PERFORMANCE OF A TRIPLE-PRESSURE LEVELS ABSORPTION CYCLE

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ABSTRACT

In the developed triple-pressure levels single stage cycle a jet ejector of a special design is added at the absorber inlet. The device serves two major functions: it facilitates pressure recovery and improves the mixing process between the weak solution and the refrigerant vapor coming from the evaporator. These effects enhance the absorption process of the refrigerant vapor into the solution drops. To facilitate the design of a jet ejector for absorption machines, a numerical model of simultaneous heat and mass transfer between the liquid and the gas phases in the ejector was developed. The refrigerant R125 and the absorbent DMETEG were used in these calculations.

Based on the computerized simulation program a parametric study of the triple-pressure levels single stage absorption cycle was carried out. The influence of the jet-ejector on the performance of the absorption cycle was studied.

KEYWORDS

Absorption cycle, Jet ejector, Cycle analysis, COP

1. INTRODUCTION

Various types of absorption heat pumps, both single and multi-stages, can implement utilization of available heat sources for cooling and refrigeration. However, the utilization of low potential heat sources for cooling and refrigeration (<0°C) is limited by the properties of the working fluids and the cycle configuration of the heat pump. For utilization of low potential heat sources (70-120°C) for cooling and refrigeration to <0°C, a single-stage absorption heat pump based on organic working fluids is preferable, since conventional working fluids such as ammonia-water or water-lithium bromide are limited to the above described operation conditions.

The temperature of the heat source and the cooling or refrigeration demands are usually the factors that determine the type of working fluid to be used and the type of the absorption heat pump system to be used.

The commonly used working fluids are ammonia-water or water-lithium bromide. The ammonia-water combination requires a heat source temperature above 120°C for cooling temperature below to 0°C. It is a high-pressure system that requires a rectification column [1]. Ammonia has acceptable thermophysical properties, but it is a flammable fluid. It is toxic, strongly irritant and corrosive to copper. The water-lithium bromide solution can be used with a heat source temperature above 70°C for air-conditioning but not for cooling and refrigeration because of the limitation for the evaporator temperature to be above 0°C. This system operates under vacuum and does not require a rectification column. The water-lithium bromide solution is highly corrosive and extremely viscous (viscosity-reducing agents are frequently required). The limitations of using these common working fluids [2] for utilizing low potential heat sources (80-120°C) for cooling and refrigeration (<0°C) are thus self-evident.

To overcome these limitations, we have chosen working fluids based on fluorocarbon (HFC) refrigerants and organic absorbents [3-8]. The refrigerants are not toxic or corrosive. The organic working fluids are environmentally acceptable. In this system a rectification column is not needed, since the difference between the normal boiling points of the absorbent and the refrigerant is about 200°C.

The performance of these working fluids in a conventional single-stage absorption cycle is expressed in terms of a coefficient of performance (COP)* of about 0.5 and a circulation ratio (f)** in the range of 3-7.

2. TRIPLE-PRESSURE-LEVELS SINGLE-STAGE ABSORPTION CYCLE

In order to utilize a low-potential-heat source between 70 to 100°C for cooling temperature between -5 to -15°C, an advanced single-stage absorption heat pump can be used, i.e., a triple-pressure-levels device. This device may be implemented in a number of different ways. One such design is known as the compression/ absorption cycle [9-12], in which a compressor is placed between the evaporator and the absorber. The main disadvantage of such a device is the extra electrical energy supply required for the compressor.

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* Defined as the heat rejected from the evaporator divided by the heat supply to the generator and the energy supply to the pump.

** Defined as the ratio between the mass flow rate of the strong solution in the pump to the mass flow rate of the refrigerant.

