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Simulation and comparison of combined ejector-absorption and single effect absorption refrigeration systems

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Abstract. Refrigeration by absorption is gaining more and more importance nowadays especially in applications where the source of energy used in the generator is renewable. However the major problem of this type of refrigeration lies in the COP, which seems to be weaker than compression machines. The use of an ejector is one of the means that can help overcome this problem. In this work, we are interested in the ammonia-water absorption cycle comprising a gas-gas ejector interposed between the generator and the condenser. We suppose that adding a flash tank between the condenser and the evaporator could help improve the entrainment ratio of the ejector. Simulations using the Hysys software are performed in order to look for the optimal conditions for the work of this machine and to make a comparison in terms of performance with single effect cycles. Results showed a significant improvement in the COP and proved therefore that it has better performance than single effect cycles.

1 Introduction

The artificial production of cold relies mainly on mechanical vapor compression refrigeration machines which have a negative effect on the environment. To overcome this problem we find new ways to achieve energy efficient systems while having a low environmental impact. In this context, the absorption technology for refrigeration is generating great interest due to the fact that the source of energy used in the generator is renewable. This technology uses as working fluids solutions that incorporate natural refrigerants; the most common are H2O–LiBr and NH3–H2O.

Therefore, several researches are carried out to improve the performances of these machines through combining them, for example, with the technology of the ejectors. Sun [2] studied this cycle working with the LiBr-H2O couple, he compared it to that of the single-effect cycle and he noticed a considerable improvement of the COP. Alexis [3] carried out an analytical study using two simple models to characterize the performances of an ejector system used for air conditioning, Chen [4] examined a combined cycle with R22 / DME-TEG and he showed that there is an improvement in COP compared to the conventional cycle, especially at lower generator temperatures. R. Sirwan [5] studied the improvement of the ejector cycle by adding a vapor-liquid separator after the refrigerant expander and booster. He mentioned that there is a great improvement in the performance of this cycle.

In this work, we are interested in the ammonia-water absorption cycle comprising a gas-gas ejector interposed between the generator and the condenser. We suppose that adding a flash tank between the condenser and the evaporator could help improve the entrainment ratio of the ejector.

2 Analysis and modelling

2.1 Description of absorption systems Single effect

The absorption machine uses a binary mixture; one fluid is more volatile than the other and constitutes the refrigerant. In this case, ammonia is the refrigerant and water is the absorbent. We describe the operating principle of the absorption machine in the different elements as it is shown in figure 1, [2]:
-Absorber: The vapor produced in the evaporator is absorbed by the refrigerant-poor solution, this absorption is carried out with an increase temperature and while pressure stays almost the same (Absorber pressure = Evaporator pressure)
-Pump: It is used to lead the rich solution from low pressure (BP) to high pressure (HP)
- Exchanger: The rich solution is preheated by the poor solution coming from the generator
-Generator: The rich solution (1) enters the generator where it is heated to the boiling temperature of the refrigerant.
-Condenser: the vapor of the refrigerant produced (2) is discharged to the condenser where it is condensed
- Expansion valve: is used to pass the condensed fluid (3) from HP to BP this is accompanied by a cooling of the liquid refrigerant and a partial vaporization.
-Evaporator: The remainder of the liquid refrigerant is evaporated in the evaporator usually at constant

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temperature by absorbing a quantity of heat from the cold source.Returning to the cycle of thermal compression, the poor solution produced in the generator is cooled in the exchanger (7-8) then it is expanded (8-9) before going to the absorber and the cycle is repeated.
The absorption cycle analysis is based on the following assumptions:
- Pressure drops and heat losses are neglected.
- Expansion is supposed to be isenthalpic

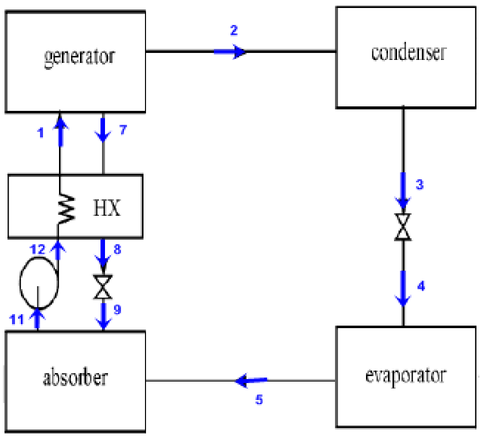

Fig 1: Schematic representation of absorption cycle.

