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Optimization of geothermal energy aided absorption refrigeration system—GAARS: A novel ANN-based approach

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ABSTRACT

The aim of this study is to optimize the geothermal energy aided absorption refrigeration system using NH_3–H_2O as the working fluid. A total of 3660 different designs, with different solution fractions and working parameters, were analyzed by means of energy-exergy and net present value (*NPV*) analysis. The obtained data was modeled by a novel two stage artificial neural network (ANN) with 14650 data points. Of this, 10248 points were used for training, and the remaining used for testing. The best topology of ANN were performed by using the back-propagation learning algorithm with three different variants such as Levenberg-Marquardt (LM), Pola-Ribiere Conjugate Gradient (CGP), and Scaled Conjugate Gradient (SCG). According to ANN results, the error rates were determined in an acceptable range change between 0.07% and 6% for the engineering applications. The R^2 values of best network structures were calculated in higher acceptable range change between 0.9958 and 1.000 for LM. The optimum designs were determined using the obtained weights and biases of the best ANN topology, yielding a coefficient of performance (*COP*) and exergy efficiency (ε) of 0.5722 and 0.6201, respectively. *NPV* values were respectively calculated as 1.778 million US$, 6.328 million US$ and 27.183 million US$ for quince, apple and grape.

1. Introduction

Refrigeration technologies are among the main technologies frequently needed in forming comfortable living environment and preserving food as well as in other living environments. This is why studies to improve refrigeration technologies increase day by day. There are numerous studies on absorption refrigeration systems. In these studies, it is aimed to investigate the performance of the system with different fluid couples by using thermodynamic laws (Talbi and Agnew, 2000; Lee and Sherif, 2001; Pilatowsky et al., 2001; De Lucas et al., 2004; Adewusi and Zubair, 2004; Kizilkan et al., 2007; Kaushik and Arora, 2009; Yılmazoglu, 2010; Gong and Boulama, 2014; Tugcu et al., 2016).

From engineering point of view, it is more important to applicate the most optimum system design taking the thermodynamic and economic parameters into account. At this point, it is very hard to get a quick and acceptable solution. By this way, artificial neural networks (ANNs) are an alternative method. ANNs were used in various studies for different purposes and also for refrigeration applications (Mohanraj et al., 2012). Ertunc and Hosoz (2006) conducted an application of ANN to predict the performance of a refrigeration system with an evaporative condenser. Hosoz and Ertunc (2006) performed the applicability of ANN to predict the performance of automotive air conditioning systems. Tahavvor and Yaghoubi (2011) studied on ANN to predict frost thickness and density around a cooled horizontal circular cylinder. Antonio and Afonso (2011) used ANN method with supervised learning performed using a Genetic Algorithm for the prediction of temperatures of a commercial household refrigerator. Sahin (2011) handled ANN for the performance analysis of single-stage vapor compression refrigeration system with internal heat exchanger. Kumlutas et al. (2012) presented an application of ANN to predict the design parameter's values of the static type domestic refrigerator. Chiang Ng et al. (2014), in their study, implemented a Model Predictive Controller (MPC) using an online trained ANN for an automotive air conditioning system. Mora et al. (2014), in their study, used ANN for prediction of thermodynamic properties of refrigerants in vapor-liquid equilibrium. Belman-Flores and Ledesma (2015), studied on the application of ANN to carry out a statistical analysis of the energy performance for a compression vapor system. Deng et al. (2016) used ANN based on genetic algorithm to pre-

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Nomenclature

B_t	Cumulative cash flow (US$)
b	Bias
C	Cost (US$)
$\dot{E}$	Energy (kWh)
$\dot{E}x$	Exergy (kW)
fr	Circulation rate
h	Specific enthalpy (kJ kg^{-1})
$\dot{m}$	Mass flow (kg s^{-1})
P	Pressure (kPa)
$\dot{Q}$	Heat energy (kW)
r	Discount rate (%)
s	Entropy (kJ kg^{-1} K^{-1})
t	Time (year)
T	Temperature (°C)
$\dot{W}$	Work energy (kW)
X	NH_3 ratio (%)
ε	Energy efficiency (%)
η	Exergy efficiency (%)
υ	Specific volume (m^3 kg^{-1})
ψ	Specific exergy (kJ kg^{-1})

