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On the validity of a design method for a solar-assisted ejector cooling system

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Abstract

A solar-assisted ejector cooling system is simulated in order to investigate the validity of a design methodology. Hourly simulation results allow for computing the solar fraction, in cases when the cooling capacity of the ejector cycle is kept constant during daily periods. The computed solar fraction is compared with estimates obtained from the f–$\bar{\phi}$-chart method based on the utilizability concept. An equivalent minimum temperature for the utilizability of the solar system is found, which proves to be different, but close to, the vapor generator temperature of the ejector cycle. It is shown that the solar fraction derived from the utilizability concept based on the monthly means of the global solar radiation is applicable to solar-assisted ejector cooling cycles, in cases when the minimum temperature at which solar heat is supplied to the load is determined. Good agreement is found between the solar fraction results obtained from the simulations and those obtained by the f–$\bar{\phi}$-chart method.

Keywords: Solar fraction; Solar cooling; Ejector; f–$\bar{\phi}$-chart

1. Introduction

The past decades have seen an increase on research leading to develop renewable energy systems as a measure to achieve substantial reduction in emissions of greenhouse effect gases. Solar energy is considered worldwide as an effective renewable energy alternative; with potential to contribute to reductions in fossil fuel and electric energy consumption, mostly for domestic air and water heating applications. Collectors of the flat plate and evacuated tube types are cost effective for many applications in domestic and industrial process heat, if the required temperatures are lower than 100 °C. The situation is different for solar-assisted cooling cycles, which are hardly competitive with mechanical compression cycles (Arbel and Sokolov, 2004), mostly due to the high capital cost associated with the acquisition of a large number of solar collectors needed to supply the required heat, and the relatively long payback time. Regarding solar driven absorption cooling systems, there are only a few applications in which they can be competitive with mechanical compression (Herold et al., 1996). Capital cost of solar collectors, and barriers arising from architecture constraints, contribute to reduce the economical advantages in favor of absorption cooling cycles. Furthermore, mechanical compressors have decreased their cost and have become more efficient in the past years. The situation is not better for ejector cooling cycles. The coefficient of performance (COP) of a single stage lithium

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Nomenclature

A_c	solar collector area (m^2)
A_{ev}	effective heat exchanger area – changing phase section (m^2)
A_s	effective heat exchanger area – single-phase section (m^2)
A_{rcs}	total heat exchanger area (m^2)
c_p	specific heat of the solar heating system working fluid (kJ/kg°C)
c_{rl}	specific heat of the ejector working fluid – saturated liquid (kJ/kg°C)
COP	coefficient of performance of the ejector cycle
f	hourly solar fraction
f_a	annual solar fraction
f_ϕ	annual solar fraction given by the f–$\bar{\phi}$-chart correlation
F_R	heat removal factor of the solar collector
h_c	enthalpy of the ejector working fluid at temperature
T_c	subcooled state (kJ/kg)
h_l	enthalpy of the saturated liquid (kJ/kg)
h_v	enthalpy of the saturated vapor (kJ/kg)
$K_{\tau\alpha}$	incidence angle modifier
Q_{aux}	auxiliary heat power (kW)
Q_g	heat power input to the vapor generator of the ejector cycle (kW)
Q_r	ejector cycle cooling load (kW)
T_c	temperature of the ejector subcooled working fluid (°C)
T_f	temperature of the ejector working fluid (°C)
T_g	temperature of vapor generation (°C)
T_r	ejector cycle evaporator temperature (°C)
T_s	temperature of the solar heating system working fluid (°C)
U_{ev}	global heat transfer coefficient for the changing phase section of the heat exchanger (kW/m^2°C)
U_L	solar collector heat loss coefficient (kW/m^2°C)
U_s	global heat transfer coefficient for the single-phase section of the heat exchanger (kW/m^2°C)
W_{max}	maximum hourly thermal capacitance between $(\omega c_p)_s$ and $\omega_{ej}c_{rl}$ (kW/°C)
W_{min}	minimum hourly thermal capacitance between $(\omega c_p)_s$ and $\omega_{ej}c_{rl}$ (kW/°C)
x_f	vapor quality

Greeks

ε	heat exchanger effectiveness
$\bar{\phi}$	monthly utilizability of the solar collector
ω	mass flow rate of working fluid (kg/s)
$(\omega c_p)_s$	hourly thermal capacitance of the solar heating working fluid (kW/°C)
$\omega_{ej}c_{rl}$	hourly thermal capacitance of the ejector working fluid (kW/°C)
$(\tau\alpha)$	normal transmittance – absorptance factor of the solar collector

Subscripts and Superscripts

s	single phase (heat exchanger effectiveness)
ej	ejector working fluid mass rate
ev	two-phase (heat exchanger effectiveness)
n	normal
s	solar

bromide/water absorption chiller can reach 0.7 (Herold et al., 1996), while the COP of an ejector cycle, under the same operation temperatures can reach 0.48 (Pridasawas and Lundqvist, 2007). A low value of the COP implies that a large optimum collector area is needed in order to meet the cycle heat load requirements. Therefore, potential advantages arising from the lower cost of an ejector cooling system are balanced by the requirement of increased collector area.

Solar-assisted ejector systems are usually simulated on an hourly basis (Vidal and Colle, 2004), by using data from typical meteorological year (TMY) databases, which are readily available at meteorological services of developed countries. However, good quality TMY database are seldom available in developing and undeveloped countries, which could take advantage of solar-assisted systems to reduce their expenditures in primary energy sources like fossil fuels. Monthly averages of global and beam solar radiation incident on horizontal surfaces have recently become available to several countries, thanks to the successful modeling techniques used to estimate incoming solar radiation derived from satellite data (Pereira et al., 2008). Satellite-derived solar radiation can presently be estimated with uncertainty levels around 5%, according to comparisons with land-based monitoring stations.

The solar fraction, defined as the ratio of solar-supplied heat to total thermal load, is dependent on available solar radiation, collector efficiency, collector surface area, and thermal load. The cost of solar-assisted cooling cycles is therefore linked to the solar fraction, which determines the optimal collector area, and the cost of operating an auxiliary heating system. A proper estimation of hourly, daily, monthly mean, and yearly mean solar fraction allows for correct dimensioning of a solar-assisted cooling system, and for an accurate estimation of capital and operation costs during its life cycle. Varying conditions for available solar radiation exist in every geographical location, which difficults the application of standardized solutions. It is