DESING OF ABSORPTION SYSTEM WATER-AMMONIA BY USING SOLAR RADIATION AS THERMAL SOURCE

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Abstract: *An absorption refrigeration system with the simgle effect of par ammonia water with 1.758 kW (1 / 2 RT) cooling capacity was designed. The system was operating under conditions of 5°C evaporation and 45 °C condensation temperature. The absorption system has a heat exchanger to improve performance.*

The heat source is the cylinder parabolic solar concentrator (CPC). The design of the concentrator was estimated based on experimental data of the pilot plant built in the Solar Energy Laboratory, Federal University of Rio Grande do Norte (SLE / UFRN). The thermodynamic model with heat and mass transfer was made to the project areas of heat exchange (absorber) and consequent construction of the system. The rectifying column was modeling assuming that liquid is in equilibrium with the vapor state in all plate. The results should show the dimensions of the compact and allows a future assessment of the operational cost.

Keywords: *Absorption, Ammonia, cylinder-parabolic concentrator, solar radiation*

1- INTRODUCTION

Solar energy is a clean energy alternative that can replace conventional systems. The increase in electricity demand mainly applied in the refrigeration sector encourages the development of equipment that could replace conventional systems. The absorption system does not consume as much energy as the cycles of vapor compression refrigeration, due instead of the compressor, using the set: pump, absorber and generator. The heat source most used at generator is the hot gases of combustion obtained by the burn of any fuel. To reduce fuel consumption, projected to the absorption system utilizing solar energy as a supplier of heat using a solar concentrator that heats water, which flows through a pipe passing through the mirror concentrator and a serpentine heat exchange with the system.

The determination of the areas of heat exchange was done by the global coefficient of heat transfer. Florides et al (2003) presents a design of an absorption refrigeration system where the absorber are vertical. Menna (2008) modeled an absorption refrigeration system using correlations Florides et al (2003). In this paper, the absorber is horizontal shell and tube heat exchangers. Siddiqui (1995) designed a heat exchanger in a horizontal position. Their correlations determine the coefficients of heat transfer by convection to the inside and outside tubes, which have significant influence at the overall coefficient of heat transfer.

A model was developed using the software EES (Engineering Equation Solver) for the simulation of processes and obtain the areas of heat exchange, therefore the number of tubes. This model determine the heat flux of each component of the system by the laws of thermodynamics and heat transfer and mass and estimate the coefficient of performance of the absorption system.

The objective of the paper is to design a compact absorption refrigeration system operating with solar radiation. The model evaluated the effect of temperature on the efficiency of the absorber of the collector. The system must be compact and can promote the refrigeration in remote locations.

The characteristic of system are: The temperature of the condenser and evaporator are 45 ° C and 5 º C, respectively. The pump is isoentropic. The efficiency of Heat transfer is 75.0%. The temperature of the mixture leaves the absorber is 35 ° C. The strong and wake solution concentration are 54.33% and 44.59% respectively. The pressure of condenser and evaporator are 1786 and 516.9 kPa. The output of condenser is subcolled in 5 º C.

The configuration of absorption cooling systems with the equipment is show by (Stoecker and Jones, 1985) at the Fig. 1.

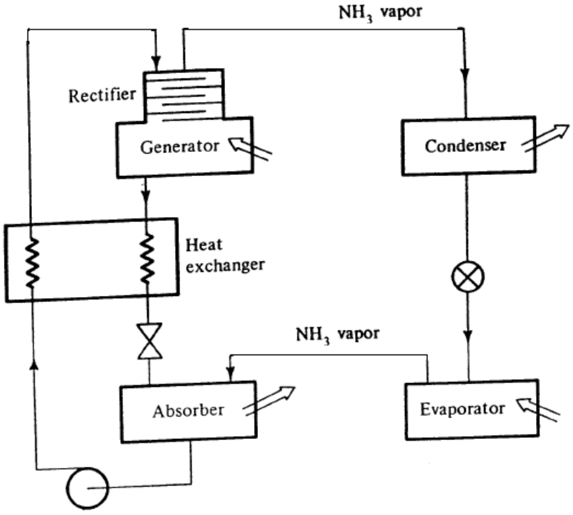

Figure.1 – Schematic diagram of simple absorption system

2- THERMAL DESIGN

The mass and energy balance were made in the input and output flow of each component for the design the system.