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In our triple-pressure-levels single-stage heat pump a specially designed jet ejector is placed at the absorber inlet (Figure 1). The purpose of incorporating a jet ejector into the absorption cycle is thus to increase the absorber pressure relative to the evaporator pressure (by partially recovering the high pressure of the generator) and to improve the mixing process and the pre-absorption between the weak solution and the refrigerant coming from the evaporator [13-15]. The mixing process in the jet ejector is very intensive as a result of spray generation of the liquid phase and of extensive subcooling of the weak solution in the solution heat exchanger. Schematic representation of the jet-ejector is shown in Figure 2.

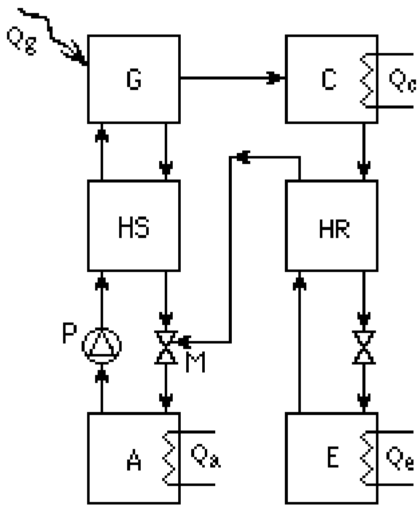

Figure 1: Schematic representation of a triple-pressure-levels single-stage advanced absorption cycle. (G - generator, A - absorber, C - condenser, E - evaporator, HS - solution heat exchanger P - solution pump, M - jet ejector mixer).

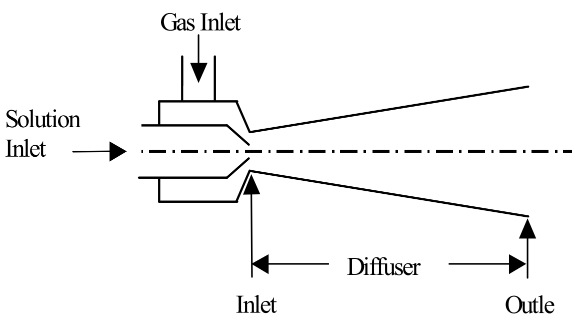

Figure 2: Schematic representation of jet-ejector

A similar absorption cycle was suggested by Li-Ting Chen [16] where the ejector was described as a device for mixing and pressure recovery. The analysis of the two phase mixture flow through the ejector was based on a single-phase model of pseudo fluid. No heat and mass transfer were taken into consideration. Thus, only a Bernoulli type of equation was used.

2.1 Jet ejector

The ejector is characterized by a lack of moving parts and the absence of a requirement for an additional energy source. It basically consists of a nozzle and a diffuser. In the nozzle, potential energy (pressure difference between the generator and the absorber) is transformed into kinetic energy by producing, at the outlet of the nozzle, a spray of weak solution in a full cone stream of small high-velocity drop. In the diffuser inlet (low pressure of the evaporator), the drops of weak solution mixes with the refrigerant vapor coming from the evaporator. Pressure recovery in the diffuser is thus obtained by transforming kinetic energy to potential energy. As a result, the velocities of both drops and the gas are reduced.

To facilitate the design of the jet ejector for absorption machines, a numerical model of simultaneous mass, momentum and heat transfer between the liquid and gas phases in the jet ejector was developed based on the mathematical model described by Levy et al [17].

The jet ejector model, as a pre-absorber, was solved numerically for the absorbent fluid [dimethylether tetraethyleneglycol (DMETEG)] with pentafluoroethane (R125) as the refrigerant. The solution of R125-DMETEG [13] was modelled as the dispersed phase while R125 as the continuous gas phase. The numerical solution was obtained by means of Gear's fifth-order BDF method, which is available in the IMSL library.

The influence of the design parameters on the pressure recovery, temperature and concentration of the refrigerant in the solution, and velocities of the gas and liquid drops was examined. The parametric study involved examination and ways of augmentation of the mass transfer process in the diffuser with the ultimate aim of designing a compact and efficient unit. The numerical simulation demonstrated that the pressure recovery and preabsorption in the jet ejector would improve the efficiency of the absorption process and hence the overall efficiency of the refrigeration cycle.

