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Waste heat recovery from Refrigeration machine

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Abstract *: With the aim of saving energy and to reduce global warming effect, our work focuses on the valorization of the waste heat evacuated by the condenser of a refrigeration machine (air-conditioner) for the desalination of sea water. In this paper, the conception of a new system combining air-conditioning and desalination is realized. The modelling of the heat exchanges of each part of the system is realized. To improve the performance of the system, various experimental tests are represented and discussed. Comparison between simulation and experimental results shows a good agreement and present a courageous motive for the system application.*

Keywords **:** *heat, desalination, refrigerating machine, air conditioner, modelling .*

I. INTRODUCTION

Fresh water shortage affects many countries in our world. Desalination processes have the aim to extract fresh water from brackish water but it's consume a large quantities of heat energy which is leads to the need of an innovative and more economic desalination processes.

Air-conditioning systems becomes more outspread due to technological development. In one hand, these systems cools a local, in the other hand dump energy into the environment leading to global warming. This is a waste of energy and can be utilized for useful purposes.

In this study, we want to combine air-conditioning and desalination in the same unit witch the aim is to product fresh water from sea water using the heat removed by the condenser of an air-conditioner.

Srithar et al [1] studied the recovery of the waste heat from the condenser and evaporator of a vapor compression refrigeration system using humidification dehumidification desalination process. They found that the coefficient of performance of the system improved to 7.6 and the distillate water flow rate reached 0,4 l/m^2 h.

Santosh et al [2] investigated the performance of a humidification dehumidification desalination system through the waste heat recovered from household air-conditioning unit. They found that the cost of production of fresh water is $0,1658/Kg.

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Locapure and Joshi [3] designed a new system which heat up water using the waste heat from air-conditioning system and improve the coefficient of performance of the system up to 13%. Sapali et al [4] interested by recovering the waste heat from bulk milk coolers for water heating. The COP of the system increased from 3 to 4,8. Ramyashree et al [5] suggested to recover the heat from air conditioner to produce hot water and they found that the coefficient of performance increased by 6%. Hawlader et al [6] fabricated a heat pump assisted desalination unit. The experimental tests gave a performance ratio from 0,77 to 1,15 and a COP between 5 and 7. Gao et al [7] analyzed a humidification dehumidification desalination system connected with heat pump. Yuan et al [8] suggested a combining system for air-conditioning and desalination using humidification dehumidification process. We can mention also the work of Ben Slama, R [9] concerning the coupling of a refrigerator and water heater in which the water temperature reached 60°C and the heating floor reached 30°C in 24 hours. Ben Halima, H et al [10] studied the coupling of a solar still and heat pump. They found that the production of fresh water of the new still improved comparing with ordinary still witch lead to the importance of desalination using heat pumps.

II. SYSTEM DESCRIPTION

An air conditioner contains two exchangers: the evaporator to create the cold by vaporization of Freon (refrigerant), and the condenser to give the heat to the surrounding environment by condensation of the Freon, this heat evacuated by the condenser constitutes a loss of energy and which has consequences on global warming.

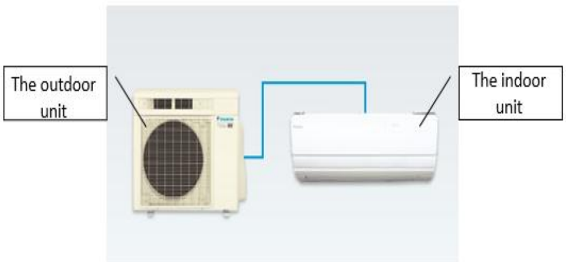

Fig. 1.Image of Split Air conditioner.

A Split air conditioner is a type of air conditioner that has two parts, an indoor unit containing the evaporator and which diffuses the conditioned air at the temperature chosen for the user and an outdoor unit containing the condenser in which the Freon condenses by the outside air.

Fig. 2.Photographs of the experimental prototype.