The COP of the cycle can be calculated by the following equation:

$$COP = \frac{Q_e}{Q_g + W_p} \quad (1)$$

With Qev: The heat exchanged in the evaporator
Qg: The heat exchanged in the generator
Wp: Pump work

2.2 Oldham diagram

The refrigeration cycle is shown in the Oldham diagram that is the most used and most convenient for the absorption machine study. As shown in fig.2, the x-axis is scaled in (1/T) and the y-axis in (Log P), on which we can draw the iso-titles of the solution. [5], the straight line with 100% of concentration corresponds to the vapor-liquid equilibrium of pure ammonia, and the one with 0% of concentration corresponds to vapor-liquid equilibrium of pure water.
The absorption machine is supposed to function according to the following operating conditions:
Low pressure: Pe =327 kPa (the pressure of the evaporator).

- High pressure: Pc =1167 kPa (the pressure of the condenser).
- The temperature of the generator = 103 ° C.
- The temperature of the absorber = 25 ° C.

By fixing evaporation and condensation pressures (Pe=327 kPa, Pc=1167kPa), the points of intersection with the iso-titration curves corresponding to 99% of NH3 represent the evaporator and the condenser then we draw the verticals which can read the corresponding temperatures (Te= -1°C ,Tc=30°C) on the diagram . The generator operates at the same pressure as the condenser. Knowing the generator's temperature, in this example it is taken as 103 ° C, it proceeds in the same way by raising the vertical up to the intersection with the high pressure Pc. The point of intersection therefore represents the output of the generator. This point belongs to the constant concentration (xp = 0.34) where xp is the composition of the poor solution leaving the generator.
The absorber operates at the same pressure as the evaporator. By raising the vertical line corresponding to the absorption temperature (Ta = 25°C), the intersection point obtained thus characterizing the absorber allows to read on the diagram the composition (xr =0.52) of the rich solution. The intersection of the rich solution line and the isobaric at condenser pressure indicates the threshold temperature (Ts).
The threshold temperature (Ts) is the minimum temperature of the generator, below which the installation does not work, we see that (Ts = 68.14°C). The Oldham diagram leads to the results shown in Table 1.

Table 1: The values of temperature, pressure and mass fraction during the discharge phase.

Points	3	5	7	11
T (°C)	30	-1	103	25
P (kPa)	1167	327	1167	327
x_{NH3}(%)	100	100	34	52
x_{H2O}(%)	0	0	66	48

2.3 Description of ejector-absorption combined systems

The ejector is a static device based on the effect of Venturi that uses the kinetic energy of a drive fluid, injected under pressure by a convergent or convergent-divergent nozzle into a lower pressure zone, to suck and drive a secondary fluid at low pressure and to compress the mixed flow thus obtained at the desired intermediate pressure.