Subscripts

abs	Absorber
ch	Chemical property
cns	Construction
con	Condenser
c,w	Cooling water
d	Destruction
e	Electric
evap	Evaporator
gf	Geothermal fluid
h	Heater
hex	Solution heat exchanger
hg	Heater group
i	Inlet
ins	Installation
inv	Initial investment
m	Maintenance and repair
o	Outlet
O&M	Operating and maintenance
p	Pump
ph	Physical property
pr	Profit
rv	Refrigeration expansion valve
sal	Salvage
sv	Solution expansion valve
stf	Staff
val	Valves
tot	Total
0	Dead state

dict the normal boiling point of refrigerants. Saleh and Aly (2016), improved a new technique using ANN to predict the mass flow rates in the electronic expansion valves. Sozen et al. (2003) determined thermodynamic characteristics of methanol/LiBr solution, an alternative fluid couple for absorption systems, using ANN method. Sencan (2007) developed a new formulation based on ANN model for the analysis of absorption refrigeration system with NH_3-H_2O fluid couple and they obtained optimum results using ANN model. *COP* and *fr* (circulation rate) were predicted upon temperature of system components and concentration values. As seen from given summary of the literature, ANN is a useful tool for prediction of some parameters of the systems. ANN is also useful for the optimization of the systems. Arslan (2011) used ANN to make a decision for the optimum working conditions of Kalina cycle system. Arslan and Yetik (2011) performed ANN to optimize the system parameters of supercritical ORC-Binary geothermal power plant. In another study, Arslan and Yetik (2014) performed ANN to optimize the system parameters of supercritical ORC-Binary geothermal power plant. Arslan (2014), in his study, determined the optimum working conditions of combustion chambers using ANN tool. Arat and Arslan (2017), in their study, determined the optimum system of geothermal aided heat pump system using a multistage and multilevel ANN model.

In this study, the design data of geothermal energy aided single-stage absorption food refrigerator system using NH_3-H_2O solution compiled through energy, exergy and cost analyses to evaluate the geothermal sources in Simav district of the city of Kutahya were modelled with ANN. In this aim, a novel approach was conducted including two different stages in ANN. Finally, using bias and weights of the most appropriate composite model, the handled system was optimized.

Table 1
Characteristics of the wells in Simav geothermal field (Anonymous, 2014; Pinar, 2014).

Well	Depth (m)	Mass rate (kg s^{-1})	Temperature[a] (°C)
EJ-1	725	72	162
EJ-3	424	50	93
EJ-4	588	65	152
EJ-5	603	60	152
E-6	169.6	50	157
E-8	205	80	92
E-9	208	60	98
E-10	288	Re-injection well	
E-11	502	35	99
E-12	241	35	150

[a] Well bottom temperature, x: positive, o: negative.

2. Material and methods

In the study, geothermal resources of Simav region were taken into account for the design of absorption refrigeration system. Simav geothermal field, being one of Turkey's most important 15 geothermal fields, has 10 wells either in use or ready to use. Table 1 shows characteristic values of these wells.

2.1. Design of GAARS

Formed through mixture of Simav geothermal wells, the geothermal fluid has a high level energy potential with 133.5 °C temperature and 462 kg s^{-1} flow. To harness this potential, taking the target production group planned to be cooled and the system conditions into account, a single-stage absorption refrigeration system was dealt with in the study, which allows applications below 0 °C, eliminates crystallization risk by using NH_3-H_2O fluid couple. The flow diagram of the system is shown in Fig. 1.

By changing entrance and exit temperatures of geothermal fluid, 3660 designs were achieved according to different solution concentrations and different temperature parameters. These designs were evaluated with energy and exergy analysis. The governing equations used for designing of GAARS are given in Table 2. In the analysis, considering the worst case (uninsulated case) in the interaction of the heater group with the environment, a 5% loss was assumed. Since the average heat in other heat exchangers is an aim, this rate isn't included into computations. Pump efficiencies were included into computations as 60% and surface heat loss is neglected. The detailed information can be achieved from the previous study of authors (Tugcu et al., 2016). Thermodynamic values