Our innovative contribution is to replace the air-conditioner condenser (the outdoor unit) by a new designed condenser. This new condenser will make it possible to use the heat rejected by the Freon for desalination of sea water instead of throwing it outside.

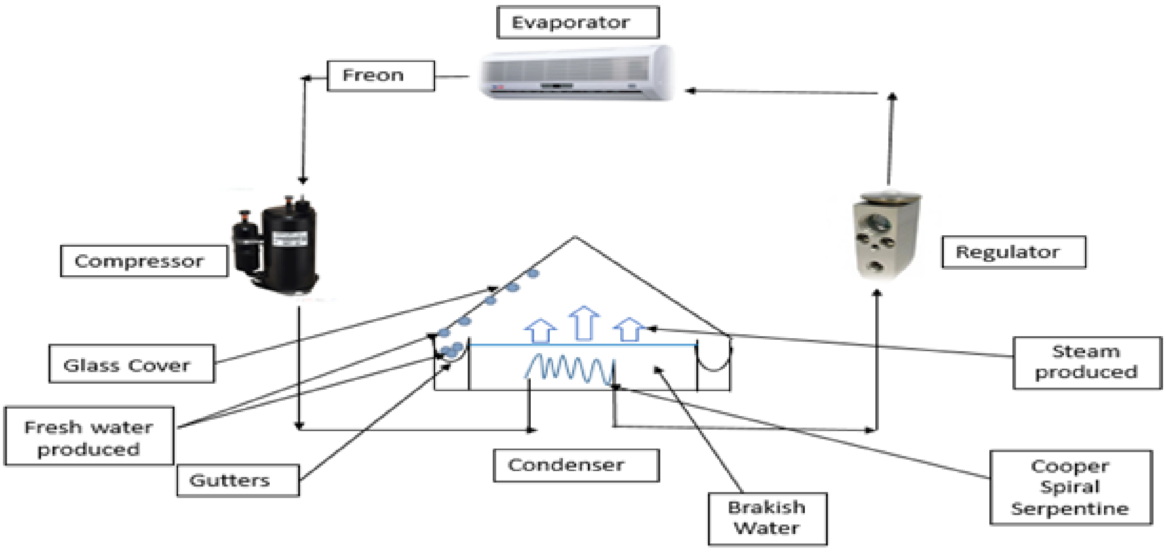

Fig. 3. The combined air conditioning-desalination system.

Fig. 2 and Fig. 3 illustrate our new system.

The new condenser is composed by a cooper spiral serpentine placed in a water basin covered by a pyramidal glass cover. Sea water will receive the latent heat liberated by the Freon condensation and lead to his evaporation before obtaining the fresh water from the condensation of the steam produced.

The Freon passes through a closed cycle: evaporator, compressor, condenser, and regulator. The Freon leaves the evaporator, in the vapor state towards the compressor. It exits compressor at high pressure and high temperature and directs towards the condenser where it yields its heat to sea water, hence the evaporation of water and the condensation of the
Freon. Then it passes through the regulator in which there is a drop in temperature and pressure and finally it returns to the evaporator and a new cycle begins. The steam produced condenses on the glass cover and accumulates in the gutters so we recuperate the fresh water.

III. CONCEPTION OF THE NEW CONDENSER

The major contribution of our work is to valorize the energy dumped in environment by air-conditioners and use it for useful purpose. In this concept, we have though to use this waste energy for water desalination.

In the air-conditioner condenser, the Freon release his condensation heat in the outside air. Our contribution is done in this level specifically to recuperate this heat by replacing the condenser by a new designed condenser.

The new condenser consists mainly of a sea water basin in which is immersed a cooper serpentine.

Fig. 4. The new condenser.

A pyramidal cover covers the sea water basin which is isolated by glass wool.

The Freon passes into the spiral serpentine where it condensates and yields its heat to sea water.

