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Thermodynamic Analysis of an Absorption/Compression Refrigeration System Using Geothermal Energy

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Abstract: This article presents the potential use and exploration of geothermal energy for cooling applications using a combined absorption/compression system. The considered system uses R134a for the compression part and the cool water-ammonia for the absorption part of the installation. The geothermal temperature source is in the range 343-349K, the condensation temperature is 308 K, and in order to produce ice, the R134a evaporation temperature is 263 K. The COP is about 5.4. Therefore, based on the typical geothermal energy sources in Tunisia which present a refrigeration potential power of 9.1 MW, the quantity of ice that could be produced is about 82 tons per hour. The greenhouse gas emissions should thus be reduced by about 5884 tons of CO_2 per year, which represents (59%).

Key words: Absorption, Ammonia, Geothermal Energy, Refrigeration, R134a

INTRODUCTION

Geothermal energy accounts for 2% of the world power consumption[1]. It is used in multiple applications and more than 60 countries exploit this energy[2-3], 12% of this energy is used as a source for the generators of the heat pumps[3].

Considering the importance of this renewable energy several research tasks are carried out in the world, for relevant exploitation. This exploitation depends closely on the thermodynamic and physicochemical data of water to emergence (dry Pressure, Temperature, flow, residues...).

Among these applications, we find the heat pumps with absorption[4-10], air-conditioning with absorption[11, 12] and other passive applications.

In Tunisia, up to the year 2000, hydraulics and wind energies represented only 2% of the national power consumption, even though Tunisia has a substantial geothermal potential. These sources are mainly exploited in sericulture, in the heat of the buildings and in aquiculture[13] and in order to irrigate the neighboring areas with drinkable and industrial irrigation water, the geothermal water of Chott Fdjej (south of Tunisia), which temperature exceeds 343 K, is cooled in cooling towers[14].

Tunisian Geothermal Resources: Much investigating work was carried out in the south of Tunisia, in order to determine the physicochemical characteristics of drilling water in this area.

To locate them, the Directorate-General of the Water Resources (DGRE) tried to divide Tunisian territory into maps, where each one contains several geothermal wells.

Geothermal wells which show the most favorable thermodynamic characteristics, such as the highest temperatures and flows, are localized in the area of Chotts: Kebili, Tozeur and El Hamma (south of Tunisia).

The thermodynamic characteristics and physicochemical analysis of the water are indicated in Table 1 and 2.

Description of the Combined Cycle: Hybrid absorption/compression installations using geothermal energy have been studied by several authors[15-18], and the most used couples are H_2O/NH_3 and $LiBr/H_2O$[12,19, 20].

In order to produce cold at negative temperatures, the studied cycle is formed by the association of ammonia-water absorption loop, supplied with geothermal water, and of vapor compression loop, using R134a like refrigerant (Fig. 1).

For the absorption loop, the generator temperature T_G is fixed by the geothermal temperature source T_F (T_g<T_F).

The temperature of the considered wells is in the range 342-348 K. By taking account of the variation ΔT_{Fg} between the fluid of heating (geothermal water) and the weak solution in the generator, the generator temperature is fixed to 335 K.

By taking account of the climatic conditions of the area of the Chott, the condensation and absorbable temperatures T_c and T_a are taken equal to 308 K.

According to the Oldham diagram, if the triplet (T_g, T_c= T_a), and the mass concentration difference between the strong and weak solutions, Δx_{rp}, are fixed, the evaporation temperature T_{ev} is also fixed[21].

For the absorption loop and the indicated conditions, the mass concentrations are given from the Merkel diagram[22]. $x_r = 0.66$ and $x_p = 0.56$.

In order to produce ice we associate a compression vapor cycle using R134a like refrigerant, functioning between 2.01 bars (T_f =263 K) and 6.08 bars (T_{cc}=295 K), (Fig. 1).

The thermodynamic data relating to the combined installation are indicated in Table 3.

For the absorption system, the energy balances are established on the basis of the following assumptions:

* No imperfections in both generating and absorber.
* The generator and evaporator pinch temperature is fixed at $\Delta T_{pin} = 5$ K
* At the generator exit, the ammonia vapor is pure.

Energy and Mass Combined Installation Balances

Generator: The energy and mass balances are established to evaluate the generator energy consumption and the solution mass which provides one kg of pure refrigerant (Fig. 1).