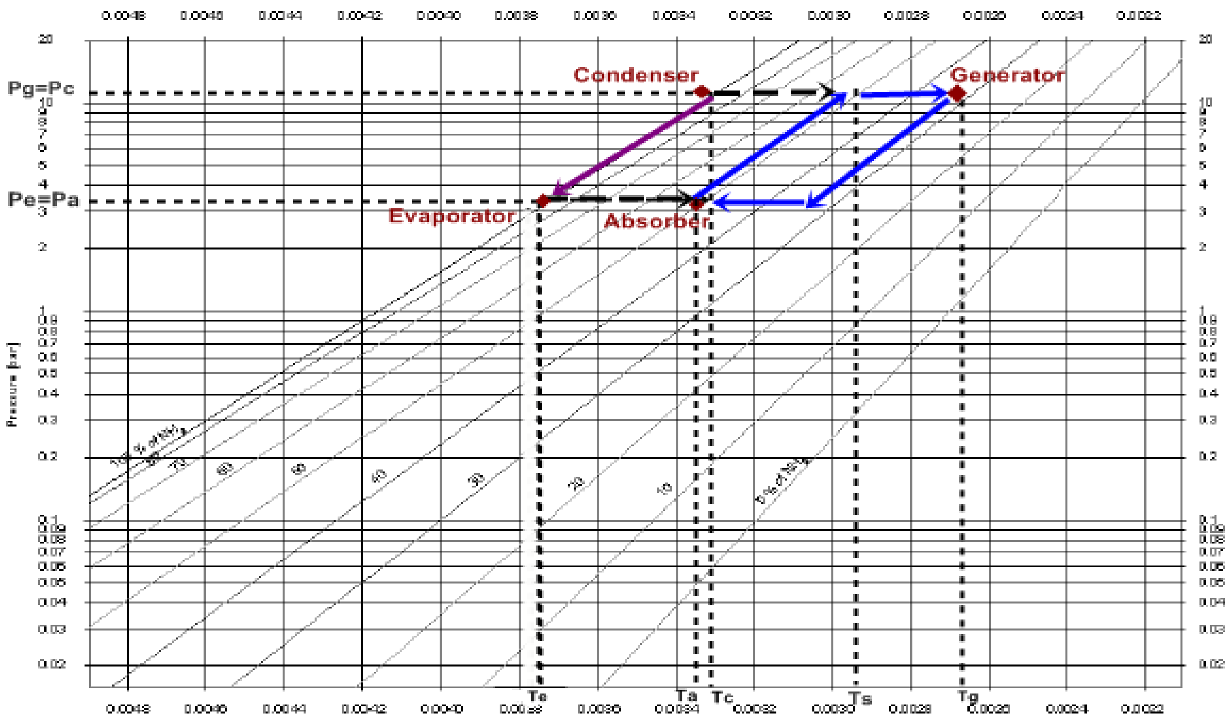

Fig 2: Representation of the refrigeration cycle on the Oldham

In this configuration, the ejector, when placed between the generator and the condenser, will suck up a quantity of vapor of the refrigerant coming from the flash tank. We suppose that adding a flash tank between the condenser and the evaporator could help improve entrainment ratio of the ejector. The combined cycle ejector-absorption is shown in figure 3.

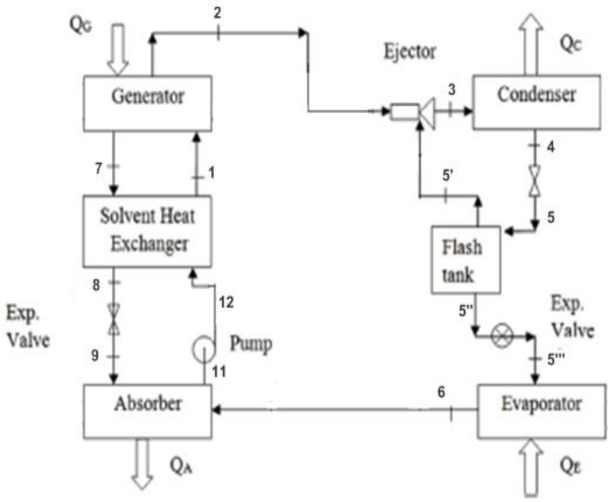

Fig 3: The combined ejector-absorption cycle

Working method

Our analysis is based on the integral method [6].This method is based on a one-dimensional model of the isentropic flow of ideal gases. It considers the characteristics of the driving and induced fluids at the mixing chamber inlet and the characteristics of the mixture at the mixing chamber exit.

Figure 4 is specifying the notations at the various points of the ejector.

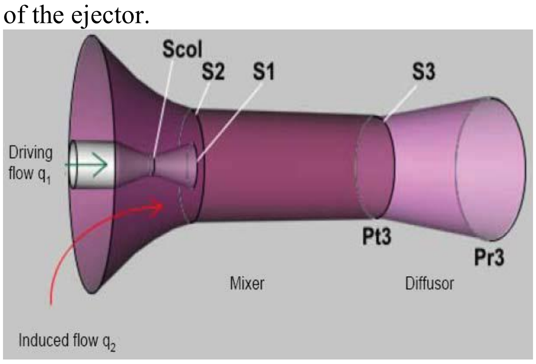

Fig 4: Diagram of the studied ejector specifying the notations at the various points

To determine the outlet pressure Pr3, firstly we specify the pressure P1 of the motive fluid and P2 of the induced fluid, the associated total temperatures T1, T2, the entrainment ratio q2/q1 (driving flow/induced flow), (figure 4).

