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Thermoeconomic evaluation and optimization of a double-effect H_2O/LiBr vapour-absorption refrigeration system

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Abstract

In this paper, the thermoeconomic concept is applied to the optimization of a double-effect H_2O/LiBr VAR system, aimed at minimizing its overall product cost. A simplified cost minimization methodology based on the thermoeconomic concept is applied to calculate the economic costs of all the internal flows and products of the system by formulating thermoeconomic cost balances. Once these costs are determined, the system is thermoeconomically evaluated to identify the effects of the design variables on cost of the flows and products. This enables to suggest changes of the design variables that would make the overall system cost-effective. Finally, an approximate optimum design configuration is obtained by means of an iterative procedure. The result shows significant improvement in the system performance. The sensitivity analysis shows that the changes in optimal values of the decision variables are negligible with changes in the fuel cost.

Keywords: Absorption system; Water/lithium bromide; Double-effect system; Optimization; Design

Evaluation thermoéconomique et optimisation d'un système frigorifique à absorption au H_2O/LiBr à double effet

Mots clés : Système à absorption ; Eau/bromure de lithium ; Système biétagé ; Optimisation ; Conception

1. Introduction

The environmental regulations have forced the refrigeration-based industries to direct the research trend in search of alternative refrigerants and alternative technologies [1]. Regarding the alternative technologies, absorption technology appears to be a promising alternative to vapour-compression system as it uses zero ozone depletion potential fluids and zero global warming potential fluids. Moreover, these systems are heat-powered and need very little electricity. These systems, however, are less efficient and costlier than the vapour compression counterpart. This calls for performance enhancement with reduction in investment cost. In this respect, the thermoeconomic concept that combines the thermodynamic principles with the economic parameters can play a vital role in the optimization complex thermal systems. The most significant advantage of the thermoeconomic optimization

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Nomenclature

A	heat transfer surface area (m^2)
B	constant in cost equations ($\$ \, kW^{-0,8}$)
C	cost per exergy unit ($\$ \, GJ^{-1}$, $\$ \, kJ^{-1}$)
$\dot{C}$	cost flow rate ($\$ \, h^{-1}$)
e	specific exergy ($kJ \, kg^{-1}$)
$\dot{E}$	exergy flow rate (kW)
f	thermoeconomic factor (%)
h	specific enthalpy ($kJ \, kg^{-1}$)
$\dot{m}$	mass flow rate ($kg \, s^{-1}$)
M	molecular weight ($kg \, kmol^{-1}$)
$\dot{Q}$	heat transfer rate (kW)
r	relative cost difference (%)
$\dot{R}$	O and M cost invariable to optimization
s	specific entropy ($kJ \, kg^{-1} \, K^{-1}$)
t	temperature on centigrade scale (C)
T	temperature on Kelvin scale (K)
$\dot{W}$	work flow rate or power (kW)
Y	ratio of exergy destruction (or loss) to total exergy supplied to the system
Y^*	ratio of energy destruction to total energy destruction of the system
z	concentration
Z	investment cost of the system components ($)
$\dot{Z}$	levelized (annual) investment cost of the system components ($\$ \, s^{-1}$)

Greek letters

β	coefficient expressing accounts for the fixed O and M costs that depends upon the total investment cost for a system component
χ	effectiveness of the solution heat exchanger
ε	exergetic efficiency (%)
η	isentropic or mechanical efficiency
τ	annual number of hours of system operations
ω	coefficient expressing variable levelized O and M costs for a system component
ξ	capital recovery factor
Δ	difference

Superscripts

Ch	chemical component
CI	capital investment
Ph	physical component
OM	operation and maintenance
OPT	optimum
x	efficiency exponent in cost equations
y	capacity exponent in cost equations
0	standard state at normal temperature

Subscripts

0	environmental state
1, 2, 3,…,i,…17, 18	system state points
a	absorber
c	condenser
D	energy destruction
E	evaporator
ea	evaporator assembly
ex	expansion valve
F	fuel
htg	high temperature generator (HTG)
H	steam energy
Shx	solution heat exchanger
H_2O	water
in	entering streams
k	the kth component of the system
ltg	low temperature generator (LTG)
L	energy losses
m	electric motor
out	leaving streams
p	pump
P	product
Q	energy rate due to heat transfer
total	total system
v	throttling valve
W	energy rate due to work transfer

Vector and matrices

$[A]$	matrix containing the unknowns
$[X]$	vector of unknown variables
$[Y]$	vector of known variables

method lies in its capacity to solve complex practical problems without using sophisticated numerical analysis.

The research, during the last 25 years or so, has put the thermoeconomic optimization methodologies to the maturity level. The various thermoeconomic methodologies developed so far are the thermoeconomic evaluation and optimization (TEO) [2,3], the exergetic cost theory (ECT) [4], the thermoeconomic functional analysis (TFA) [5], and the engineering functional analysis (EFA) [6]. The major fields of application of these methods are mainly those of large cogeneration and combined power plants, chemical plants, etc. [3–6], whereas the domain of refrigeration and air-conditioning are still nominal. It is because the industrial utilities are probably considered with great interest, as they are capital intensive. However, civil applications like refrigeration and air-conditioning have even higher rates of energy consumption and poor efficiency. These, therefore, deserve greater attention both in the design phase and in everyday handling. In this respect, d'Accadia and de Rossi [7] have presented thermoeconomic optimization of a vapour-compression refrigerator using the ECT method. In the field of absorption refrigeration, Misra et al. [8,9] have used the TEO method and the ECT