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Numerical investigation of single effect absorption ejector cycle

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Abstract:

This paper presents a numerical model of a single-effect ejector-absorption refrigeration cycles working with NH3/LiNO3 and NH3/NaSCN as working fluid, operating under steady-state conditions.
The gas–gas ejector, ejector between condenser and generator, entrains refrigerant vapor from the evaporator.
A computer simulation program was developed for the combined cycle and used to examine the influence of various operating parameters (generator, condenser and evaporator temperatures) on performance and to compare it with single effect cycles. Optimum operating conditions and ejector design data are also provided. The results show that the combined cycle provides potentially high *COP* that reach 1.4 higher than that of the conventional absorption machine for refrigeration and air-conditioning.

Keywords:
Single-effect Absorption Refrigeration System, Combined Ejector-Absorption, COP, Simulations, NH3/LiNO3, NH3/NaSCN.

1. Introduction

Conventional absorption cycles for cooling systems represent an alternative to predominant compressor refrigerating cycles by using low grade thermal energy (solar thermal energy, waste heat from industrial processes) to save energy. Absorption technology leads so to a reduction in carbon dioxide emissions. Further, this cold production technique uses natural refrigerants (commonly H2O/LiBr and NH3/H2O) with less or no harmful impact on the environment.
However, these working fluid systems have some drawbacks: crystallization of the salt in the water/LiBr installations and the need for rectification to separate the refrigerant and the solvent associated at high generator temperatures (180-220°C) for the NH3/H2O system. The search for new working fluids with better thermodynamic properties is an actual research objective. The ammonia-salt mixtures NH3/LiNO3 and NH3/NaSCN appear as interesting alternatives. Their properties have been experimentally investigated and the data regressed in form of correlations by different authors [1-3]. These fluid mixtures present the important advantage of no need for vapour purification. Performance evaluations of cooling systems operating with these mixtures had been performed in the last decades.
Sun [4] and Dehu et al. [6] compared the performances of NH3/H2O, NH3/NaSCN, NH3/LiNO3 absorption cooling cycles and concluded that they do better than the water/ammonia system. However, the COP (Coefficient Of Performance) of the absorption cycles working with these fluid mixtures is in general lower in comparison to that of the vapour compression refrigeration machines. In order to improve the performances of the absorption cooling, the incorporation of ejectors as components in so-called ejector combined cycles is now

discussed. Various authors studied the combination of the ejector with absorption cooling systems for different working fluids and cycle configurations. They generally concluded that the combined cycle provided higher COP.

Sun et al. [7] studied theoretically a combined refrigeration model cycle using H2O/LiBr as working fluid for variable geometries of ejector; they concluded that the COP of the novel cycle is higher as compared to the conventional cycle for refrigeration as well as for air-conditioning.
Aphornratana et al. [8] built a three-pressure combined ejector-absorption refrigeration machine and showed that the COP of the three-pressure configuration is 30-60% higher than the COP of the basic absorption cycle and reaches the COP of small commercial double-effect absorption systems.
Jiang et al. [9] compared also the coefficient of performance of combined ejector-absorption refrigeration systems and small double-effect absorption refrigerators using H2O/LiBr. They found that the COP of the combined absorption-ejector system is up to 0.9-1.0, just slightly lower than that of the commercial double-effect absorption systems.
Sirwan et al. [10] carried out a theoretical study on a combined absorption-ejector cooling system using aqua-ammonia. The design configuration is modified by adding a flash tank between ejector and evaporator. They developed a computer program to analyse the effect of the flash tank on the entertainment ratio.
In the present paper, a simulation program based on Sun ejector theory is developed to simulate the behaviour of the ejector and to determine the performance of the ejector combined system for various generator, condenser and evaporator temperatures. The predicted performances are to be compared to those of conventional cycles working at the same temperature levels.

2. System description

The combined cycle is same like an basic absorption cycle whereas an ejector is added in between the generator and the condenser. Figure 1 presents a schematic representation of the studied refrigeration machine. The basic working principle of the system is represented as follows. In the generator, the working fluid pair salt-solution (NH3/LiNO3 or NH3/NaSCN) is heated by an external heat source, Qg is provided, to produce vapor as refrigerant and separate it from the solution. The produced refrigerant vapour is at high-pressure (ammonia) is introduced in the ejector as primary flow. The flux vapours coming from the evaporator as secondary flow are entrained by the primary flow into the ejector, mixed together in the mixing chamber and later compressed in the diffuser before entering to the condenser. In the condenser the vapours are condensed by rejecting the heat Qcond to the environment. The produced liquid ammonia expands then through an adiabatic expansion valve and flows to the evaporator where it is evaporated by producing the desired cooling capacity Qevp.