2.1- Paraboloidal Cylindrical Collectors

The type of solar collector is the elliptical parabolic concentrator. The design of solar collector was estimate through parameters collected at the prototype tested in the laboratory of Solar Energy Laboratory UFRN. The collector operate with steam to supply the generator. This apparatus was built in fiberglass. The surface of the concentrator of 2.24 m² was covered by layers of mirror of 0.02 m wide. The steam was produced in the absorber consists of a copper pipe of 0.028 m in diameter. The prototype has an automatic tracking of apparent motion of the sun, providing more convenience to the user of solar concentrator and uses an inexpensive electronic circuit that drives a motor through photo-sensor and timer. The schematic of the prototype solar collector in the figure below.

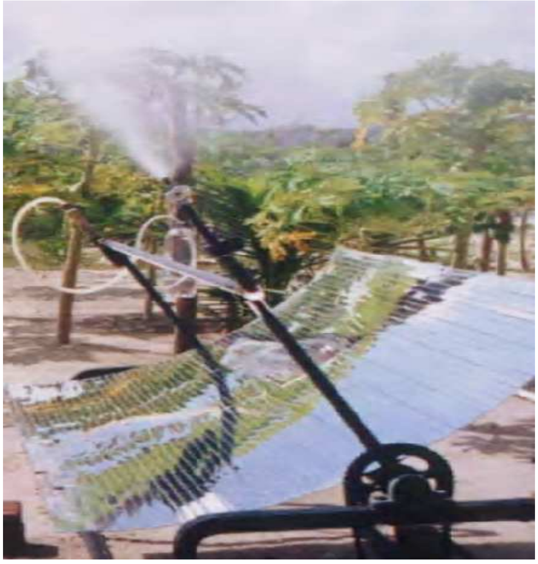

Figure 1. Elliptical parabolic concentrator of the laboratory of Solar Energy Laboratory UFRN

Duffie (1991) presents an energy balance in the solar collector. The collector receives direct solar radiation that part is lost to the environment and partly by optical losses and the remainder reaches the absorber of the collector. The useful power (P_u) and lost power (P_p) are defined by:

$$P_u = P_{abs} - P_p \tag{1}$$

$$P_p = P_{conv} + P_{rad} \tag{2}$$

The losses of the collector are convective and radiative and because of this depends on the temperature of the absorber of the collector. According to Souza Filho (2008), the greatest loss power of collector is loss convective, represented about 75% of loss power. The energy balance on the collector is shown in the figure 2.

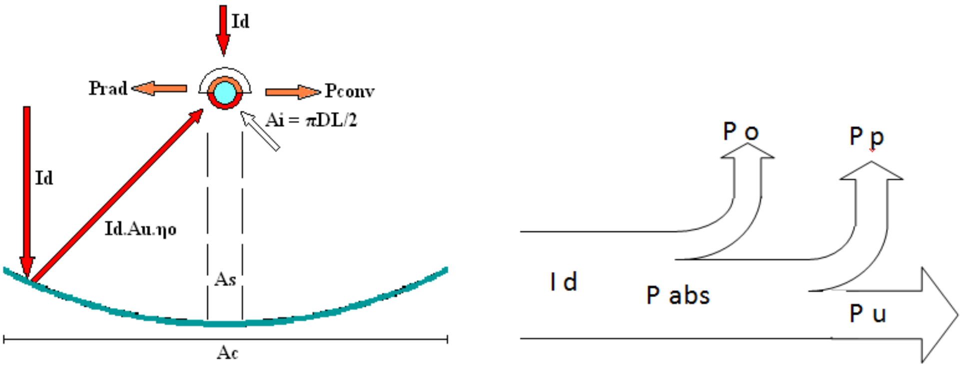

Figure 2. Energy flow of the cylinder-parabolic concentrator.

Where:

Id - instantaneous direct solar radiation collected by the traps (W/m^2)
P_{abs} - The maximum power that reaches the absorber tube (W)
P_{conv} - Power lost by convection (W)
P_{rad} - power lost by radiation to the environment (W)
A_u = (Ac - As) - Area of the concentrator (m^2)
A_c - Total area of the catchment surface (m^2)
A_s - area shaded by the absorber tube (m^2)
A_i - absorber area illuminated by the reflected radiation (m^2)

Due the losses are the efficiencies optical, thermal and useful, can be defined by:

Useful efficiency of collector

$$\eta_u = \frac{P_u}{I_D} = \eta_o \times \eta_t \tag{3}$$

Optical efficiency of collector

$$\eta_o = \frac{P_{abs}}{I_D} \tag{4}$$

Thermal efficiency of collector

$$\eta_t = \frac{P_u}{P_{abs}} \tag{5}$$

To diagnose the efficiency of the proposed concentrator were made many tests, (Souza Filho, 2008). The Measurements were collect from 8 to 15 pm each hour and calculated the daily average values. There were available the efficiencies of solar concentrator. A relationship between the daily average efficiency of the collector and useful temperature of the absorber can be seen in the figure 3.

