Energy Performances of Various (HFC-Organic Absorbents) Pairs in an Absorption Refrigeration System Using Geothermal Energy

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***Abstract*— the aim of this work was to study the possibility of using geothermal energy to supply vapour absorption refrigeration system. The geothermal temperature source that used have temperatures ranging between 55 and 95°C. While (R245fa-DMF), (R32-DMAC) and (R134a-DMETEG) are used as refrigerant-absorbent pairs. In the first step, P-T-X curves has been constructed. In the second step the machine studied in the following conditions, the ambient temperature was between 30 and 40 ° C, the evaporator temperature between 2 and 20 ° C, 10kW for evaporator capacity and 0.8 for effectiveness of solution heat exchanger (SHX). The performances of the studied working pairs is compared in terms of the coefficient of performance (COP) and circulation ratio. For the proposed conditions, the result of this theoretical study show that the values of the COP for the three mixtures is between (0.2-0.6) and the coefficient of performance of this system is quite high, however, high temperature of the geothermal sources.**

***Keywords*— geothermal energy; vapour absorption refrigeration system; coefficient of performance; Organic Absorbents.**

I. Introduction

The easiest material air conditioning and refrigeration systems consume a large amount of electrical energy. A great tow advantages of absorption cooling systems, they used thermal energy, and not use atmosphere-harming halogenated refrigerants CFCs. These properties allows these systems economically attractive and acceptable in terms environmental. At a time when thermal energy of geothermal sources, solar energy and heat from plants is lost. Therefore, absorption systems are a good alternative to the traditional air conditioning systems. Absorption refrigeration systems belong to the class of vapor cycles, similar to vapor compression refrigeration systems [1]. [2] Studied experimentally the absorption refrigeration system with geothermal energy, [3] presented a possibility application of a large-scale geothermal absorption air-conditioning system to provide base load cooling to the main campus of the University of Western Australia.[4] Describes the experimental studies of an ammonia/lithium nitrate absorption cooler operated on low of geothermal energy. This prototype was successfully operated with generator temperatures from 90 to 145°C and with cold chamber temperatures from zero to -10°C. [5] showed experimentally that an ammonia/water absorption cooler can be successfully operated using low enthalpy geothermal heat, the unit has operated successfully with generator temperatures as low as 91°C and with cooling chamber temperatures down to -5°C. This group tested other prototype of ammonia/water absorption cooler was installed in the Cerro Prieto geothermal field, where the ambient temperatures exceed 40°C and the cooling water temperatures reach 30°C [6].

The major working pairs used in the absorption refrigeration systems are H_2O-LiBr and NH_3-H_2O, but they both present advantages and disadvantages. These two systems are studied theoretically and experimentally in many works. Now the research is focused on the study and development of new cycles and new working fluids pairs. [7] Study the performance of the absorber DMF with different refrigerants (R22, R134a, and R32) in single-stage absorption refrigeration system at low generating temperatures. [8] Explained a thermodynamic design data for absorption heat pump system operating on water - lithium chloride. [9]

Presented a complete review of working fluids of absorption cycles. Performance of an absorption cycle is critically dependent on the thermodynamic properties of working fluids [10], in this regard, [11] measured experimentally the P-T-X behavior of R22 with five different absorbents in the temperature range 0-100°C and mole fraction range 0.05-0.95 of R22. These authors [12] investigated new refrigerant-absorbent combinations for use in absorption refrigeration system. [13] gave the measurements of thermo physical properties of the (water + lithium bromide + potassium acetate) system.

This paper presents the possibility of using absorption machine at different geothermal energy resources in the north of Algeria. Three (refrigerant / absorbent) are investigated in this study, (R245fa-DMF), (R32-DMAC) and (R134a-DMETEG). The curves of temperature-pressure-concentration has been plotted using UNIFAC model and these plots are used in analyzing the absorption cycles. Heat and mass balance for the cycle has been done. The performances of the studied working pairs is compared in terms of the coefficient of performance (COP) and circulation ratio.

