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Numerical optimisation of a two-stage ejector refrigeration plant

Giuseppe Grazzini*, Andrea Rocchetti

Dipartimento di Energetica "S. Stecco", Università di Firenze, Via di Santa Marta, 3, 50139 Firenze, Italy

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Abstract

Jet-refrigeration cycles seem to provide an interesting solution to the increasing interest in environment protection and the need for energy saving due to their low plant costs, reliability and possibility to use water as operating fluid. A steam/steam ejector cycle refrigerator is investigated introducing a two-stage ejector with annular primary at the second stage. The steady_state refrigerator, exchanging heat with the water streams at inlet fixed temperatures at the three shell and tube heat exchangers, evaporator, condenser and generator, is considered as an open system. Heat transfer irreversibilities in the heat exchangers and external friction losses in the water streams are considered, ignoring the internal pressure drop of the vapor. A simulation program numerically searches the maximum COP at given external inlet fluid temperatures as a function of mass flows, dimensions and temperature differences in the heat exchangers. The code gives the ejector and heat exchangers design parameters. © 2002 Elsevier Science Ltd and IIR. All rights reserved.

Keywords: Refrigerating system; Ejector system; Steam; Two-stage system; Design; Performance; Modelling

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Optimisation numérique d'un système frigorifique biétagé à éjection

Résumé

Le cycle frigorifique à éjection apparaît comme une réponse très intéressante à la demande croissante de protection de l'environnement et d'économies d'énergie grâce à son faible coût, à sa fiabilité et à la possibilité d'utiliser de l'eau comme fluide actif. Un système à vapeur d'eau à éjection a été étudié. C'est un système biétagé qui présente un composant annulaire au second étage. On a considéré ce système comme étant un système ouvert fonctionnant en régime permanent avec échange de la puissance thermique dans trois échangeurs à tubes et calandre, l'évaporateur, le condenseur et le générateur, avec l'eau entrant à des températures prédeterminées. Les irréversibilités thermodynamiques liées aux échanges thermiques et des chutes dues au frottement ont été considérées, mais no celles de la vapeur. Le programme de simulation numérique utilisé permet de chercher le COP maximum pour des températures données des fluides à l'entrée, en fonction des débits massiques, des dimensions et des différences de température au niveau des échangeurs de chaleur. Le code fournit toutes les dimensions géométriques de l'éjecteur et des échangeurs de chaleur. © 2002 Elsevier Science Ltd and IIR. All rights reserved.

Mots clés : Système frigorifique ; Système à éjecteur ; Vapeur d'eau ; Système biétagé ; Conception ; Performance ; Modélisation

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* Corresponding author. Tel.: +39-055-479-6242; fax: +39-055-479-6342.
E-mail address: ggrazzini@ing.unifi.it (G. Grazzini).

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Nomenclature

A	area (m^2)
C	capacity rate ($J\ kg^{-1}$)
c_p	specific heat ($J\ kg^{-1}\ K^{-1}$)
COP	coefficient of performance. Eq. (9)
d	diameter of the ejector sections (m)
D	inner diameter of the heat exchanger tubes (m)
g	gravity factor ($m\ s^{-2}$)
h	heat exchange coefficient ($Wm^{-2}\ K^{-1}$)
H	ring width of the annular nozzle (m)
i	specific enthalpy ($J\ kg^{-1}$)
k	thermal conductivity ($Wm^{-1}\ K^{-1}$)
K	factor defined by Eq. (11) ($W\ K^{-1}$)
L	tube length of the heat exchanger (m)
m	cycle fluid flow rate ($kg\ s^{-1}$)
M	external water flow rate ($kg\ s^{-1}$)
Ma	mach number
n	number of heat exchanger tubes
Nu	Nusselt number
P	pressure (Pa)
Pr	Prandtl number
Q	thermal power (W)
r	latent heat ($J\ kg^{-1}$)
Ra	Rayleigh number
Re	Reynolds number
s	thickness (m)
T	temperature (K)
U	global thermal exchange coefficient ($W\ K^{-1}$)
W	power (W)
ΔTML	logarithmic mean temperature difference (K)

Greek letters

$\beta = P_{out}/P_s$	compression ratio
ε	absolute roughness of the heat exchanger tubes (m)
ε_K	Kay's efficiency. Eq. (10)
η	efficiency
λ	friction factor
μ	dynamic viscosity ($Ns\ m^{-2}$)
ν	kinematic viscosity ($m^2\ s^{-1}$)
ρ	density ($kg\ m^{-3}$)
$\omega = m_s/m_p$	entrainment ratio
$\xi = P_G/P_E$	motive pressure ratio

Subscripts

I	ejector first stage
II	ejector second stage
b	boiling section
C	condenser
Ca	carnot
co	condensing section
e	external
E	evaporator
eje	ejector
ex	nozzle outlet section
f	working cycle fluid
G	generator
in	inlet
l	saturated liquid
max	maximum
min	minimum
mix	mixing section of the ejector
out	outlet
p	primary nozzle
Pu	pump
r	rank
s	ejector secondary flow
S	second Law
sat	saturation
th	nozzle throat
v	saturated steam
x	first cooling rank section of the condenser
y	generator superheating section
z	generator preheating section
w	water
wa	wall
λ	related to pressure losses

1. Introduction

The ejector is a well-known device since the early twentieth century. It was largely experimented and used in industrial process and plane propulsion. Recently, the increasing interest in environment safety is opening new possibilities in the refrigeration field, reintroducing the steam ejector refrigeration cycle in spite of low efficiencies compared with the traditional refrigeration plants. Many works about physical model formulation of the ejector integrated on the refrigeration thermodynamic cycle were carried out [1–5] using the typical ejector pattern. Further attempts [6] to improve the ejector low performances modifying the traditional ejector scheme, were proposed.

Therefore, the ejector refrigeration plant analysis and optimisation, including heat transfer irreversibilities, with an unusual ejector scheme seems interesting.