In a conventional basic cycle the entire refrigerant vapour (ammonia) exiting the evaporator passes into the absorber. In the combined novel cycle, a fraction of the vapour is sucked into the ejector as a secondary flow. The rest of the vapour enters in the absorber where it is dissolved in the salt solution coming back from the generator via the solution heat exchanger and the expansion device. The absorption heat Qabs is rejected into the environment. By the end, the refrigerant solution exiting the absorber is pumped back to the generator.

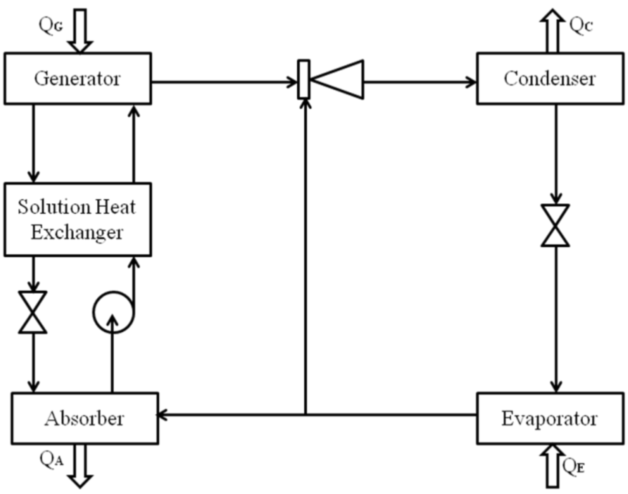

Fig.1 Schematic presentation of a single-effect combined absorption-ejector cooling system

3. Model and methods

3.1. Description of the ejector

The ejector is the key component in the ejector absorption refrigeration cycle. Usually, a steam ejector composed from four principal parts, the primary nozzle (also named motive nozzle), the suction chamber, the mixing chamber (consists of a convergent duct and a constant-area throat tube) and the subsonic diffuser.

Normally the primary nozzle is a convergent–divergent nozzle where high pressure primary fluid expands and accelerates, creating a very low pressure region at the nozzle exit plane. The secondary flow is entrained inside andinto the mixing chamber.

By the end of the mixing chamber, the combined two streams are assumed to becompletely mixed at a uniform pressure.Due to the existence of a high pressure area downstream of the mixing chamber throat, the mixed stream undergoes a succession of normal shock waves within the constant-area section: the pressure rises, and a compression effect is created.

3.2. Ejector model

The ejector performance is correlated to the entrainment ratio. To predict the ejector performance, the complicated flow and mixing problems within the ejector must be solved mathematically. Current modelling uses the ejector theory proposed mainly by Sun and others [7-11]. This ejector analysis is based on following assumptions:

- Primary fluid expands isentropically in nozzle, and mixture of primary and secondary fluid compresses isentropically in diffuser.
- Inlet velocities of primary and entrained fluids are insignificant.
- Velocity of the compressed mixture at ejector outlet is neglected.
- Mixing of primary and secondary fluids in the suction chamber occur at constant pressure.
- Flow in ejector is adiabatic.
- Isentropic efficiencies take into account of friction losses in nozzle and diffuser.
- Primary and the secondary fluids have comparable molecular weights and ratios of specific heats.
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3.3. Machine model

Sun study [7] shows that the performance of an ejector-absorption refrigeration cycle is mainly affected by the ejector design. In order to evaluate the performancesof the actual cycle, the thermodynamic properties (pressure, concentration, enthalpy, temperature and density) for both gas and liquid phases are required. In this work, the equations derived by Sun [4] for the binary mixtures of sodium thiocyanate–ammonia and lithium nitrate–ammonia as well as for pure ammonia are used.

Following assumptions are considered for the machine model:

- NH_3/NaSCN and $NH_3/LiNO_3$ solutions in the generator and absorber are in saturated state at the respective pressure and temperature.
- Ammonia in ejector, condenser and evaporator is pure and saturated.
- Thermodynamic properties of non-equilibrium solution have the same values as the equilibrium properties for the same temperature and concentration.
- Pressure losses due to friction in ducts and heat exchangers are neglected.
- The system is used to produce chilled water (7-12°C) for air-conditioning applications.