It is to be noticed according to Table 3, that the ammonia mass vapor concentration is approximately 0.997, which educes the needs for a rectification of this vapor.

The specific strong solution circulation is given from the mass balance and it represents the mass of solution per kg of vapor refrigerant leaving the generator:

$$f = \frac{x'' - x_p}{x_r - x_p} \quad (1)$$

The calorific generator power is given by the following expressions:

$$\dot{Q}_g = \dot{m}_{NH_3}(h_2 + (f-1)h_3 - f\,h_{1''}) \quad (2)$$

$$\dot{Q}_g = \dot{m}_F C_{PF}(T_F - (T_g + \Delta T_{pin})) \quad (3)$$

The ammonia mass flow rate is deduced from the expressions (2) and (3):

$$\dot{m}_{NH_3} = \frac{\dot{m}_F C_{PF}\ (T_F - (T_g + \Delta T_{pin}))}{(h_2 + (f-1)h_3 - f\,h_{1''})} \quad (4)$$

Expression (4) will be used for the determination of the realizable refrigerating potential by each geothermal well according to its mass flow rate $\dot{m}_F$ and its temperature T_F.

Evaporator: The refrigerating power obtained on the evaporator of the absorption installation and which will be used to cool the condenser of the associated installation is given by:

$$\dot{Q}_{ev} = \dot{m}_{NH_3}(h_5 - h_{4'}) \quad (5)$$

By neglecting the pump work, *the COP_{ev}* of the absorption loop is defined by:

$$COP_{ev} = \frac{\dot{Q}_{ev}}{\dot{Q}_g} \quad (6)$$

The obtained potential could be exploited in air-conditioning, but considering the socioeconomic conditions of these areas, it is desirable to produce ice, that will be used in the storage of the agricultural produce and the fishery products.

It is thus convenient to associate the absorption installation with the vapor compression installation using R134a (Fig. 1).

R134a Vapor Compression Installation: The vapor compression circuit (Fig. 1), functions between the evaporation temperature T_f = 263 K and the condensation temperature T_{cc}= 295 K. These data make it possible to evaluate the various enthalpies, by using the Mollier diagram[22].

The energy balances are established on the basis of the following assumptions:

* At the entry of the compressor, the vapor is saturated.
* At the entry of the adiabatic throttling valve the liquid is also saturated.
* The isentropic and electric efficiency of the compressor are given by[23]:

$$\eta_{is} = 0.874 - 0.0135\tau \quad (8)$$

$$\eta_e = 0.9 \quad (7)$$

Produced refrigerating power:

$$\dot{Q}_f = \dot{m}_{R134a}(h_6 - h_{8'}) \quad (9)$$

Power released on the condenser:

$$\dot{Q}_{cc} = \dot{m}_{R134a}(h_7 - h_8) \quad (10)$$

Mechanical power consumed by the compressor:

$$\dot{W} = \dot{m}_{R134a}\frac{h_{7'} - h_6}{\eta_{is}} \quad (11)$$

Electrical power consumed by the compressor:

