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Thermodynamic and economic investigation of geothermal powered absorption cooling system for buildings

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ABSTRACT

A geothermal powered absorption cooling system is considered for cooling of buildings. The system is analyzed by thermodynamic performance parameters such as cooling load and coefficient of performance (COP). An economic analysis of the system is performed to assess cost structure, potential revenues, payback periods and life cycle cost analysis. Effect of geothermal water temperature on the annual cooling cost and payback periods are investigated. A liquid geothermal source at a temperature of 100 °C with a mass flow rate of 100 kg/s is considered for İzmir city of Turkey. The COP of the ammonia-water absorption cycle is determined to be 0.441. The number of degree-days for the cooling season is calculated to be 1791 °C and cooling load is calculated to be 12,870,000 kWh by the DD (degree − days) method. The annual potential revenue of geothermal cooling is estimated to be 653,818 $/yr with simple and discounted payback periods of 5.684 and 8.816 years. The geothermal cooling is provided an annual monetary benefit of 166,610 $/yr on the entire lifetime of the system by the life cycle cost analysis. So, the unit product cooling cost is calculated to be 0.01295 $/kWh, respectively.

1. Introduction

Geothermal energy has been used for power generation, space and process heating and space cooling. Some part of this energy is rarely used for cogeneration. Geothermal energy is a promising source for any heat driven applications whether involving direct or indirect thermal processes. A separation process of a geothermal fluid mixture is needed for indirect geothermal utilization, especially in power generation cycles. The separation process disposes of the liquid form of low grade thermal energy which could be utilized further for other direct and indirect utilizations such as a power plant bottoming unit, heating and cooling purposes or other heat driven processes, depending on how much of the available energy remains (Febrianto et al., 2016).

Geothermal resources vary widely from one location to another, depending on the temperature and depth of the reservoir, the type of rock and the chemistry and abundance of ground water. Geothermal resources are usually classified into three categories: i) high enthalpy resources (liquid and vapor reservoirs at temperature above 180–200 °C), ii) medium enthalpy resources (at temperatures around 100–180 °C), iii) low enthalpy resources (at temperatures below 100 °C). The wide spectrum of geothermal energy applications is given on the diagram of Fig. 1 (Tesha, 2009).

In developed countries, around 35% of total primary energy consumption is used in buildings. The European Union's commitment to reduce green house gas emissions by 20% by the year 2020 opens a huge potential for geothermal applications. In direct use, the potential of geothermal energy is large for space cooling and heating, and water heating. Geothermal resources are already widely used in the world for space heating and cooling (Li et al., 2014). The utilization of geothermal steam for electricity generation is not the only one way application of geothermal energy. Hot geothermal water that appears to be present in big parts of all the continents can also be exploited and offer interesting prospects for the future. Especially in Turkey geothermal sources are to be proper to the space heating and cooling processes.

Geothermal energy is used to generate electricity and for direct uses such as space heating and cooling, industrial processes, and greenhouse heating. The geothermal electrical capacity and the direct use capacity in the world are about 7000 MW and 8500 MW, respectively. High temperature geothermal resources above 150 °C are generally used for power generation. Moderate temperature (between 90 °C and 150 °C) and low-temperature (below 90 °C) geothermal resources are best suited for direct uses (Kanoglu, 2002).

A geothermal well can produce hot water, wet steam (liquid–vapor mixture), dry steam (saturated steam), or superheated steam. Liquid-dominated systems are much more common than vapor-dominated systems and can be produced either as brine or as a brine–steam mixture, depending on the pressure maintained on the production system (Kanoğlu and Çengel, 1999). Geothermal energy is more effective when used directly than when converted to electricity, since the direct use of

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Nomenclature

A	Annuity ($)
ARC	Absorption refrigeration cycle
c	Unit energy cost ($/kJ)
$\dot{C}$	Energy cost rate ($/h)
COP	Coefficient of performance
CRF	Capital recovery factor
DD	Degree days (°C-day)
h	Enthalpy (kJ/kg)
i	Interest rate (%)
LAC	Levelized annual cost ($/yr)
$\dot{m}$	Mass flow rate (kg/s)
N	Period (year)
OMC	Operating and maintenance costs ($/yr)
PEC	Purchased equipment cost ($)
P	Present value of the payment ($)
$\dot{Q}$	Heat (kW)
r_n	Nominal escalation rate (%)
T	Temperature (°C)
TCI	Total cost of investment ($)
T_0	Environment temperature (°C)
$\dot{W}$	Power (kW)
U	Uniform series amount of money ($)
UPC	Unit product cost ($/Wh)
UCC	Unit cooling cost ($/kWh)
$\dot{Z}$	Equipment cost rate ($/h)