After sea water evaporation, the steam produced go up to the pyramidal cover where it condensates.

The drops of water coming from condensation of hot steam produced follow the interior surface of pyramidal cover and gathers in the gutters or collectors so recuperation of distilled water.

The different characteristics of the system are represented in Table- I.

Table- I. Characteristics of the system.

Parameters	Value	Symbol
Freon	R-22	-
Material of the cover	Plexiglas	-
Mass of the cover	7,14 Kg/m^2	m_g
Specific heat of the cover	1470 J/ Kg K	C_g
Surface of the cover	0,93 m^2	A_g
Mass of water	40 Kg/m^2	m_w
Specific heat of water	4178 J /Kg K	C_w
Surface of water	0,49 m^2	A_w

IV. THEORITICAL STUDY

The heat balance equations for the new condenser components are as follow:

Balance energy for the glass cover:

$$m_g\, C_g \frac{dT_g}{dt} = q_{ev(w\text{-}g)} + q_{c(w\text{-}g)} + q_{r(w\text{-}g)} - q_{loss} \quad (1)$$

Balance energy for the water:

$$m_w C_w \frac{dT_w}{dt} = \frac{COP\,W}{A_w} - (q_{ev(w\text{-}g)} + q_{c(w\text{-}g)} + q_{r(w\text{-}g)}) \frac{A_g}{A_w} - q_{loss} \quad (2)$$

Condensation rate:

$$\frac{dm_c}{dt} = \frac{q_{ev}}{L_e} \quad (3)$$

The expressions for each term in the above equations are:

- The radiation heat transfer between water and glass cover is given by [7] :

$$q_{r(w\text{-}g)} = 0{,}9\, \sigma\, (T_w^{\,4} - T_g^{\,4}) \quad (4)$$

- The convective heat transfer between water and glass cover is given by [7] :

$$q_{c(w\text{-}g)} = h_{c(w\text{-}g)} (T_w - T_g) \quad (5)$$

Where the convective heat transfer coefficient between water and glass cover is given by [7] :

$$h_{c(w\text{-}g)} = 0{,}884 \left[T_w - T_g + \frac{(P_w - P_g)(T_w + 273{,}15)}{268{,}9\ 10^3 - P_w}\right]^{1/3} \quad (6)$$

Where Pw and Pg are the vapor pressure at water and glass temperatures, respectively, and are given by the following relation [7]:

$$P(T) = \exp\left(25{,}317 - \frac{5144}{T + 273{,}15}\right) \quad (7)$$

- The evaporative heat transfer between water and glass cover is given by [7] :

$$q_{ev(w\text{-}g)} = h_{ev(w\text{-}g)} (T_w - T_g) \quad (8)$$

Where the evaporative heat transfer coefficient between water and glass cover is given by [7]:

$$h_{ev(w\text{-}g)} = 16{,}273\ 10^{-3}\ h_{c(w\text{-}g)} \frac{P_w - P_g}{T_w - T_g} \quad (9)$$

- The latent heat of evaporation of water is given by this relation [7] :
-

$$L_e = (2501{,}67 - 2{,}389\ T_e) 10^3 \quad (10)$$

- The heat loss from the glass cover is given by :

$$q_{loss} = \left(\frac{e_g}{k_g} + \frac{1}{h_a}\right)^{-1} (T_g - T_a) \quad (11)$$

- The heat loss from the water is given by :

$$q_{loss} = U(T_w - T_a) \quad (12)$$

$$U = \left(2\frac{e_b}{k_b} + \frac{e_i}{k_i} + \frac{1}{h_a}\right)^{-1} \quad (13)$$

- The coefficient of performance is given by :

$$COP = \frac{T_{cond}}{T_{cond} - T_{ev}} \quad (14)$$

V. RESULT AND DISCUSSION

The functions of the air-conditioner condenser are resolved by differential equations of first order.