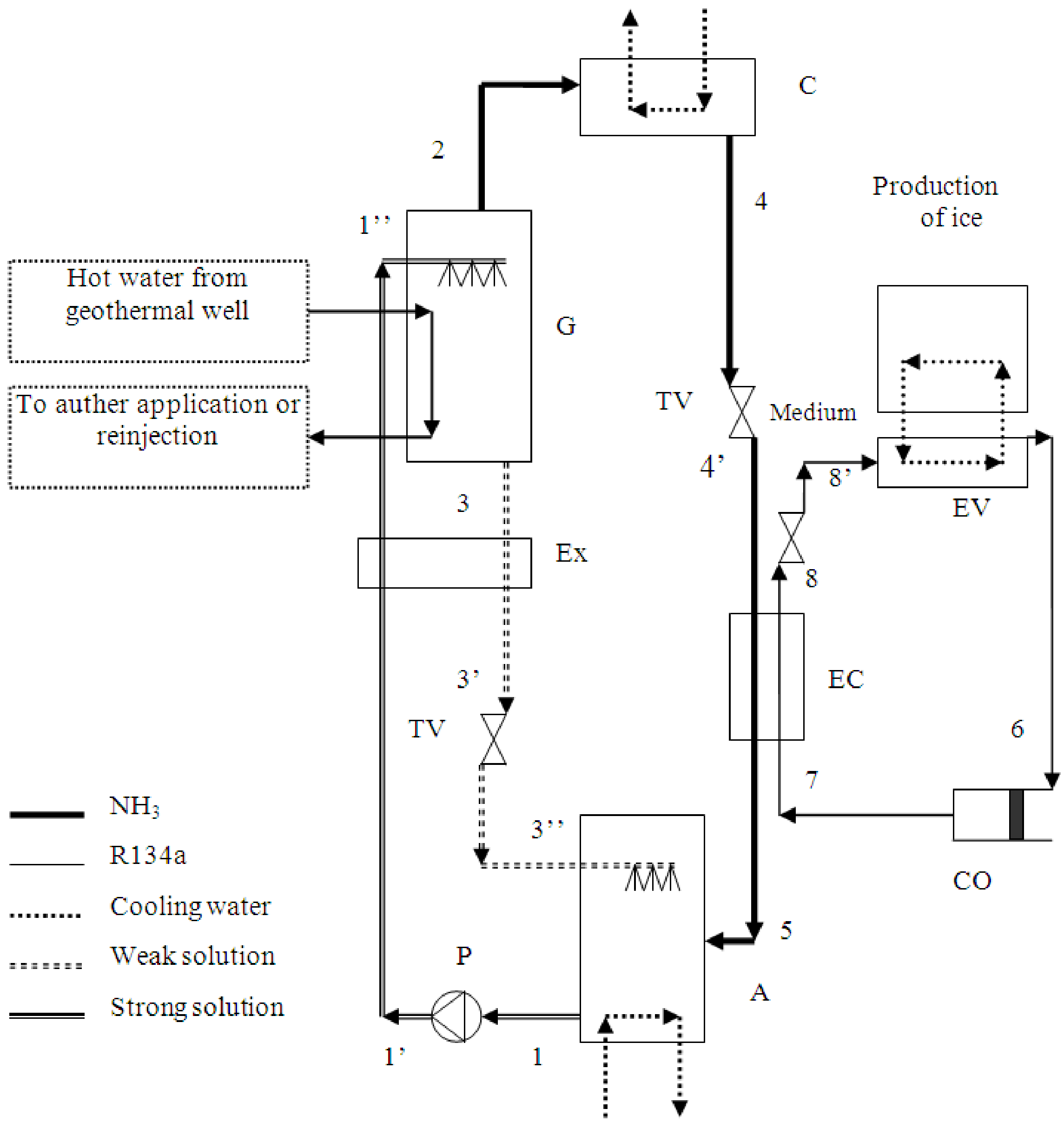

Fig. 1: Schematic View of the Combined System (A: Absorber, C: Condenser, CO: Compressor, EC: Evaporator/Condenser, EV: Evaporator, Ex: Exchanger, G: Generator, P: Pump, TV: Throttling Valve)

$$\dot{W}_e = \dot{m}_{R134a} \frac{(h_{7'} - h_6)}{\eta_{is}\eta_e} \quad (12)$$

The coefficient of performance of the vapor compression loop is noted, COP_{R134a}:

$$COP_{R134a} = \frac{\dot{Q}_f}{\dot{W}_e} \quad (13)$$

Combined Installation: In the adiabatic evaporator/condenser, the expressions (5) and (10) are equal:

Table 1: Thermodynamic Characteristics of the Considered Sources (Source DGRE)

Label	Drilling	Location	T (K)	Mass flow rate (kg s^{-1})
1	El Mahassen	Hamma Djerid	348	100
2	Degache CI2	Hamma Djerid	346	22
3	Chott Fdjej 2	El Hamma	343	70
4	Debbacha	Menchia	344	100
5	Seftimi NC17	Kebili	345.6	70
6	Zaouiet Echourfa	Menchia	343.2	90
7	Zaouia NCI5	Menchia	343.9	70
8	Menchia NCI6	Menchia	344	70
9	Limaguess NCI8	Kebili	345.5	70

Table 2: Physicochemical Analysis of the Water (Source DGRE)