A simulation model has been developed by formulating the mass and energy balances for every component of the machine, associated with the thermodynamic properties model and the operating conditions and assumptions. A computer simulation program is worked out using the EES (Equation Engineering Solver, F-Chart)software [11] to analyse the proposed combined cycle. Given the operating conditions and the cooling load, the software predicts the system and ejector performances.

NH_3/NaSCN and $NH_3/LiNO_3$are considered in the current study. We set for the nozzle and diffuser efficiencies $\eta_n = 0.85$ and $\eta_d = 0.85$, respectively and for the solution heat exchanger effectiveness $E_{ex} = 80\%$.

4. Results and discussion

Our simulation model is first validated by comparing our results for a H2O/LiBr combined absorption cooling system with the results of Ref. [7] for the same system. Next we investigated the effect of generator and condenser temperatures on the performances of the ejector and the cycle.

4.1. Effect of the generator temperature

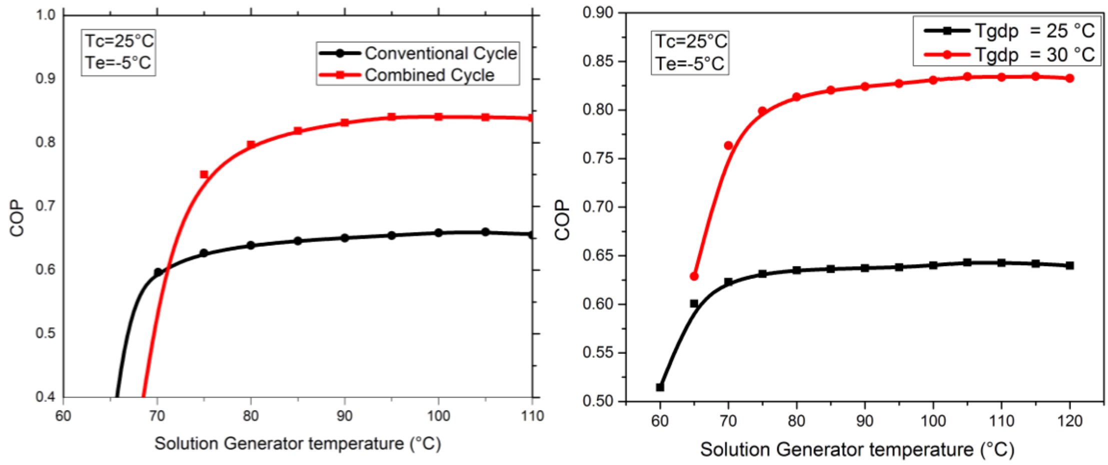

Fig.2 Variation of the COP with generating temperature T: (A) NH3/NaSCN, (B) NH3/LiNO3

Figs. 2 A and 2 B show the effect of the generator temperature on the *COP*, for a basic (without ejector) and a combined (with ejector) cycle. As can be seen the *COP* of the basic cycle increases sharply and reaches a constant value of 0.6-0.7. The *COP* of the combined starts to increase at higher generator temperatures but reaches higher *COP* values (in the order of 0.8 to 0.85). The thiocianate system seems to reach higher values of *COP* for the same operating condition than the nitrate system.

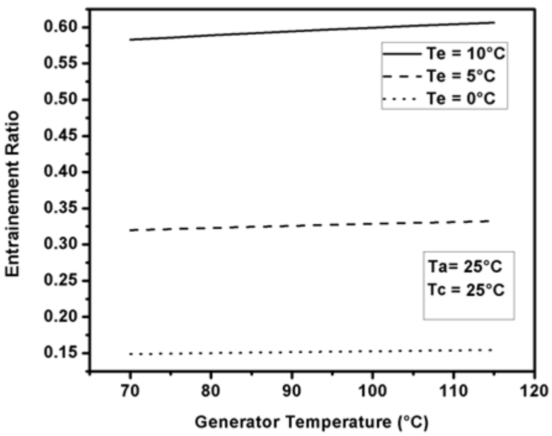

Fig.3 Variation of the entrainment ratio with generator temperature: identical curves for both fluid systems

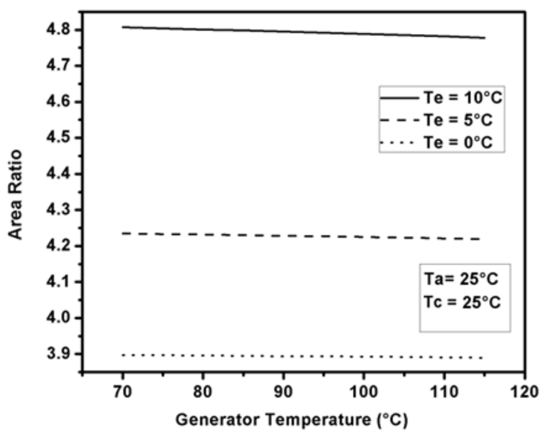

Fig.4 Variation of area ratio with generator temperature: identical curves for both fluid systems

In Fi.4 is represented the evolution of the area ratio (ratio of nozzle section and the mixing chamber section) with the generator temperature. It is shown that the area ratio is unaffected by the generator temperature but largely influenced by the evaporator temperature. For both mixtures the entrainment and area ratios are identical for the same operating conditions.