In conventional used absorption heat pumps, the absorber pressure is equal to the evaporator pressure (when pressure drop along the pipe line is taken as zero). The pressure recovery is defined as the pressure difference between the outlet and inlet of the diffuser. Therefore the absorber pressure is higher than the evaporator pressure. This effect may be utilized in several ways. In the first way, the same absorber outlet temperature and a higher absorber pressure produces a higher weight fraction of the refrigerant in the solution. This increases the weight fraction at the absorber outlet and leads to a reduction in the circulation ratio (f), i.e. a reduction in the mass flow rate of the strong solution in the pump, and to a reduction in the amount of heat to be transferred in the solution heat exchanger and slightly the heat input at the generator. In the second way, keeping the absorber outlet pressure and temperature as a constant, results in lower evaporator pressure, which leads to lower evaporator temperature. In the third way, at constant circulation ratio, the system can be operated in a slightly higher surrounding temperature (condenser and absorber) at the same evaporator temperature.

2.2 System analysis

A combination of the computerized simulation program for the single-stage absorption cycle with the program for the jet ejector facilitated evaluation of the influence of the jet ejector on the performance of the absorption cycle. The computerized program of the jet ejector integrated in an absorption cycle was used to calculate the performances of a triple-pressure-levels single-stage absorption cycle with DMETEG and R125 [4] as the model working fluids.

In a conventional single-stage absorption cycle (when the pressure drops are negligible), the absorber pressure is equal to the evaporator pressure. Based on the computerized program, the COP and f were calculated under the following operating conditions: condenser temperature 32°C, absorber temperature 28°C, generator temperature in the range of 60 to 120°C, and evaporator temperatures of 0, -5, -10 and -15°C.

The prediction indicated that when the pressure recovered by the jet ejector is added to the evaporator pressure, the absorber pressure is increased. At the same absorber outlet temperature, the weight fraction of the refrigerant in the solution increased. This increase of the weight fraction at the absorber outlet will cause a reduction in f (a reduction in the mass flow rate of the strong solution in the pump) and to a reduction in the amount of heat to be transferred in the solution heat exchange and slightly the heat input to the generator.

The prediction of the numerical simulations for the COP and f at constant evaporator temperature (case 1) are shown in Figure 3 and 4. The calculated COP and f for a conventional single-stage absorption cycle are shown in Fig. 3a and 4a respectively, and the values for a triple-pressure-levels advanced absorption cycle with a jet ejector are shown in Fig. 3b and 4b respectively.

As can be seen in Figure 3, the COPs of the triple-pressure-levels advanced absorption cycle with a jet ejector are higher than the COPs of the conventional single-stage absorption cycle and can be achieved at lower generator temperature, for all the evaporator temperature. The improvement in the COP is more significant as the evaporator temperature is lower and at the same operating conditions it is about 10-20%.

In term of the circulation ratio f, the values of f in the triple-pressure-levels advanced absorption cycle with a jet ejector are much lower than the values of f in the conventional single-stage absorption cycle, as can be seen in Figure 4. At the same operating conditions the reduction in the values of f can be up to 100%.

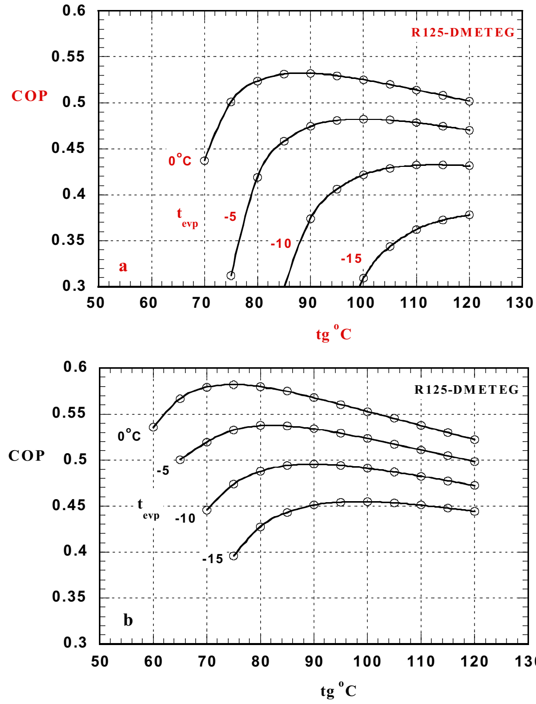

Figure 3: Variation of COP with generator temperature, (a) without a jet ejector and (b) with a jet ejector