According to the following equation we can determine the pressure at the exit of the ejector:

$$\frac{P_{r3}^{\frac{\gamma_3-1}{\gamma_3}} - P_2^{\frac{\gamma_2-1}{\gamma_2}}}{P_1^{\frac{\gamma_1-1}{\gamma_1}} - P_{r3}^{\frac{\gamma_3-1}{\gamma_3}}}\left(\frac{P_1^{\frac{\gamma_1-1}{\gamma_1}}}{P_2^{\frac{\gamma_2-1}{\gamma_2}}}\right) = f\left(\frac{q_2}{q_1}\sqrt{\frac{r_2T_2\gamma_1}{r_1T_1\gamma_2}}\right) \quad (2)$$

After simplifying this equation, we obtain:

$$P_{r3} = \left(\frac{P_1^{\frac{\gamma_1-1}{\gamma_1}}.Y + P_2^{\frac{\gamma_2-1}{\gamma_2}}.A}{A+Y}\right)^{\frac{\gamma_3}{\gamma_3-1}} \quad (3)$$

- The value of Pr3 is determined using a spreadsheet implemented in HYSYS and based on equations (2) and (3).

3 Results and discussion

3.1 Simulation of absorption systems Single effect

The work done in this section, is based on the modeling and simulation of the refrigeration machine using the Aspen-Hysys software which is an advanced flow-sheeting tool for process simulation. It has a rich library of model calculations of thermodynamic properties.
Figure 5 illustrates the absorption machine model in Aspen-Hysys. The temperatures obtained by the Oldham Diagram (Te= -1°C, Tc =30°C) are used for the simulation of the machine. Stated below in table 2 are the characteristics of the generator's inlet in 1.

Table 2: Characteristics of the generator's inlet

Parameters	Values
Temperature (°C)	67.7
Pressure (kPa)	1167
Mass Flowrate (kg/h)	213
x_{NH3} (%)	52
x_{H2O} (%)	48

The results of the Aspen-Hysys simulation are shown in Tables 3 and 4. The absorption refrigerating machine works correctly according to the operating parameters presented in the following table.

Table 3: Main simulation results

Stream	1	3	5	7	11
Temperature(°C)	40.98	30	-1	103.6	24.6
Pressure(kPa)	1167	1167	327	1167	327
x_{NH3}(%)	99.93	99.93	99.93	33.38	52
x_{H2O}(%)	0.07	0.07	0.07	66.62	42
Mass flowrate (kg/h)	57.98	57.98	57.98	155	224

Upon comparing the pressure and fractions results given by the Oldham diagram and the results obtained using Hysys (Table 3), we notice that we get almost the same values of temperature, pressure and composition. This means that the results by Hysys are accurate. Hence, this simulation can be used to study the effect of various operating parameters on the efficiency of the absorption machine.

Table 4: Main Heat loads

Main Heat loads	VALUES (kW)
Qev	18.19
Qg	28.16
Wp	0.08
COP	**0.64**

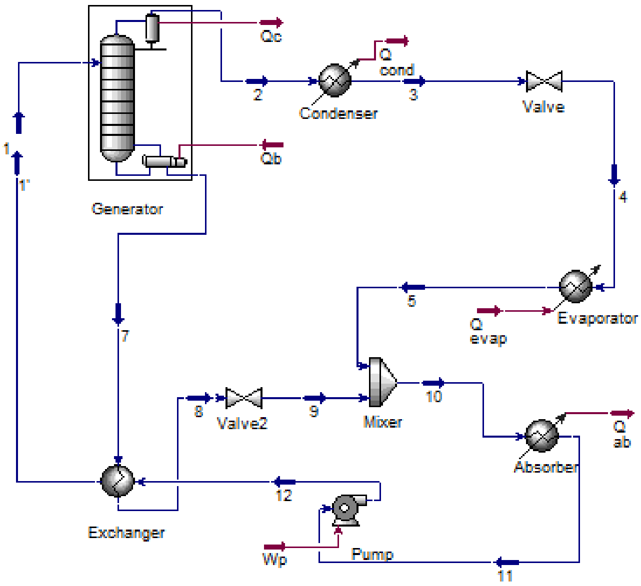

Fig 5: The absorption machine Single effect model in Aspen-Hysys

3.2 Simulation of ejector-absorption combined systems

Illustrated in figure 6 is the combined ejector-absorption machine model in Aspen-Hysys. Table 5 shows the ejector parameter given by Hysys.

