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Latra Boumaraf
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# PREFACE

The object of this chapter is to introduce the subject of ejector in refrigerating plants in view of energy savings.

A first part concerns the use of an ejector in a heat-operated system for the production of cold (refrigeration or air conditioning). The ejector refrigeration system using an environment friendly fluid allows combining two advantages: one related to the energy saving by the use of thermal energy wasted from industrial processes at average or low temperatures or a free energy source (solar energy) and the other related to the environment protection by reduction of $CO_2$ emissions in the atmosphere. The performance of this system depends strongly on that of its ejector, thus many works have been focused on this component. Particularly, it has been the subject of theoretical and experimental studies in the Thermal Center of Lyon (France) and the mechanical department of Annaba university (Algeria) during many years. In addition to a literature review, the paper provides a summary of these works, which have been previously published in several journals and presented in many international conferences. In this chapter, these studies are gathered and discussed in several sections, i.e. ejector behavior analysis in different operating modes, performance characteristics, working fluids, modeling of an ejector refrigeration system based on those of its components in design and off-design conditions.

A second part consists of an original simulation program of a transcritical $CO_2$ refrigeration system using an ejector as an expansion device in order to improve the *COP* of the basic transcritical $CO_2$ system by reducing the isenthalpic expansion losses. A constant-area mixing model is used to design the ejector for typical air conditioning applications. By using this ejector model, a thermodynamic cycle analysis of the transcritical $CO_2$ system with expansion by ejector is performed. The results highlight the benefit of using ejector as an expansion device in improving the system energetic efficiency.

**Keywords**: Ejector; Modeling; Simulation; COP; Refrigerant fluid; Transcritical $CO_2$ cycle; Expansion device

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# NOMENCLATURE

| | |
|---|---|
| A | constant in Eq. (II.15) or area section of ejector ($m^2$) |
| $A_P^*$ | area section of primary nozzle throat ($m^2$) |
| $A_S^*$ | area section of the secondary flow choking throat ($m^2$) |
| a | constant in Eq. (II.15) |
| C | refrigerant mass in the ejector refrigeration system (kg) |
| $C_P$ | specific heat of the gas or vapor at constant pressure (J/kg K) |
| $C_w$ | specific heat of the HTF (J/kg K) |
| COP | coefficient of performance |
| $COP_C$ | performance coefficient of Carnot cycle |
| D | diameter of the ejector cylindrical tube (m) |
| d | diameter of the primary nozzle exit section (m) |
| $d_D$ | diameter of the diffuser (m) |
| Er | error |
| h | specific enthalpy (J/kg) |
| I | improvement of the ejector expansion transcritical $CO_2$ refrigeration system equal to $COP/COP_b$ |
| K | constant in Eq. (I.14) |
| L | length (m) |
| $L_V$ | latent heat of the refrigerant fluid (J/kg) |
| M | Mach number |
| M' | molecular weight of the motive fluid in Eqs. (I.14-15) |
| M" | molecular weight of the driven fluid in Eqs. (I.14-15) |
| $M_F$ | mass of the refrigerant fluid in a heat exchanger (kg) |
| $\dot{M}_W$ | mass flow rate of the HTF( kg/s) |
| $M_\sigma$ | refrigerant mass in the subcooling zone (kg) |
| $\dot{m}_P$ | mass flow rate of the primary fluid (kg/s) |
| $\dot{m}_S$ | mass flow rate of the secondary fluid (kg/s) |

## Nomenclature (Continued)

| | |
|---|---|
| P | pressure (Pa) |
| $P_{C0}$ | limiting condition on back pressure of the ejector operational mode (Fig I.4.) |
| $\dot{Q}$ | heat rate (W) |
| R | universal gas constant (J/kg K) |
| r | pressure lift ratio or compression ratio of an ejector equal to $P_C/P_E$ |
| Re | Reynolds number |
| S | heat transfer surface (m²) |
| s | specific entropy (J/kg K) |
| T | refrigerant temperature (°C) or (K) |
| $T_P$ | wall temperature in a heat exchanger (°C) |
| t | temperature of the HTF (°C) |
| U | entrainment ratio of an ejector (Eq. (I.1)) |
| U' | entraiment ratio of an ejector with different molecular weights of the primary and secondary fluids (Eqs. (I.14-15)) |
| V | velocity of the refrigerant fluid (m/s) |
| v | specific volume of the refrigerant fluid ($m^3$/kg) |
| W | volume of a heat exchanger ($m^3$) |
| $\dot{W}_P$ | work rate of the pump (W) |
| x | vapor quality of the refrigerant fluid or related to a geometrical parameter of an ejector in Table I.1. |
| Greek symbols | |
| $\alpha$ | characteristic angle of an ejector defined in Table I.1 or coefficient of heat transfer (W/m²K) |
| $\beta$ | characteristic angle of an ejector defined in Table I.1. |
| $\Phi$ | geometrical parameter of an ejector equal to $(D/d^*)^2$ |
| $\varphi$ | geometrical parameter of an ejector equal to $(d/d^*)^2$ |
| $\eta$ | isentropic efficiency |
| $\eta_P$ | mechanical efficiency of the pump |
| $\eta_{ex}$ | exergetic efficiency |
| $\lambda$ | thermal conductivity (W/mK) |
| $\mu$ | dynamic viscosity (kg/ms) |
| $\rho$ | density (kg/$m^3$) |
| $\sigma$ | surface tension (N/m) |
| $\Theta$ | filling amount of a heat exchanger |
| $\Gamma$ | expansion ratio of an ejector equal to $P_B/P_E$ |
| $\gamma$ | characteristic angle of an ejector defined in Table I.1 or specific heat ratio of the refrigerant fluid |
| $\Delta$ | variation |

**Nomenclature (Continued)**

| | |
|---|---|
| $\Delta T$ | Superheat (K or °C) |
| $\xi$ | driving pressure ratio of an ejector equal to $P_B/P_C$ |
| $\Omega$ | geometrical parameter of an ejector defined in Table I.1. |
| Subscripts | |
| B | boiler |
| b | related to the basic cycle |
| C | condenser or related to Carnot cycle |
| cal | calculated value |
| comp | related to the compressor |
| cr | related to the refrigerant critical state |
| D | diffuser |
| E | evaporator |
| e | related to the inlet |
| i | incremental value |
| is | isentropic process |
| L | liquid |
| M | related to the motive flow |
| N | related to the primary nozzle |
| opt | optimal |
| P | related to the primary flow |
| S | related to the secondary flow or suction chamber |
| s | related to the outlet |
| V | vapor |
| $\sigma$ | related to the subcooling zone |
| 0 | related to the stagnation state |
| 0,1, 2,… | locations in the ejector and the operating cycle of the system |
| Superscript | |
| * | at transition mode or related to a throat section |