II. Geothermal Resources in Algeria

Geothermal energy is the thermal energy within the earth's crust, thermal energy in rock and fluid [14]. In the geothermal applications, the classification depends on the temperature of resources (high temperature, intermediate temperature and low temperature). This energy is used to generate electricity and for direct uses such as space heating and cooling, industrial processes, and greenhouse heating [15]. In Algeria, calcareous rocks, sandy limestone and sandstones of Mesozoic age constitute the main geothermal reservoirs; the temperature of waters varies from 22°C to 98°C [16]. More than 240 hot springs and hot water wells recorded in the North of Algeria. The temperatures were used illustrates in the table 1[17]. Balneology is the principal utilization of geothermal waters in Algeria [16] and greenhouse heating, but the use of this energy in cold applications or air conditioning (absorption refrigeration system) remains an area for further research.

TABLE I
Temperatures of Geothermal Resources Using in this Study

Reservoir	Temperature (°C)
Chealla	94.3
Bidan	77.5
Ben Hachani	72
Sidi Trad	60
Ouled Ali	56.5

III. Absorption Refrigeration Systems

Absorption refrigeration systems belong to the class of vapor cycles, similar to vapor compression refrigeration systems; the required input to absorption systems is in the form of heat. Hence, these systems are also called as heat operated or thermal energy driven systems.

This system contains a generator, an absorber, a condenser, an evaporator, a pump, tow expansion valves, and solution heat exchanger, as shown schematically in Fig1.

In the condenser like in the traditional, condenser of the vapor compression cycle, the refrigerant enters the condenser (point 1) at high pressure and temperature of generator and it is condensed.

After refrigerant exits the condenser (point 2), the refrigerant passes through the expansion valve (2, 3), its pressure and temperature reduces suddenly. This latter then enters the evaporator.

The refrigerant at very low pressure and temperature enters the evaporator, produces the cooling effect, and flows to the absorber that acts as the suction part of the refrigeration cycle. The absorber is a sort of vessel consisting of water that acts as the absorbent, and the previous absorbed refrigerant. Thus, the absorber consists of the weak solution of the refrigerant and absorbent. When refrigerant from the evaporator enters the absorber, the absorbent due to which the pressure inside the absorber reduces further leading to more flow of the refrigerant from the evaporator to the absorber absorbs it. At high temperature, absorbent absorbs lesser refrigerant; hence, the external coolant to increase the refrigerant absorption capacity [18] cools it. When the absorbent absorbs the refrigerant strong solution of refrigerant-absorbent is formed. The pump at high pressure to the generator pumps this solution. Thus, pump increases the pressure of the solution to about 10 bar. Solution increases, the refrigerant in the solution is vaporized and it leaves the solution at high pressure. The high pressure and the high temperature refrigerant then enters the condenser [18]. In addition, the cycle repeats.

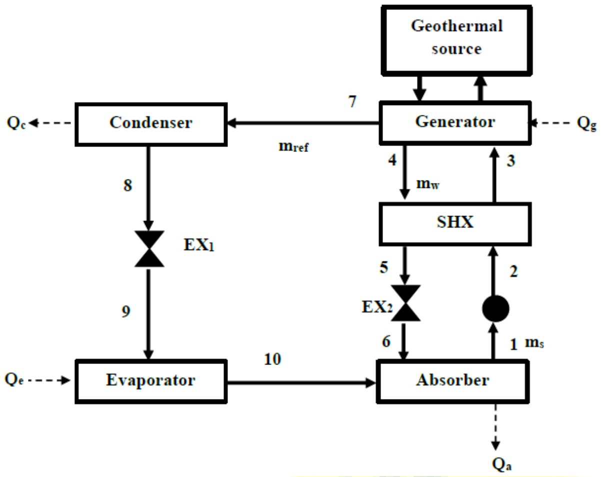

Fig. 1 Schematic of absorption refrigeration cycle powered by geothermal energy.