Table 5: The ejector parameters

Parameters	values
P_1(kPa)	1167
P_2(kPa)	680
P_{r3}(kPa)	1130
T_1(°C)	40.98
T_2(°C)	12.96
T_3(°C)	29.28
q_1(kg/h)	57.98
q_2(kg/h)	3.55
q_3(kg/h)	61.53

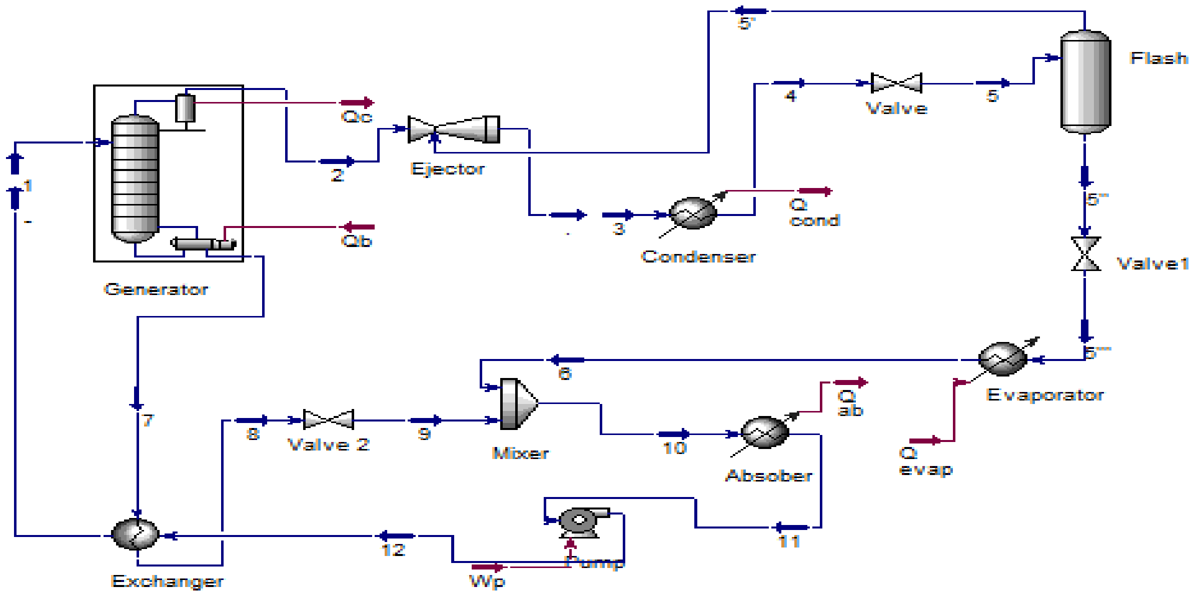

Fig 6: The model in Hysys

The results of the Aspen-Hysys simulation for the main components of this cycle are shown in Tables 6 and 7.

Table 6: Simulation results

Parameters	1	2	4	6	7	11
Temperature (°C)	67.7	40.98	25	-1	103	24.4
Pressure(kPa)	1167	1167	1130	327	1167	327
x_{NH3}(%)	52	99.93	99.93	99.94	33.4	58
x_{H2O} (%)	48	0.07	0.07	0.06	66.6	42
Mass flowrate (kg/h)	214.9	58.04	61.53	58.63	156.9	214.9

Table 7: Main Heat loads

Main Heat loads	VALUES (kW)
Qev	19.63
Qg	25.8
Wp	0.09
COP	0.76

The results of the simulation obtained by the present study, show that the use of an ejector increased the COP by up to 76%.

- Combining the ejector–flash tank with the single stage absorption cycle using NH3/H2O as the working fluid has shown considerable improvement in the COP.

Conclusions

This paper describes a refrigeration cycle using a gas-gas ejector to improve the performance of the absorption machine. A HYSYS simulation was conducted for the two different cycles and used to determine the performance of each system using NH3- H2O. This was shown an increase of the cooling capacity and the combined cycle provides potentially a COP of around of 76% higher than that of the single effect absorption cycle (COP= 64%).

Keywords

Refrigeration system, absorption machine, combined cycle, ammonia/water, simulation, COP.

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