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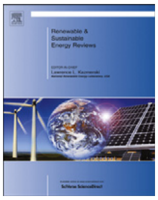

Sustainable removal of non-condensable gases from geothermal waters

Anna Khaghani*, Abhijit Date, Aliakbar Akbarzadeh

Energy Conservation and Renewable Energy Group, School of Aerospace, Mechanical and Manufacturing Engineering, PO Box 71, Bundoora East Campus, RMIT University, Bundoora, Victoria 3083, Australia

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ABSTRACT

Geothermal energy is becoming an attractive option for supplying the world with clean and sustainable energy. One of the highlighted issues in utilising the energy from geothermal systems is removal of non-condensable gases (NCGs) from geothermal waters. This paper discusses and reviews existing technologies for removing NCG with emphasis on their energy requirements further the possibility is investigated of using two-phase ejectors (also known as eductors) to remove NCGs from geothermal waters. Energy analysis of isothermal and adiabatic vacuum processes for removing non-condensable gases by an ideal vacuum machine are presented and later compared with the measured performance and with the energy consumption of commercial vacuum pumps and eductors. Advantages of removal of NCG using a passive method employing eductors and the prospect of improving the efficiency of these devices are also presented. Based on the experimental data, it is shown that eductors offer a sustainable alternative for NCGs removal from geothermal waters.

Contents

1. Introduction

Geothermal fluids contain non-condensable gases (NCGs) in various quantities. NCGs may have significant impact on the performance of power generation systems which use geothermal waters. In the situation where geothermal water is used as the working fluid in an expander for power generation [1], NCGs present in water can increase the pressure in the condenser and

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* Corresponding author. Tel.: +61 395 695710.
E-mail addresses: anna.khaghani@student.rmit.edu.au (A. Khaghani), abhijit.date@rmit.edu.au (A. Date), aliakbar.akbarzadeh@rmit.edu.au (A. Akbarzadeh).

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Nomenclature

A	surface area (m^2)
D	diameter (m)
I	current (amp)
L	length [m]
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (N/m^2)
$\dot{W}$	power (W)
R	specific gas constant (J/kg K)
SEC	specific energy consumption (J/kg)
t	time (s)
T	temperature (°C)
v	velocity (m/s)
V	voltage (Volts)
$\dot{V}$	volume flow rate (m^3/s)
w	specific energy (J/kg)
W	work (J)
x	distance (m)
ρ	density (kg/m^3)
α	eductor characteristic constant
γ	adiabatic index
η	efficiency

Subscripts

adia	adiabatic
atm	atmosphere
e	exit
f	final
i	initial
in	input
iso	isothermal
l	liquid
mf	motive fluid
r	relative
s	suction

therefore decrease the thermodynamic efficiency of the power generator.

Depending on the source, the fraction of the NCGs in geothermal water can vary from less than 0.2% by mass to greater than 12% by mass [2]. It is important that the selected NCG removal process is appropriate to the concentration of NCG in the source as the removal process uses a large amount of auxiliary power [3]. By using an appropriate NCG removal process the overall performance of the power plant can be improved [4].

The common NCGs present in geothermal water are a mixture of CO_2, H_2S, H_2, Hg, NH_3 and CH_4 [5]. The most prevalent gas is carbon dioxide constituting approximately 95% by weight of the mixture [3].

The following are some of the NCG removal methods used in industrial processes:

1. Extraction using commercially available vacuum pumps [6].
2. Steam ejectors used in order to create a vacuum which assists in the removal of NCGs [8].
3. Not allowing NCGs to enter the system: this can be achieved by degasification of the source fluid before it enters the system [9];
    a. Degasification by pressure reduction, as the quantity of a dissolved gas in a liquid is proportional to its partial pressure.
    b. Degasification by temperature increase. In some cases, however, the solvent and/or the solute decompose react with each other, or evaporate at high temperature and the rate of removal is less controllable.

Angulo et al. have been working on removal of NCG from flash geothermal steam. They have considered condensation and re-evaporation of the steam in a heat exchanger, upstream of a power plant [3]. The main component of their system was a vertical shell and tube heat exchanger with 50 titanium tubes. Steam was fed into the shell side of the heat exchanger. This flowed upwards and most of the steam condensed on the walls of the tubes. The non-condensable gases, together with a small amount of steam, were vented through a purge line located at the upper part of the shell. The condensate flowed into a transfer tank, which acted as a steam seal, and finally, into a storage tank, operated at a lower pressure than the shell side. In this way, a temperature difference was created between the incoming steam and the stored condensate. From the bottom of the storage tank, a pump transferred condensate to the flood box, from which it flowed inside the tubes. The latent heat of the incoming steam was transferred, causing a portion of the condensate to be evaporated, thus producing steam with a low gas content that was discharged at the upper part of the storage tank. The nominal capacity of their equipment was 0.4 t per hour of steam which resulted in achievement of a mean value of 94% for gas removal efficiency by their system. They also found that non-condensable gas removal efficiency was found to depend on the fraction of steam vented with the non-condensable gases [3].

Yildirim Ozcan and Gokcen have studied the net power output and specific steam consumption of a single-flash geothermal power plant which depended on the separator pressure, NCG fraction and wet bulb temperature of the environment. Three different conventional gas removal options were considered, which were a two-stage steam jet ejector system, a two-stage hybrid system and a two-stage compressor system. They found that increasing the NCG fraction decreases, by different amounts, the net power output for each option regardless of separator pressure. It was concluded that in relation to sensitivity of geothermal power plant performance to the NCG fraction, the compressor system is the most efficient and robust system where the influence of the NCG fraction is limited. On the other hand, steam jet ejectors are highly affected by increasing NCG fraction since the driving steam flow rate to the steam jet ejectors is directly related to NCG fraction [4].

Michaelides has investigated influence of non-condensable gases on turbine work, turbine efficiency and extraction work. For his study, as carbon dioxide constituted the major fraction of the non-condensable gases with its concentration always more than 85%, he assumed that the mass of non-condensable gases can be replaced by an equivalent mass-fraction of CO_2. Therefore, he assumed that an ideal gaseous mixture of CO_2 and steam enters the turbine. He concluded that the presence of non-condensable gases in geothermal steam power plants has an adverse effect on the net work produced. This is attributed both to the decrease of the turbine work and to the power supplied to the gas-extraction equipment. In his study, liquid brine is supplied to a primary flashing chamber where a small reduction of pressure releases most of the CO_2 and some steam. This mixture passes through an atmospheric turbine and is vented to the surroundings. The remaining brine, free of most of the CO_2, is