IV. Properties of Refrigerant/ Absorbent Used in Absorption Cycles

The performance of a absorption system is substantially dependent of physic chemical and thermodynamic properties of the fluids [15, 16]. Therefore, the combination refrigerant / absorbent must meet certain characteristics [17] such that:

- A large difference between the boiling point of the pure refrigerant and the absorbent.
- The concentration of the refrigerant in the mixture should be sufficiently wide as possible.
- The heat of vaporization of the refrigerant to be high.
- The transport properties (viscosity, thermal conductivity, diffusivity) must be favorable.
- The mixture must be chemically stable, non-toxic and non-explosive. It must also be non-corrosive and less costly.

In this study, different mixtures made calculations are:

R245fa /DMF

R32/ DMAC

R134a/DMETEG

The advantages of selected refrigerants are

- ✓ R245fa has a relatively low operating pressure, non-caustic and non-toxic.
- ✓ R134a is hydro fluorocarbons (HFCs), it has no impact on the ozone layer (ODP = 0) and was designated to replace the various CFC.
- ✓ R32 is an HFC, chemically more stable, no effect on the ozone layer, moderately flammable, zero ODP, and used for the lower temperatures.

A. *P-T-x behaviour of refrigerant-absorbent pairs*

P-T-X behavior of binary system containing refrigerant/absorbent are important factor to determine whether the binary solution is suitable for absorption refrigeration system, His account is based on vapor-liquid equilibrium (VLE)

For binary system, VLE can be written as:

$$\phi_i^V y_i P = \gamma_i x_i f^{OL} \quad (1)$$

In this communication, UNIFAC method for prediction VLE has been used.

B. *Energy analysis*

The generator

Work of pump hot water

$$\dot W_{gep} = g\frac{\dot m_f h_g \rho}{\eta_{gep}} \quad (2)$$

The generator

$$Q_g = m_7 h_7 + m_4 h_4 - m_3 h_3 \quad (3)$$

The condenser

$$m_7 = m_8 \quad (4)$$

$$Q_c = m_r (h_8 - h_7) \quad (5)$$

The evaporator

$$Q_v = m_r (h_{10} - h_9) \quad (6)$$

$$m_r = \frac{Q_v}{(h_{10} - h_9)} \quad (7)$$

$$m_w = m_r \frac{(X_r - X_s)}{(X_s - X_w)} \quad (8)$$

$$m_s = m_r + m_w \quad (9)$$

The coefficients of performance for various systems

$$COP_{abs} = Q_v / Q_g \quad (10)$$

The power of the pump is the product of the volumetric flow rate and pressure increase of the fluid, and the work of the pump is calculated by:

$$\dot W_{pump} = \frac{\dot m_5 v_5 (P_6 - P_5)}{\eta_{sp}} = \dot m_6 h_6 - \dot m_5 h_5 \quad (11)$$

When $\eta_{sp} = 0.8$

The solution heat exchanger

$$\dot m_6 + \dot m_8 = \dot m_7 + \dot m_9 \quad (12)$$

Accordingly, the effectiveness of the solution heat exchanger is defined as:

$$\varepsilon = \frac{T_8 - T_9}{T_8 - T_6} \quad (13)$$

$$\dot m_6 h_6 + \dot m_8 h_8 = \dot m_7 h_7 + \dot m_9 h_9 \quad (14)$$

The flow ratio is also determined by:

$$FR = \frac{\dot m_s}{\dot m_{11}} = \frac{X_g}{X_g - X_a} \quad (15)$$

The coefficients of performance for various systems

The absorption section:

$$COP_{abs} = \dot{Q}_{v2}/(\dot{Q}_g + \dot{w}_{pump}) \quad (16)$$

V. RESULTS AND DISCUSSION

Fig. 2 shows validation of the UNIFAC model and experimental data for R134a +MEGDME mixture pressure. The model predictions are in good agreement with experimental data.