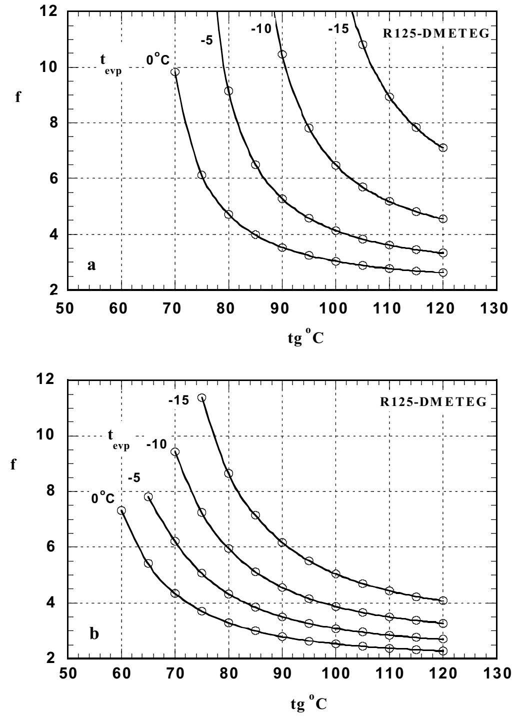

Figure 4: Variation of f with generator temperature, (a) without a jet ejector and (b) with a jet ejector

The generator temperature and the circulation ratio for maximum COP as a function of the evaporator temperature are given in table-1

For example, the influence of this pressure recovery on the performance of the triple-pressure-levels advanced absorption cycle with a jet ejector in compare with the conventional single-stage absorption cycle where $t_{evp}=-5\,^{o}C$, $t_{abs}=32^{o}C$ and $t_{con}=28^{o}C$ was examined. The increase of COP up to 28%, the decrease of f up to 50% and the rate of reduction in the heat transferred by the generator (Q/Q gen)* up to 1.25, absorber (Q/Q abs) up to 1.3 and solution heat exchanger (Q/Q hs) up to 2.4, as a function of the generator temperature in the range of 80-120 ^{o}C, are presented in Figure 5.

Keeping the absorber outlet condition and decreasing the evaporator pressure by the amount of the pressure recovery (case 2), enables achieving lower evaporator temperature. This reduction in the evaporator temperature, was predicted by the numerical simulations as a function of the generator temperature, while the COP, f and amount of heat transfer in the solution heat exchanger (as calculated for the conventional single-stage absorption cycle) were similar. The results of these calculations are shown in Figure 6.

In the third case, where the circulation ratio (as calculated for the conventional single-stage absorption cycle) remains constant, i.e. the same mass flow rate in the solution pump, the condenser and absorber temperature can be increased slightly at the same evaporator temperature. Practically it means that the temperature of the cooling water from the cooling tower can be higher.

2.3. Conclusion

The cycle analysis showed that in the first case, (same absorber outlet temperature and a higher absorber pressure) the COP was increased by 20%; the mass flow rate of the strong solution was reduced by 50%, and the amount of heat to be transferred in the solution heat exchanger was reduced by up to 3. In the second case, (keeping the absorber outlet pressure and temperature as a constant, results in lower evaporator pressure) the evaporator temperature could be lowered by -10°C. In the third way, the condenser and absorber temperature can be increased by several degrees C. It should be noted that these improvements are function of the operating conditions and the thermophysical properties of the working fluids.

