A comparative study of two different refrigeration systems based on absorption cycle

Ouassila Larkeche[1]; Abdeslam-Hassen Meniai[2]
1: Process engineering faculty, Constantine 3 University, Constantine, Algeria, email: larkech_wassila @yahoo.fr
2: Process engineering faculty, Constantine 3 University, Constantine, Algeria, email:meniai@yahoo.fr

Abstract

Due to environmental concerns, new refrigerants are urgently needed and therefore energetically efficient and environmentally safe systems have to be developed.
Although the vapor absorption refrigeration cycle is quite old, it is still being widely used in many industrial applications, with still the two traditional systems, namely Water/Lithium Bromide and water/Ammonia, as the working pairs.
However, many research studies are based on the proposition and test of new refrigerant-absorbent pairs for the vapor-absorption cycle, as well as the corresponding adequate machines.
Consequently, in this work a new absorption refrigeration cycle based on phase separation has been studied, where new combinations refrigerant-absorbent have been tested.
The model is based on heat and mass balance equations in order to determine thermal efficiency of the cycle, trough the calculations of the coefficient of performance (COP). The relevant thermodynamic properties have been computed using group contribution methods. The obtained results are encouraging with, in some cases, reaching quite good values of the COP.
In conclusion, this new cycle is promising and can be regarded as an interesting alternative both, environmentally and energetically, mainly due to hardware savings i.e. absence of condenser.

Keywords: *Phase separation; Refrigeration cycle; Refrigerant; Absorbent; COP*

I. Introduction

Restrictions concerning the use of certain compounds as refrigerants are getting more and more severe because of their disastrous consequences towards the environment, particularly their potential to deplete the ozone layer. As an example, CFC's and HCFC's can be cited. Consequently, alternatives have to be developed and should provide similar benefits as the existing compounds being phased out. This has encouraged the use of certain machines such as those based on an absorption cycle, which should also be energetically efficient as well as being compatible with the proposed new compounds. Therefore, the problem can be regarded as involving the following two steps:

- Search for environmentally safe and efficient refrigerant compounds;
- Development of new, compatible and efficient machines or improvement of existing ones.

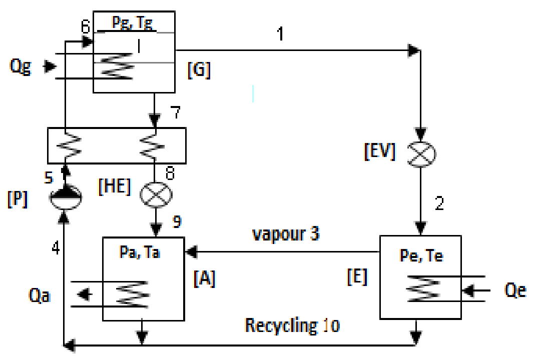
Generally, this is a complex problem due to the influence and interaction between various parameters such as:

- The reactivity towards the environment;
  - The physical properties of the compounds involved;
  - The thermodynamic properties;
  - The efficiency;
  - The compatibility with the machine.

Consequently, this work is a comparative study between two different machines, both based on absorption cycle, but presenting an important difference at the generator level. In fact, the first machine is based on the classical configuration including the usual items whereas in the second one, a condenser is avoided since the two-phase streams issuing from the generator are at a liquid state as described in the literature [1]. This is the major difference between the two machine types considered and this has not been subject to an extended study, a fact which has encouraged its further consideration in more details. The two machines are compared according to the two key parameters, namely the coefficient of performance (COP) and the circulation ratio (CR).

II. Description of the two refrigeration units

The classical configuration includes a condenser after the boiler whereas Figure 1 shows the refrigeration unit based on liquid phase separation where the phases are separated in the generator, as two liquid streams, just when the two phases region is reached, and one can see the absence of any condenser, prior to the evaporator unit and that is the main feature of this cycle. The two phases are



[G]: Generator; **[P]:** Pump; **[EV]:** Expansion valve; **[A]**: Absorber; **[E]**: Evaporator; **[HE]**: Heat Exchanger.