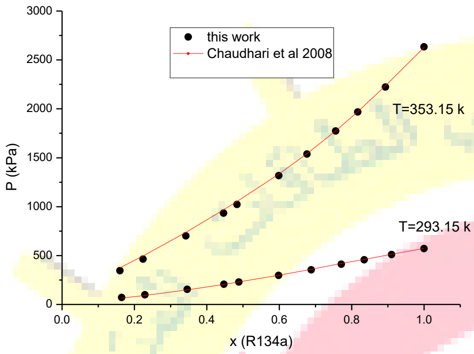

Fig. 2 Comparison of this work and experimental work for vapour pressure for R134a (1) +MEGDME (2) at temperatures: 293.15 K and 353.15K

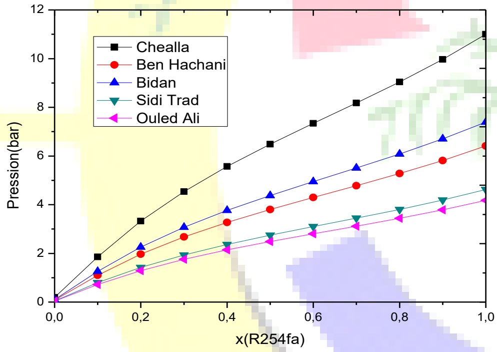

Fig. 3 PTX behavior for the mixture R245fa /DMF

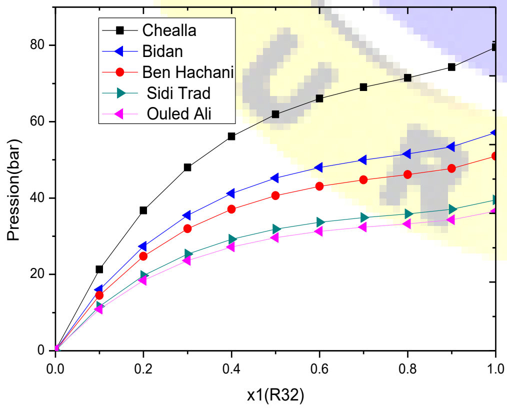

Fig. 4 PTX behavior for the mixture R32/ DMAC

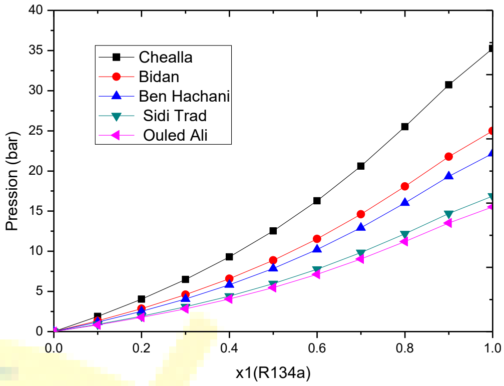

Fig. 5 PTX behavior for the mixture R134a/DMETEG

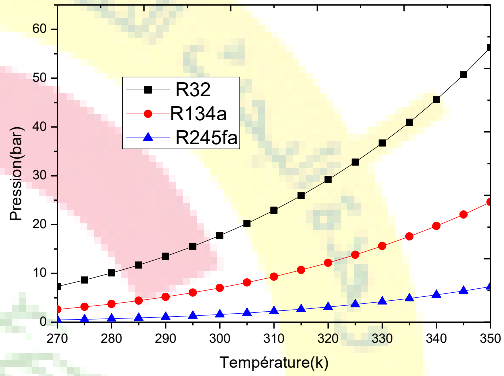

Fig. 6 Variation of pressure with the temperature for the fluids R245fa, R32 and R134a in the part (condenser, expansion valve and evaporator)

Figures (3, 4 and 5) show vapour–liquid equilibrium were predicted for three binary used in the absorption machine. Was evaluated under the following operating conditions: generator temperature in the range 56.5-94.3°C, evaporator temperature of 10°C, condenser temperature of 30 °C and absorber temperature of 30°C. In the concentration range of (0-1), the curves were established with UNIFAC model. The observed refrigerant solubility is very high in H.chealla compared all other resources.

From this figures, when the temperature is constant, the slope of the curve increases as the pressure increases.

Indeed, in the process of absorption, such as increasing the concentration of R245fa in absorbent products, the absorbing capacity will decrease. The system (R32 + DMAC) has a high system pressure; temperature of the generator should be high.