Subscripts

0	Dead states
abs	Absorber
act	Actual
CI	Investment cost
DCU	District cooling unit
elect	Electricity
cond	Condenser
dpp	Discount payback period
evap	Evaporator
F	Fuel
GAU	Geothermal absorption cooling unit
gen	Generator
geo	Geothermal
N	Time period (yr)
OM	Operation and maintenance
P	Product
rev	Reversible
spp	Simple payback period

geothermal heat such as for heating and cooling would replace the burning of fossil fuels from which electricity can be generated much more efficiently.

Direct utilization of geothermal energy is useful and common application of geothermal energy usages. The five countries in the worldwide with the largest direct utilization installed capacity in MWt are: China, USA, Sweden, Turkey and Germany accounting for 65.8% of the world capacity. The five countries with the largest annual energy use in TJ/year are: China, USA, Sweden, Turkey and Iceland accounting for 63.2% of the world usage potential (Lund and Boyd, 2016). As it can be seen in Table 1, Turkey is the largest geothermal water area in the Europe. To compensate for the decline in low temperature geothermal water sources but high availability of energy, it is moving to toward less energy intensive water. This relationship is just one aspect the low enthalpy and low energy intensive, so this low energy sources is not proper to produce the electricity generation but that is more suitable heating and cooling applications for buildings.

Geothermal energy can be used for space cooling by using an absorption refrigeration cycle. Ammonia water absorption chillers are available in a wide range of cooling capacities. Absorption chillers perform best when the heat source can supply heat at a high temperature with little temperature drop, since the chillers were originally designed for steam input to the generator and heat transfer from the condensing steam is a constant temperature process.

The single-stage absorption cooling system chillers are typically rated at an input temperature of 115 °C. The chillers will also perform at lower temperature, but their capacity defined as the rate of heat removed from the cooled space decreases sharply with decreasing source temperature, about 12.5% for each 5 °C drop in the source temperature. For example, the capacity will go down to 50% when the source temperature drops to 95 °C. In that case, one needs to double the size (and thus the cost) of the chiller to achieve the same cooling. The coefficient of performance (COP) of the chiller is defined as the ratio of the capacity to the heat input to the chiller and is affected relatively less by the decline of the source temperature. The COP drops by 2.5% for each 5 °C drop in the source temperature. The nominal COP of single-

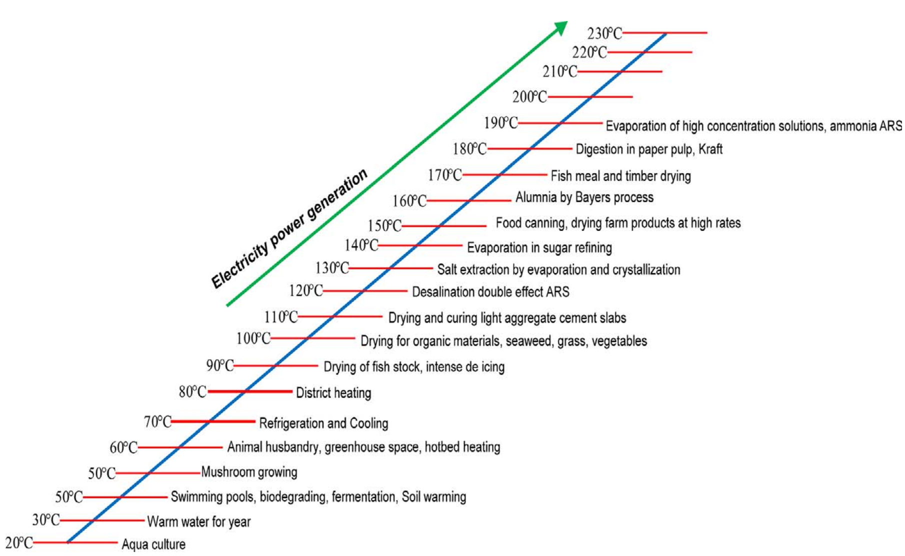

Fig. 1. The wide spectrum of geothermal energy applications diagram (Tesha, 2009).