Figure1. Schematic Representation of the classical refrigeration absorption cycle using phase separation denoted by Phase I and Phase II and are rich and poor in refrigerant, respectively. Phase I **(point 1)** crosses and expansion valve **(point 2)** and goes into evaporator unit to provide the refrigeration effect the refrigeration effect. The vapour phase exiting from the evaporator **(point 3)** goes into the absorber to be absorbed by PhaseII coming out from the generator **(point 9)** whereas the solution from the evaporator is pumped back into the generator **(point 4).** A heat exchanger is incorporated between the generator and the absorption unit and operates counter-currently with PhaseII stream exiting the generator (**(point 7)** and the solution coming out of the absorption unit **(point 5).**

III. Thermodynamic analysis

3.1 the refrigeration cycle with phase separation

In the calculation concerning the refrigeration cycle with phase separation, the mixture flow rate as well as the state variables such as the pressure, temperature and the compositions at any point of the unit, particularly at the entry and exit of each compartment of the machine, have to be known. These will serve to compute the different enthalpies and energy fluxes involved in each part of the system to end up finally with the coefficient of performance of the machine (COP).

In this work, a model calculation is shown where a priori the candidate pair (refrigerant-absorbent) to be used in the refrigeration cycle with phase separation, has to be selected. A huge number of binary liquid pairs exhibit phase separation at reasonable temperatures, but the lower the value of the critical solution temperature (LCST), the better for the system performance. For the sake of illustration, four different system extracted from the literature [1], have been tested and where their common characteristic is that the LCST is just above 40 C. Namely these systems are (Benzyl Ethyl Amine + Glycerol), (Hexanoic acid + Water), (Hexanone + Water), and (Ethyl propionate + Water) and are denoted by A, B, C and D respectively.

3.2 Model hypotheses

To enable a thermodynamic study of the cycle, the proposed model has been based on a number of hypotheses similar to the ones reported in the literature [1, 2]

3.3 Calculation of coefficient of performance (COP) and computer experiments

A priori, heat and mass balances have to be performed over each essential part of the refrigeration unit *i.e.* the generator, the evaporator and the absorber and the results are summarized in the following table:

Table 2. Heat and mass balances

Item	Global mass balance	Individual mass balance	Heat balance
Generator	$m_6 = m_7 + m_1$	$m_6 .X_6 = m_7 .X_7 + m_1.X_1$	$m_6 .h_6 + Q_g = m_7 .h_7 + m_1 .h_1$
Evaporator	$m_2 = m_3 + m_{10}$	$m_2 .X_2 = m_3 .X_3 + m_{10}.X_{10}$	$m_2 .h_2 + Q_e = m_3 .h_3 + m_{10} .h_{10}$
absorber	$m_9 = m_3 + m_4$	$m_9 .X_9 + m_3 .X_3 = m_4.X_4$	$m_9 .h_9 + m_3 .h_3 = m_4 .h_4 + Q_a$
Notes	$m_7 = m_{II}$; $m_1 = m_I$; $X_1 = X_r$; $X_7 = X_P$; $h_1 = h_2$		

Referring to Figure 1, the COP can be expressed as follows:

$$COP = \frac{m_3 \cdot (h_3 - h_2) + m_{10} \cdot (h_{10} - h_2)}{m_7 \cdot (h_7 - h_6) + m_1 \cdot (h_1 - h_6)}$$

Computer simulations have been performed, like fixing the temperature in the evaporator and following the variation of the COP in terms of the generator temperature and this for the four systems considered. The results are presented in the following table as follows:

Table 3. Evolution of the COP in terms of the generator temperature

Generator temperature T_g (°C)	Temperature of the evaporator T_e [K]											
	T_e = 277.15				T_e =280.15				T_e=283.15			
	A	B	C	D	A	B	C	D	A	B	C	D
75	0.745	-	-	-	0.764	-	-	-	0.774	-	-	-
100	0.85	1.036	0.373	-	0.859	1.06	0.381	-	0.87	1.084	0.389	-
125	0.607	0.707	0.228	0.379	0.611	0.718	0.203	0.397	0.609	0.728	0.233	0.417
150	0.462	0.523	0.164	0.216	0.464	0.529	0.165	0.222	0.406	0.535	0.166	0.227
175	0.364	0.416	0.125	0.138	0.339	0.419	0.122	0.139	0.369	0.422	0.126	0.142

To be able to perform comparisons between the four pairs considered, as far as the cycle efficiency is concerned, the same conditions (temperature at the evaporator, temperature at the generator, heat exchanger efficiency, refrigeration power at the evaporator