3. ACKNOWLEDGMENTS

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Table-1. Generator temperature and circulation ratio at maximum COP as a function of the evaporator temperature.

	Triple-pressure-levels absorption cycle			Conventional single-stage absorption cycle		
t_{evp}	t_{gen}	COP	f	t_g	COP	f
0	75	0.58	3.7	87	0.53	3.8
-5	80	0.54	4.4	100	0.48	4.2
-10	90	0.49	4.6	110	0.43	5.2
-15	98	0.45	5.2	>120		

t_{evp}, t_{gen} - ^{o}C

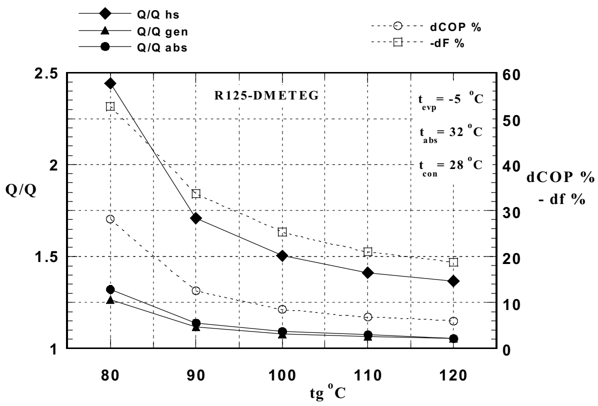

Figure 5: The increase of COP, the decrease of f and the rate of reduction in the heat transferred by the generator, absorber and solution heat exchanger as a function of the generator temperature where $t_{evp}=-5^{o}C$, $t_{abs}=32\ ^{o}C$ and $t_{con}=28\ ^{o}C$, and (Q/Q)=(Qconventional/Qtriple).

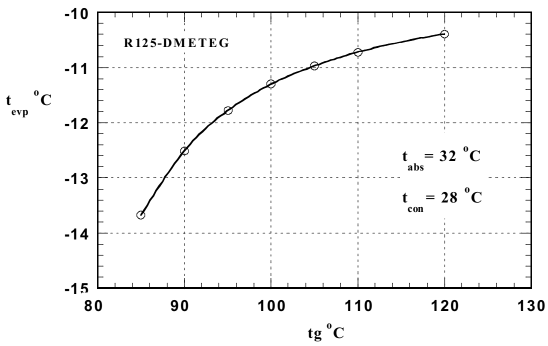

Figure 6. Evaporator temperature as a function of the generator temperature while the values of COP, f and Q_{HS} of a common single-stage absorption cycle were similar.

* Q/Q - The ratio of the heat transferred by a component in a conventional single-stage absorption cycle to the heat transferred by the same component in a triple-pressure-levels absorption cycle.

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5. NOMENCLATURE

COP - Coefficient of performance
f - Circulation ratio
t - Temperature

Subscripts

abs - Absorber
con - Condenser
evp - Evaporator
gen - Generator

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PERFORMANCES DUN CYCLE DABSORPTION A TRIPLE NIVEAU DE PRESSION

RESUME

Dans le cycle monoétagé a trois niveaux de pression développe, un éjecteur a jet dessine spécialement est ajoute a l'entrée de l'absorbeur. L'appareil rempli deux importantes fonctions: il facilite la récupération de la pression et améliore le processus du mélange entre la solution pauvre et la vapeur du calorigéne provenant de l'évaporateur. Ces effets accroissent le processus d'absorption de la vapeur du calorigéne dans les gouttes de solution. Pour le dessin d'un éjecteur a jet pour les machines a absorption, un modèle numérique de transfer simultané de chaleur et masse entre les phases liquide et gazeuse a été développe. Le calorigéne R125 et l'absorbent DMETEG ont été utilises dans ces calculs.
Sur la base du programme de simulation pour ordinateur, une étude paramétrique du cycle d'absorption monoétagé a trois niveaux de pression a été conduite. L'influence de l'éjecteur a jet sur la performance du cycle d'absorption a été étudie.

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