Resolution of the equations system:

$$\begin{cases} \frac{dT_g}{dt} = \frac{1}{m_g C_g}\left(q_{ev(w-g)} + q_{c(w-g)} + q_{r(w-g)} - q_{loss}\right) \\ \frac{dT_w}{dt} = \frac{1}{m_w C_w}\left(\frac{COP\ W}{A_w} - \left(q_{ev(w-g)} + q_{c(w-g)} + q_{r(w-g)}\right)\frac{A_g}{A_w} - q_{loss}\right) \\ \frac{dm_c}{dt} = \frac{q_{ev}}{L_e} \end{cases}$$

This system consists of three first-order differential equations.

We have three unknowns:

T_g : Temperature of glass cover

T_w : Temperature of seawater

m_c : Distilled water production

To solve numerically this system of differential equations of the form y '(t) = f (t, y), y (t0) = y0, we used the programming language MATLAB and precisely the Runge-Kutta method of 4-step fixed order known as ODE45 (Ordinary Differential Equation).

A. *Simulation results*

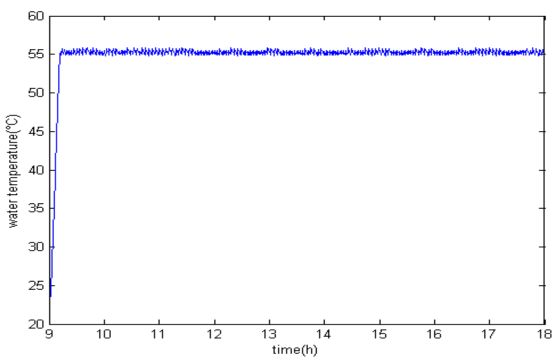

Fig. 4. Variation of sea water temperature according to time.

The variation of sea water temperature according to time is represented in Fig. 4.

We note that the sea water temperature increases at 9 am from 25°C to a value of 55°C in 30 min, and then it steal in a permanent mode of 55°C.

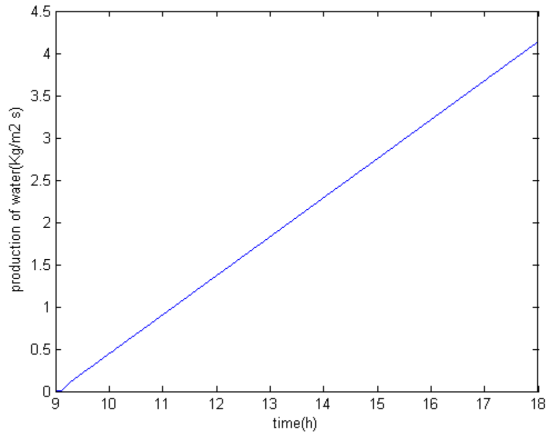

Fig. 5. Variation of distilled water production according to time.

Fig. 5 reveals the variation of distilled water production according to time, we note that after 9 hours of operating, water production reaches 4,1Kg/m^2 witch means that distilled water flow rate is 10,93 Kg/ m^2/ Day.

B. *Experimental results*

Fig. 6 and 7 illustrate experimental results previously conducted from the prototype shown in Fig. 2 existing in the National Engineering School of Gabes.

The variation of sea water temperature according to time experimentally measured is presented by Fig. 6.

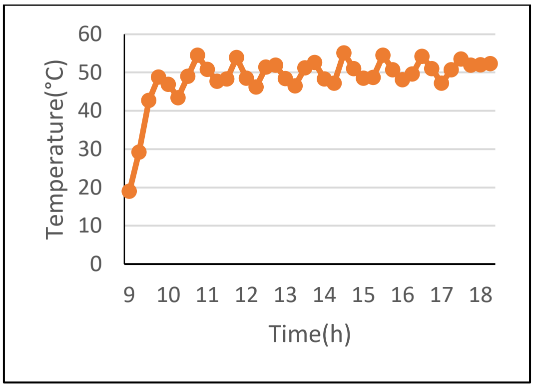

Fig. 6. Variation of sea water temperature according to time.