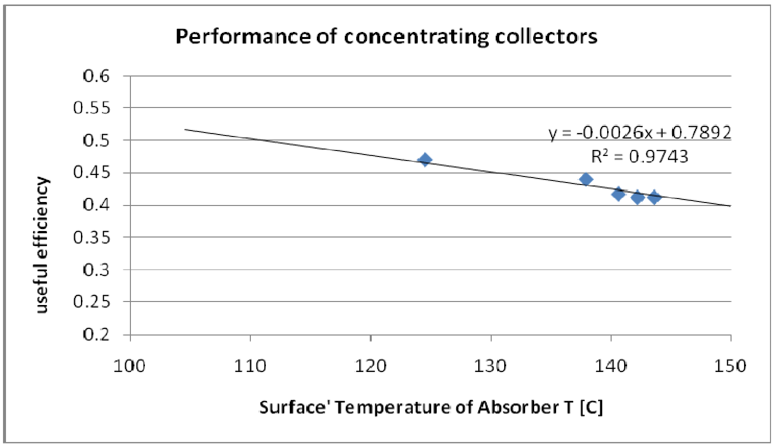

Figure 3. Effect of temperature of absorber at collector's efficiency

There was assumed a value of surface temperature of the collector's absorber that 110 ° C which corresponds to an useful efficiency of 50%.

2.2. Absorber

At absorber, the ammonia vapor from the evaporator is mixed with a solution of ammonia and water with low concentration of ammonia. Due to its chemical affinity, the solution absorbs the vapor, increasing its concentration.

The amount of vapor entering the absorber is the same as leaving the evaporator, and to be absorbed by the liquid solution, it increases their concentration (solution). The solution entering the absorber from the generator is called a weak solution or weak solution. To absorb the ammonia vapor from the evaporator, a solution becomes rich, or strong solution. The absorption of vapor by the liquid solution is an exothermic reaction and heat generated needs to be removed from the solution, so that this does not reach its equilibrium temperature (condition in which it would cease the effect of absorption). This is usually done by cooling air circulating around fins, or by passing water through coils in heat exchangers (Garimella, 2007). In this work the absorber is cooled by water entering and exiting at 30 oC to 37.29 oC. For this reason, the absorbers are usually designed with the methods and correlations used in the design of heat exchangers. In the figure is the representation of the heat exchanger-absorber.

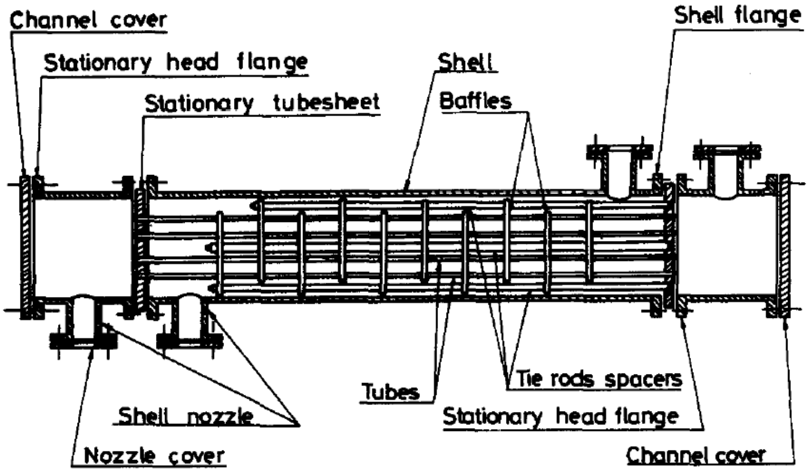

Figure 4. Schema of tube and shell heat exchanger

The shell-side heat transfer coefficient in the baffled-shell and tube type heat exchanger is calculated using the following relations that account for the various factors involved due to the baffle and tube configurations in the exchanger shell (Siddiqui 1997):

$$h_s = h_k . J_c . J_l . J_b . J_r \tag{6}$$

where: h_k is the shell-side heat transfer coefficient for an ideal tube bank, J_c is the correction factor for baffle configuration effect, J_l is the correction factors, for baffle-leakage effects, J_b is the correction factors for bundle-by-passing effects and J_r is the correction factors for adverse temperature gradient at intermediate Reynolds number. More information about the fators can be find in paper of (Siddiqui 1997).

