesia

ARTICLE INFO

Keywords:
Indonesia
Classification
Geothermal
Exergy

ABSTRACT

Indonesia is well-known for its reputation for possessing the world's largest geothermal potential, which has been characterized by high temperature geothermal resources' concentration. The geothermal energy potential of Indonesia has been estimated to be 28,617 MW, which is about 40% of the world's geothermal potential. However, only about 4.5% is being utilized as electrical energy supply in this country. This paper comprises the Indonesian geothermal resources, based on their capability of doing work and efficiency. In this study, currently operating geothermal power plants in Indonesia have been classified, based on the exergy concept and the Specific Exergy Index (SExI). The results of SExI values show that nine geothermal fields are classified as high exergy resource with their SExI values exceeding 0.5, and two remaining power plants with SExI values between 0.05 and 0.5 are classified as medium geothermal resources.

1. Introduction

Energy plays a vital role in countries' economies. The global, specially developing countries energy supply is mainly dependent on fossil fuels while their reservoirs are limited and their use creates environmental problems [1]. On the other hand, the energy consumption along with population of the world is increasing rapidly [2]. According to the World Energy Outlook (WEO) 2007, it is expected that the fossil fuels will remain as major energy source till 2030, which will cover 84% of world's energy demand [3]. Therefore, if this rate of energy consumption is continued, the existing energy resources are estimated to meet the energy demand to 2030 [4]. Thus, it is essential to assess renewable energy as an alternative resource which will minimize the environmental impacts as well as dependency on fossil fuels.

Among all the renewable resources, geothermal is the most reliable and stable energy that is constantly available regardless of weather and climate changes [5]. The total worldwide installed capacity and the produced energy from geothermal power plants up to the end of 2015 were 12,635 MWe and 73,549 GW h respectively. It was estimated that the potential shall reach 21,443 MWe in 2020 [6]. Fig. 1. presents the share of the total installed capacity for different continents up to the end of 2015. As it can be seen in Fig. 1, Asia, with 3756 MW (30%) installed geothermal power plant, has been ranked in second place after America, with 5089 MW (40%) of total geothermal power production worldwide.

Over the last several years, Indonesia was in the top five countries for installed capacity of geothermal plants, and in 2015 moved up by two steps, compared to 2010, among the Asian countries. In 2015, Indonesia could pass New Zealand, Turkey and Kenya and place themselves in third position, following USA and Philippines [7]. Utilization of geothermal to produce electricity in Indonesia started from mid-80s and early 90s, when the demand of electricity was rapidly increasing. The first geothermal power plant was successfully developed at Kamojang geothermal power plant and it has been fully operational since 1983.

Nevertheless, the exergetic classification of the geothermal resources have not been studied in Indonesia. This study aims at analyzing and focusing on each geothermal field across the country and classify them based on their specific exergy index values. This unique non-dimensional parameter, which is defined as $SExI = e/e_{max}$ can be used to compare various geothermal fields with different specifications. This approach evaluates the geothermal fields more consistently. It is also more technically meaningful than temperature and enthalpy basis classification methods. The results of this study can be helpful in comparing the Indonesian geothermal and their priority based on their work ability by comparing other geothermal resources in the country as

* Corresponding author.
E-mail address: s.mohammadzadeh66@gmail.com (S. Mohammadzadeh Bina).

https://doi.org/10.1016/j.rser.2018.05.018
Received 21 April 2017; Received in revised form 17 April 2018; Accepted 13 May 2018
1364-0321/

Nomenclature

h	enthalpy, kJ/kg
m	mass flow rate, kg/s
T	temperature, K
s	entropy, kJ/kg K
x	steam quality
e	exergy, kJ/kg
Ex	exergy rate, kW

Subscript

i	initial state
0	environment state

Measurement units

MW	megawatts
MWe	megawatt electric
GWe	gigawatt electric
GW h	gigawatt hour
t/h	tonnes per hour
bar (a)	absolute pressures
barg	gauge pressure

Abbreviations

SExI	specific exergy index

well as worldwide. Also, the achievements of this research can assist the energy decision-makers and geothermal energy developers for their future plans. Moreover, high-potential resources can be selected independent of ambient conditions by calculating the exergy index.

Hence, the main privilege of this paper involves classifying the geothermal resources, based on their location at each island, which is presented in Section 4.1. After calculating the exergy classification parameter for each field, the share of each island for different exergy classes (low, medium and high exergy) has been listed in Table 4. This method provides information and an overall view to researchers about the concentration of geothermal resources across the country.