Figure 2 shows the evolution of the COP, in function of generator temperature where one can see that the drop in the COP is the most pronounced in the case of [BEA+ Glycerol]. The four systems are classified in increasing order of efficiency as: 1. [H_2O + Hexanoic acid], 2. [BEA + Glycerol], 3. [H_2O+ Ethyl propionate] and 4. [H_2O + Hexanone]. This classification can be explained by the behaviour of the systems in the evaporator where the calculations have shown that the two systems [BEA+ Glycerol] and [H_2O+Hexanoic acid] are more volatile, compared to the two others [H_2O+ Ethyl propionate], [H_2O+Hexanone], causing a presence of the absorbent in the stream exiting the evaporator, a fact which influences its power and hence lower the COP.

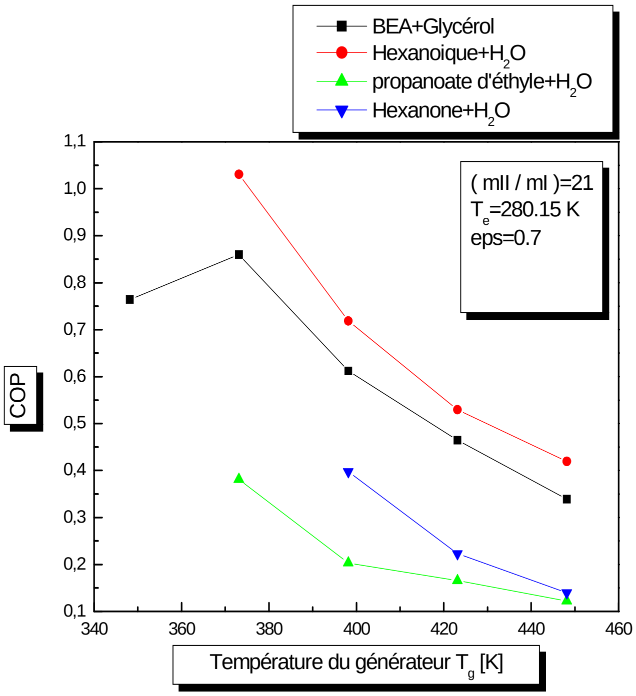


Figure2. Comparison between thermal efficiency of the considered systems

This is one major inconvenient mostly encountered in all types of absorption cycle, due to the fact that the produced refrigerant vapor contains appreciable amounts of the absorbent which reduces the evaporator power and hence the COP of the machine. This effect can be minimized by incorporating a rectification system at the expense of the overall cost [3].

Finally the results obtained from this study show that for fixed conditions, high values of the COP can be reached for the [BEA+ Glycerol] and [H_2O+Hexanoic acid] pairs. The values can even be considered as higher than the ones characterising the single effect cycle where the COP value is in the interval [0.5- 0.65] [1]. These two systems are quite suitable for this new configuration i.e. absorption cycle with phase separation. However other criteria must be considered such as the toxicity of the compounds involved, the compatibility with the machine, etc.

IV. Conclusion

In this study a refrigeration absorption cycle with a new configuration where the phases are separated as liquid streams, avoiding an extra condenser is tested theoretically. A thermodynamic analysis of this system has been performed by means of a model based on predictive group contribution methods and equation of states such as the Viriel Equation. Four different working fluid binaries have been tested and assessed according to machine COP. Interesting COP values have been obtained, although the UNIFAC model used has certain limitations. This approach can serve at least as a preliminary guide for any experimental work dealing with this type of machines. For instance for the absorption cycle with phase separation, working fluid should be selected according to the following points:

♦ A large miscibility curve for the binary system is desired with a LCST within the operating temperature range of the absorber, leading to a good separation in the generator;

♦Low values of activity coefficient to make easier the operation of absorption.

References

[1] M. Kernen, L. L. Lee, H. Perez- Blanco. A computer aided molecular design of fluids that optimize absorption cycle. Journal of energy resources technology, June (1995)

[2] Brahmanad Mohanty, Contribution à l'étude de la gestion optimale d'énergie solaire en vue de la production de froid par cycle à absorption. Thèse (1985).

[3] D. Seher, G. Holldroff, A. Aegerter. Les pompes à chaleur à absorption, Recherche, développement et perspectives. Edition Pyc. Paris (1983)