The binary system R134a- DMETEG property the lowest proportion of cycle

Figure 6 represents the evolution of the pressure as a function of temperature. R245fa curves are very close to atmospheric pressure, while those of R32 have a high pressure. R134a has significantly low pressure because of their high critical temperature. Saturated vapor pressures of lowering follows the order R32>R134a>R245fa.

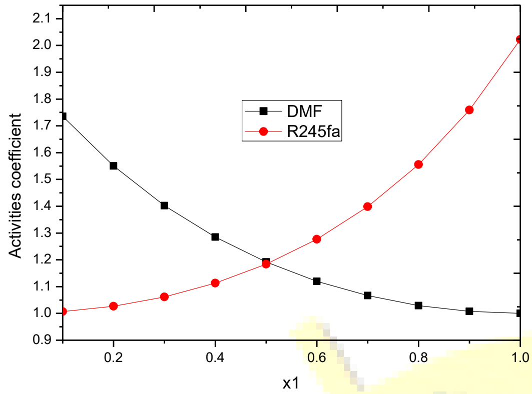

Fig. 7 Activities coefficient of R245fa and DMF at different concentration

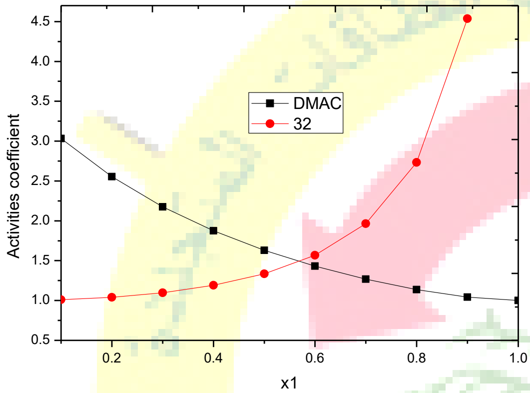

Fig. 8 Activities coefficient of R32 and DMAC at different concentration

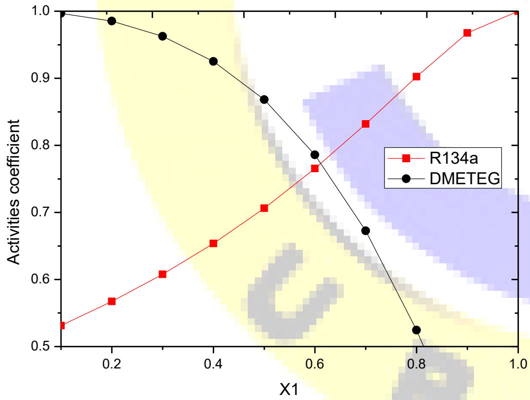

Fig. 9 Activities coefficient of R134a and DMETEG at different concentration

Figures 7, 8 and 9 show the activity coefficient, was predicted by the UNIFAC model. To examine the influence of this parameter in the mixtures considered variation of the activities coefficients of the refrigerant depending on the torque concentration of the refrigerant in each system at the temperature of the absorber. High values of the activity coefficient of the refrigerant are recognized for (R32-DMAC) system compared to other systems on the whole concentration range between x [0, 1]. Note that it is important to know the variation of the activity coefficient in the field of concentration of poor solution, where can see the following changes:

- R245fa -DMF: x between (0.02-0.5), activities coefficients between (1.01- 1.75)

R32-DMAC: x between (0.01-0.6), activities coefficients between (1- 3.01)

R134a- DMETEG: x between (0.02-0.55), activities coefficients between (0.4- 1)

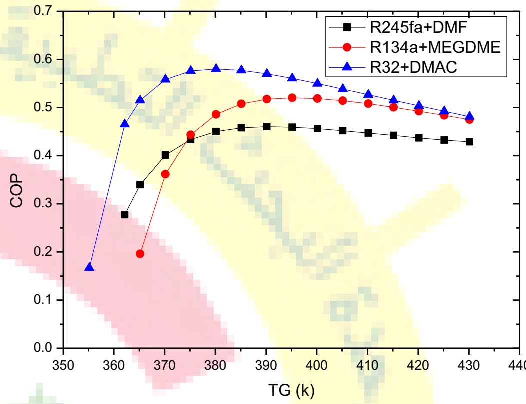

Fig.10 Variation of COP as a function of generator temperature (TG)

Fig.10 shows the variation of COP as a function of generator temperature. It is shown that, the R32-DMAC system gives the best performance and the R256fa-DMF cycle has the lowest COP. Each cycle cannot be operated at generator temperatures lower than its limit. For the R32-DMAC system, a lower generator temperature can be used than for the others. This is an important point for utilizing geothermal energy since fluid temperatures for Algerian sources are generally below 95°C.