In addition, the geothermal resources have been shown in a new combined pressure-enthalpy (*p-h*) diagram. This diagram has been combined with a map of the country, and shows the amount of power generation, thermodynamic specifications and geofluids' phase as well as the location of each field along country at the same time.

2. Classification of geothermal resources

Geothermal resources have been classified based on different geological or thermodynamic properties of their geofluid, such as temperature or enthalpy. The main disadvantage of these classifications appears since two geofluids at the same temperature and placed in same classification have completely different ability to do work.

Geothermal energy utilization based on different parameters such as thermodynamic specification of resources, geographical situation, or local demand for heat or electricity can be divided into the following two main categorizes: electric production and direct applications.

Basically, utilization of geothermal resources depends on thermodynamic and chemistry specification of their geofluid. Geothermal fluids have been classified based on various parameters such as temperature or enthalpy of reservoirs. Classification of these resources with respect to temperature, which known as Lindal diagram (Fig. 2), is an important key to feasibility of exploration [8]. The Lindal diagram shows the required temperature boundaries for different types of utilizations. As can be seen in the Fig. 2, geofluid temperature more than 150 °C is appropriate for conventional electric power production. The lower temperature boundary (100–150 °C) can also be used for electricity generation by using binary systems [9]. For district heating applications, geofluid with temperature of higher than 80 °C can be used. Geofluid with a few degrees above ambient temperature can be used as an axillary resource in a combination of boilers or other renewable energies to reduce the fuel consumption [10].

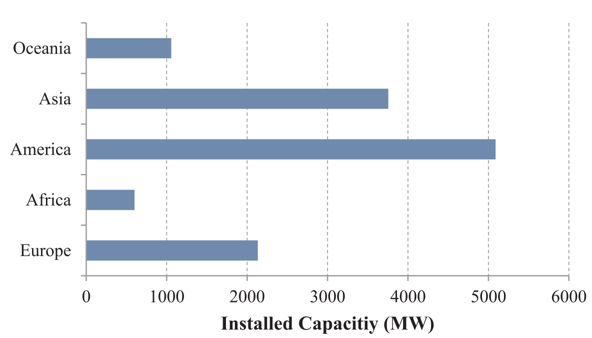

Fig. 1. Total installed capacity up to the end of 2015 for continents.

As it was already explained, the nature of available resources and their specifications are important. Once geothermal resource exploration has begun, classification of this resource with respect to temperature is a key element in future development scenarios. Therefore, over the last several years, many efforts have been made to classify geothermal resources based on their temperature. Fig. 3 briefly shows temperature classification as presented by several authors. Resources are divided into low, medium and high enthalpy. It can be seen that neither is there consensus among scholars with regard to temperature boundaries, nor is there agreement between temperature ranges for classifying resources. The main reason for popularity of this classification method is the easier estimation of resources temperature, judging from the available data in the early stages of development.

In addition, the main disadvantage of this method appears when saturated water and saturated steam are placed in the same group due to fluids' isotherm process during phase change.

Exergy classification has been used by a few researchers as a powerful tool to classify the geothermal resources worldwide. Jalilinasrabady and Itoi [17] applied the exergetic classification to 18 under operation power plants in Japan until the end of 2012. Their

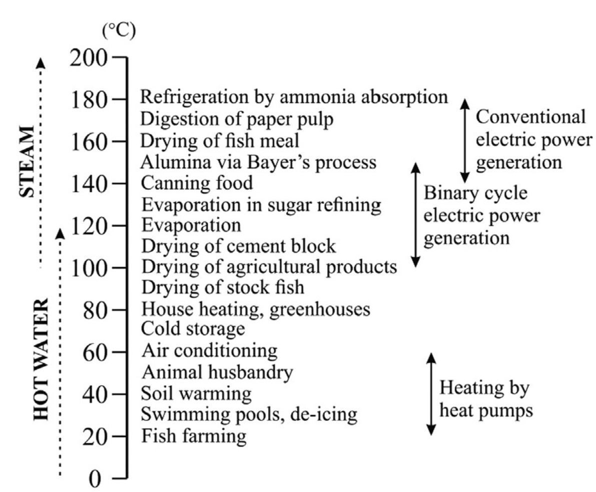

Fig. 2. Lindal diagram indicating possible uses of geothermal fluids at different temperatures. Diagram emphasizes cascade and combined uses of application of geothermal sources.