The variation of the entrainment ratio (the ratio of the secondary and the primary flow) with the generator temperature is depicted in Fig. 3. The entrained ration is less influenced by the generator temperature but is dramatically affected by the evaporator temperature: it varies from 0.15 to 0.32 to 0.57 for respective evaporator temperature of 0°C, 5°C and 10°C.

4.2.Effect of the condenser temperature

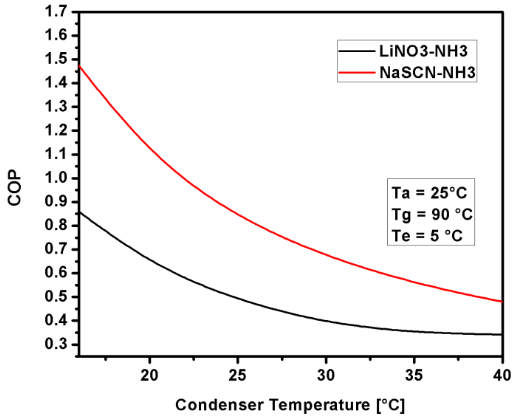

Fig.5 Variation of *COP* with the condenser temperature for both systems NH_3/NaSCN, $NH_3/LiNO_3$

Fig.5shows that the *COP* decreases with the condenser temperature and increases with evaporator temperature because the entrainment ratio increases with the evaporator temperature as is shown in Fig.6.

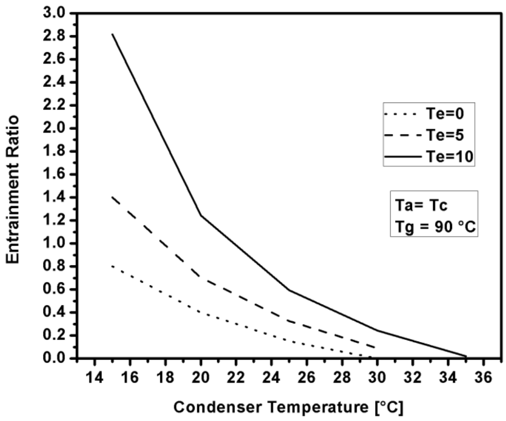

Fig.6 Variation of the entrainment ratio with condenser temperature: identical curves for both fluid systems

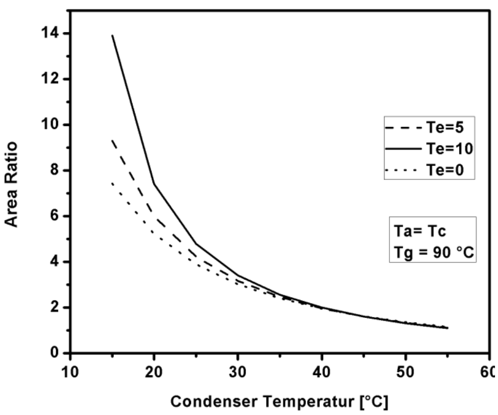

Fig.7 Variation of area ratio with condenser temperature: identical curves for both fluid systems

Fig.7shows the variation of area ratio with condenser and evaporator temperatures. The ejector parameters (entrainment ratio ad area ratio) are same for both working fluids at same operating conditions. The area ratio decreases with condenser temperature and increases with evaporator temperature.

5. Conclusion

Two combined ejector absorption cyclesare consideredusing respectively NH_3/NaSCN and $NH_3/LiNO_3$as working fluids. The numerical simulations show that the combined ejector cycle is advantageous with an improvement of 20–40% of the *COP* in comparison to the conventional single-effect absorption machine.

As a result, under normal operating conditions, the performance of the combined cycle is superior to that of a single effect cycle, despite the fact that the latter is generally operated at higher temperatures of the driving heat source.

The performance of the combined cycle could be further enhanced by operating under higher generator temperatures and pressures and by optimizing the design of the ejector.

6. References

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