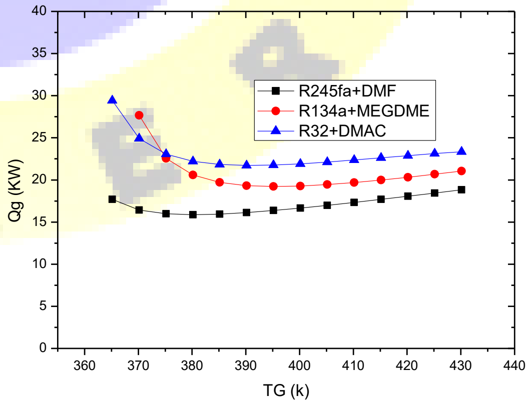

Fig.11 Variation of Qg with generator temperature

The variation in the generating capacity with the temperature of generator using (R245fa-DMF), (R134a-DMETEG) and (R32-DMAC) has been shown in Fig.11. Generation temperatures ranged from 55 to 95°C, it is the same area that represents a temperatures change of the Algerian springs (look the table 1), Q_g tends to decrease when the T_g increases then up to a certain value and proves. When the generator temperature increases, the concentration of the solution, leaving the generator increases, and the enthalpy (h_4) is increased which leads to the generator thermal load is decreased. The amount of generating capacity input to the cycle is found to be varying from (11 kW to 18 kW), (19 kW to 26 kW), and (25 kW to 30 kW) for (R245fa-DMF), (R134a-DMETEG) and (R32-DMAC) and respectively, and higher values are obtained from using (R32-DMAC). The decrease in the Q_g of the generator is directly related to the increase in the COP.

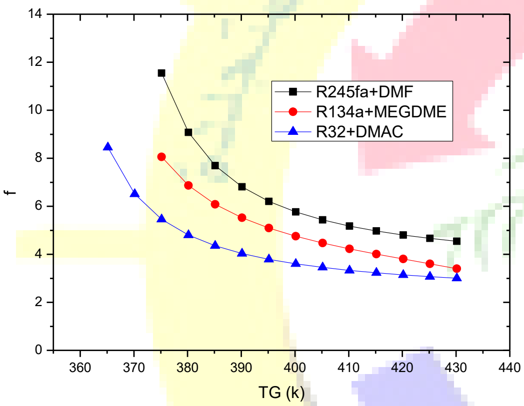

Fig.12 Variation of Circulation Ratio with generator temperature

Hence, Fig. 12 shows the corresponding comparison of circulation ratios with generator temperatures. Can see that circulation ratio decreases with an increase in generator temperature. When Tg increases, the weak solution concentration decreases. It is illustrated that the circulation ratio for the (R256fa-DMF) system is higher than for the other two systems.

VI. Conclusions

In the present study, a simulation of a single effect absorption refrigeration cycles heated by geothermal energy sources of Algeria and uses (HFC-Organic Absorbents) pairs has been presented. The system was used (R245fa-DMF), (R134a-DMETEG) and (R32-DMAC) as a working pair. The model was based on UNIFAC for calculations of PTx behavior and the heat and mass balance for analysis of the cycle. An absorption refrigeration cycle use geothermal energy of Algeria can reduce electric energy compared with a simple vapor compression cycle. This study focused on the Algerian springs that have a temperature in the field of (55 to 95°C). In this field, the higher generating capacity and the best coefficient of performance are obtained by the R32-DMAC. These results are encouraging for the exploitation of Algerian springs in absorption system, and on the other hand, effectiveness of (HFC-Organic Absorbents) pairs in this system.

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