The temperature of sea water increase gradually from 20°C at 9 am to 50°C at 10 am and then it continue to oscillate between a maximum of 55°C and a minimum of 45°C. This vibration in the profile of sea water temperature can be explained by the poses that makes air conditioner from time to time. There are moments where it stops then it start again.

Fig. 7 reveals the variation of distilled water production according to time experimentally measured. We note that we did not recuperate any fresh water in the first hour of operating from 9 am to 10 am. After that, the curves increase gradually with time until it reaches a value of 1,2 Kg/m^2 at the end of the day. Distilled water flow rate is then 3,2 Kg/ m^2/ Day.

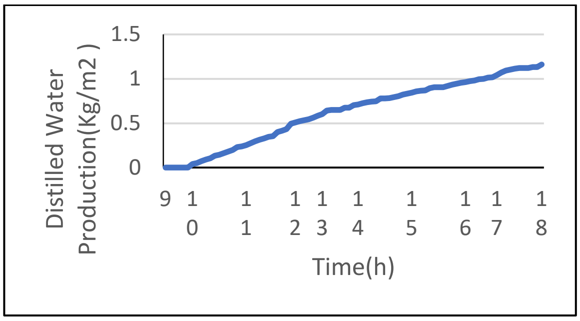

Fig. 7. Variation of distilled water production according to time.

C. *Comparison between theoretical and experimental results*

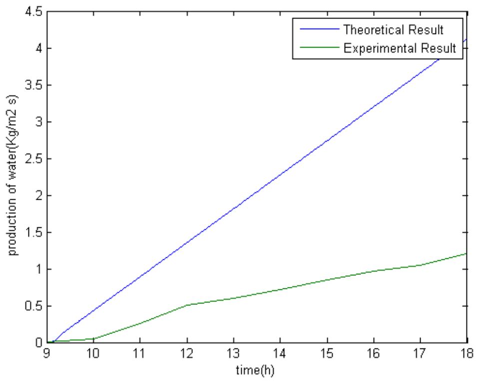

Fig. 8. Comparison between theoretical and experimental results

As shown in Fig. 8, the difference between theoretical and experimental results can be owing to the process of recuperation of distilled water (gutters) which is not very perfect. This production can be improved by augmentation of basin surface or by acceleration of steam condensation process.

VI. CONCLUSION

We tried by this work to expand the use of air-conditioner systems for water desalination. The prototype that we made allows the exploitation of the waste heat rejected by the condenser and contribute to evaporate water and extract fresh water by condensation of the steam produced while keeping the principal function of air-conditioner to cool.

After the conception and description of the new design, we present the modeling of heat exchanges of each part of the system. We used the Matlab solver ode45 to simulate the different parameters. The next step was the comparison between experimental and simulation results which shows a good agreement.

Experimentally, we found that sea water temperature reaches 55°C, distilled water flow rate reaches 3, 2 Kg/m2 /Day, these results can be improved by malty solutions like augmentation of the basin surface by adding a second stage, or by acceleration of steam condensation process by adding a bigger condenser for that purpose.

NOMENCLATURE

English Letters:

A: area	m^2
C: specific heat	$J\ Kg^{-1}\ K^{-1}$
COP: coefficient of performance	
h: convection heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
k: thermal conductivity	$m^{-1}\ K^{-1}$
m: specific mass	$Kg\ m^{-2}$
P: pressure	$N\ m^{-2}$
q: heat flux	$W\ m\text{-}^2$
T: temperature	°C
U: overall heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
e: length	m
W: compressor power	W
L: latent heat of vaporisation	$J\ Kg^{-1}$

ubscripts:
a: ambient
cond : condenser
ev: evaporation
c: convection, condensate
g: glass
w: water
b: basin
i: insulation
r: radiative

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