No.	Ca^{2+} Kg m^{-3}	Mg^{2+} Kg m^{-3}	Na^{+} Kg m^{-3}	K^{+} Kg m^{-3}	SO_4^{2-} Kg m^{-3}	Cl^{-} Kg m^{-3}	HCO_3^{-} Kg m^{-3}	PH	Dry residual Kg m^{-3}
1	0.332	0.038	0.278	0.073	0.988	0.362	0.183	7.15	2.220
2	0.308	0.048	0.292	0.072	0969	0.340	-	-	2.020
3	0.280	0.120	0.328	0.034	0.931	0.674	0.117	7.47	2.700
4	0.228	0.145	0.265	0.028	0.816	0.568	0.123	7.47	2.160
5	0.249	0.098	0.303	0.039	0.595	0.674	0.111	-	2.700
6	0.232	0.097	0.310	0.040	0.662	0.674	0.114	7.5	2.360
7	0.252	0.108	0.317	0.039	0.768	0.710	0.117	7.85	2.340
8	0.248	0.087	0.312	0.037	0.739	0.674	0.090	7.6	2.444
9	0.280	0.091	0.340	0.036	0.806	0.639	0.128	-	2.320

Table 3: Thermodynamic Data and Numerical Values

T_g =335 K	ΔT_{pin} =5 K	h_3=50 kJ kg^{-1}	h_7=418.4 $kJkg^{-1}$
T_c= T_a =308 K	PC =12. 5 bar	$h_{3''}$=-47 kJ kg^{-1}	h_8= $h_{8'}$=230.4 $kJkg^{-1}$
T_{ev} =290 K	P_{ev} =8 bar	h_4= $h_{4'}$=130 kJ kg^{-1}	x_r=0.66
T_f = 263 K	h_1= -55 kJ kg^{-1}	h_5=1280 kJ kg^{-1}	x_p=0.56
T_{cc} =295 K	$h_{1''}$ = 20 kJ kg^{-1}	h_6=390.7 kJ kg^{-1}	x''=0.997
$T_{1''}$ =321 K	h_2=1350 kJ kg^{-1}	$h_{7'}$=413.4 kJ kg^{-1}	ρ =734 kgm^{-3}
(3) $\dot{Q}_e$ = 12.849 MW		(12) =1.686 MW .	(13) COP_{R134a}=5. 4
(6) COP_{ev}=0. 8		(15) =9.1 MW	

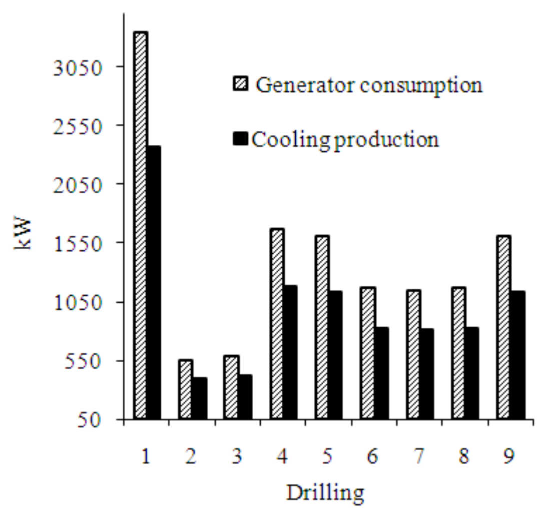

Fig. 2: Histogram of the Generator Consumption and Cooling Production

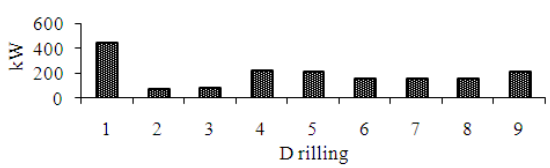

Fig. 3: Histogram of the Electricity Consumption

$$\dot{m}_{NH_3}(h_5-h_{4'}) = \dot{m}_{R134a}(h_7-h_8) \qquad (14)$$

The new expression for the refrigerating power, produced by the hybrid installation, is deduced from the expressions (4), (9) and (14).

$$\dot{Q}_f = \frac{(h_5-h_{4'})}{(h_7-h_8)}(h_6-h_8)\frac{\dot{m}_F C_{PF}(T_F-(T_g+\Delta T_{pin}))}{(h_2+(f-1)h_3-f\,h_{1''})} \qquad (15)$$

According to the expression (15), the produced refrigerating power of this hybrid installation is directly related to the characteristics of geothermal well:

The mass flow rate of source and the emergence temperature water.

