

# Numerical optimisation of a two-stage ejector refrigeration plant

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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 prédéterminées. Les irréversibilités thermodynamiques liées aux échanges thermiques et des chutes dues au frottement ont été considérées, mais pas 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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Nomenclature			
$A$	area (m <sup>2</sup> )	$\lambda$	friction factor
$C$	capacity rate (J kg <sup>-1</sup> )	$\mu$	dynamic viscosity (Ns m <sup>-2</sup> )
$c_p$	specific heat (J kg <sup>-1</sup> K <sup>-1</sup> )	$\nu$	kinematic viscosity (m <sup>2</sup> s <sup>-1</sup> )
$COP$	coefficient of performance. Eq. (9)	$\rho$	density (kg m <sup>-3</sup> )
$d$	diameter of the ejector sections (m)	$\omega = m_s/m_p$	entrainment ratio
$D$	inner diameter of the heat exchanger tubes (m)	$\xi = P_G/P_E$	motive pressure ratio
$g$	gravity factor (m s <sup>-2</sup> )	<i>Subscripts</i>	
$h$	heat exchange coefficient (Wm <sup>-2</sup> K <sup>-1</sup> )	I	ejector first stage
$H$	ring width of the annular nozzle (m)	II	ejector second stage
$i$	specific enthalpy (J kg <sup>-1</sup> )	b	boiling section
$k$	thermal conductivity (Wm <sup>-1</sup> K <sup>-1</sup> )	C	condenser
$K$	factor defined by Eq. (11) (W K <sup>-1</sup> )	Ca	carnot
$L$	tube length of the heat exchanger (m)	co	condensing section
$m$	cycle fluid flow rate (kg s <sup>-1</sup> )	e	external
$M$	external water flow rate (kg s <sup>-1</sup> )	E	evaporator
$Ma$	mach number	eje	ejector
$n$	number of heat exchanger tubes	ex	nozzle outlet section
$Nu$	Nusselt number	f	working cycle fluid
$P$	pressure (Pa)	G	generator
$Pr$	Prandtl number	in	inlet
$Q$	thermal power (W)	l	saturated liquid
$r$	latent heat (J kg <sup>-1</sup> )	max	maximum
$Ra$	Rayleigh number	min	minimum
$Re$	Reynolds number	mix	mixing section of the ejector
$s$	thickness (m)	out	outlet
$T$	temperature (K)	p	primary nozzle
$U$	global thermal exchange coefficient (W K <sup>-1</sup> )	Pu	pump
$W$	power (W)	r	rank
$\Delta TML$	logarithmic mean temperature difference (K)	s	ejector secondary flow
<i>Greek letters</i>		S	second Law
$\beta = P_{out}/P_s$	compression ratio	sat	saturation
$\varepsilon$	absolute roughness of the heat exchanger tubes (m)	th	nozzle throat
$\varepsilon_K$	Kay's efficiency. Eq. (10)	v	saturated steam
$\eta$	efficiency	x	first cooling rank section of the condenser
		y	generator superheating section
		z	generator preheating section
		w	water
		wa	wall
		$\lambda$	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.

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