The new expression of the compressor electric consumption is deduced from the expressions (4), (12) and (14):

$$\dot{W}_e = \frac{(h_5-h_{4'})}{(h_7-h_8)}\frac{(h_{7'}-h_6)}{\eta_{is}\eta_e}\dot{m}_{NH_3} \qquad (16)$$

While basing itself on the expressions (3), (4), (14), (15) and (16), we can establish for each geothermal source the refrigerating potential which it can generate if it is used to supply the generator of an ammonia-water/R134a hybrid installation and the necessary electric power to actuate this machine.

In Table 3, we gathered the calculated powers for the absorption installation and the hybrid installation.

Presentation and Interpretation of the Results: To illustrate the performances of each geothermal well, then refrigerating, electric and calorific powers are represented in the form of histograms (Fig. 2 and 3).

According to Table 3, the total refrigerating potential reaches approximately 9.1 MW. It can be exploited to produce approximately 82 tons of ice per hour, which will be useful for the conservation of the agricultural produce and fishing (some geothermal wells are located close to the coast).

This potential could be exploited in the cold rooms and even in the air-conditioning of the hotels of the Tunisian south area (very coveted by Saharan tourism).

This refrigerating potential requires an electric power of approximately 1.7 MWe

By producing this electric power, during one year, the power station would have consumed 4157 M toe and would have released approximately 9973 tons of CO_2; the fuel flaring is Natural gas.

1 MWh = 0,283 M toe and 1toe releases 2400kg of CO_2 (Decree of the Ministry for the Energy and Mines 1987 relating to the fixing of the coefficients of equivalence and the calorific values).

If the refrigerating power obtained by the combined system is carried out using a vapor compression system (R134a), working between T_f =263 K and T_{cc} =308 K, it consumes an electric power of about 2.7 MWe, is approximately 59% more than the combined installation consumption (1.7 MWe). It follows an increase in the CO_2 emissions in the same proportions, which is the equivalent of approximately 5884 tons per year, if the fuel flaring is Natural gas.

It is noticed that the study made, from 93 to 97, by the Tunisian Company of Electricity and Gas, concerning the electric request during May to September, revealed that for the interval of outside temperature 300-316 K, the variation of the load diagram follows the same form that of the temperature 1 K to the tops of 27 fact of moving the point of 9MW on average[24].

This new tendency is directly related to the increasing request in refrigeration and in air-conditioning. However, the combined system will be able to contribute to the fall in the electricity demand on the national network.

CONCLUSION

The absorption/compression combined system using a geothermal source makes it possible to increase the COP and to reduce the greenhouse emission gases.

This system could present an alternative to the reduction of the electric load, continually increasing, because of the improvement of the standard of living and the development of new activities in the Tunisian south (tourism, aquaculture, biological agriculture...), consuming cold for the conservation and air-conditioning.

It would be convenient to assemble a pilot installation based on the principle of the combined systems in order to elucidate the real constraints inherent in the use of geothermal water.

This installation can be localized in Chott Fdjej where cooling towers are supplied partly by the geothermal well of Chott Fdjej 2, for which the refrigerating and electric powers are about 414 kW and 79 kW.

A viability study can be considered thereafter by taking into account the geographical dispersion of the geothermal wells, the socioeconomic conditions of the localities and the proximity of the urban zones.

Nomenclature:

COP coefficient of performance
C_P specific heat, J kg^{-1} K^{-1}
F strong solution circulation
H specific enthalpy, J kg^{-1}
$\dot{m}$ mass flow rate, kg s^{-1}
P pressure, Pa
Q power, W
T temperature, K
X concentration fraction of the ammonia in liquid form, kg kg^{-1}
$\dot{W}_e$ electrical compressor power, W
ΔP pressure difference, Pa
Δx concentration fraction difference, kg^{-1}
ΔT_{pin} pinch temperature, K

Greek letters:

η_e electrical efficiency
η_{is} isentropic efficiency
η_g global efficiency
ρ density, kgm^{-3}
τ compression ratio

Subscripts:

a absorber
c ammonia condenser
cc R134a condenser
ev ammonia evaporator
f R134a evaporator
F geothermal source
G generator
r strong
p weak
pp pump

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