The flow of cooling water inside the tubes in heat exchangers was obtained by a correlation coefficient of the film in laminar flow, according to Incropera (1996).

$$Nu = 1.86\left(\frac{\mathrm{Re}_D.\mathrm{Pr}}{L/D}\right)^{1/3}\left(\frac{\mu}{\mu_{\sup}}\right)^{0.14} \tag{7}$$

2.3. Generator/Retifier

Modeling the rectification column are studied extensively. The rectification column is an equipment of vital importance in the recovery of energy for absorption refrigeration systems. To design the system was developed modeled a rectification column using the model by(Threlkeld 1970).

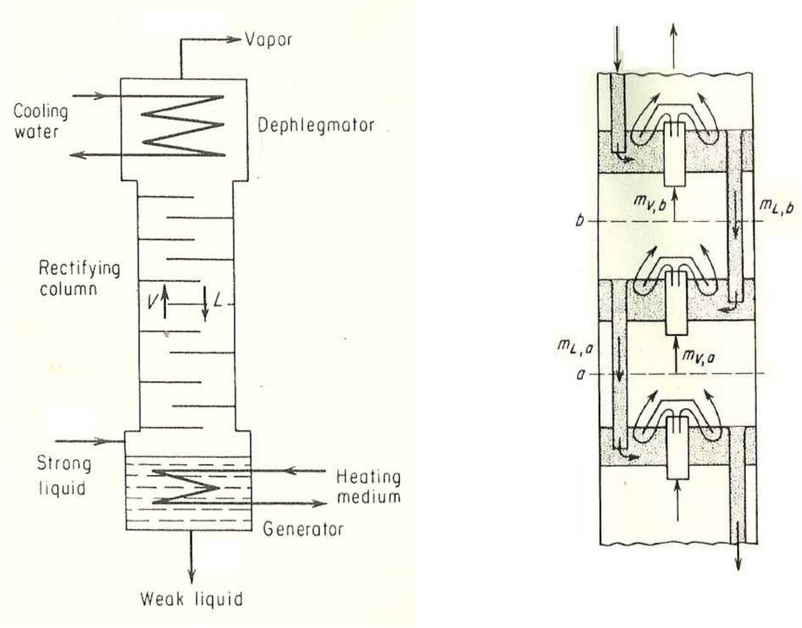

Figure 5. (a) Schema of rectifying column, (b) Flow of vapor and liquid in column

For produce an efficient separation of the binary mixture aqua-ammonia é necessary use a rectifying column between a generator and dephlegmator. The rectifying column has many capped plates or perforated plates. The vapor rise through the column and has some liquid condensed from it, while liquid downward has some vapor evaporated from it. The flow of liquid and vapor have a direct contact.

In each plate of column, the temperature of the vapor is greater than the temperature of the liquid. In limit case the both temperature are equals. Due the agitation in the generator, the temperature of vapor is the same that the temperature of the weak liquid. All liquid and vapor is assumed saturated.

The balances of mass, concentration and energy, in all plate composed by section (a) and (b), are:

$$\left(\dot{m}_v - \dot{m}_l\right)_a = \left(\dot{m}_v - \dot{m}_l\right)_b \tag{8}$$

$$\left(\dot{m}_v.x_v - \dot{m}_l.x_l\right)_a = \left(\dot{m}_v.x_v - \dot{m}_l.x_l\right)_b \tag{9}$$

$$\left(\dot{m}_v.h_v - \dot{m}_l.h_l\right)_a = \left(\dot{m}_v.h_v - \dot{m}_l.h_l\right)_b \tag{10}$$

Where: $\dot{m}$ is mass flow rate, x is mass solution concentration, h is specific enthalpy.

3- RESULTS AND DISCUTION

With the development of models is possible obtain data of each components. The data of heat transfer at absorption system with pairs water-ammonia in each component are represented in table.

Table 4. Heat transfer of the both cooling systems.

Componentes	Generator	Condenser	Evaporator	Absorver	Heat Exchanger
Heat Transfer (kW) systems NH_3-H_20	2.809	1.803	1.758	2.786	2.097

The temperature of weak solution output the generator is 98.22 ^oC and the specific pump work is 1.578 kJ/kg. The coefficient of performance of system is 0.6259.

The all components the generator consumes more heat in system. Using the rate heat transfer and the equation (6) and (7) was possible design the absorber. In the table below are the results of model.

Table 5. Characteristics of absorber

Outside diameter of tube	0.0114 m
Inside diameter of tube	0.009 m
Outside diameter of tube bundle	0.06725 m
Inside diameter of shell	0.08725 m
Number of tubes	20
Configuration of tube	triangle 30^o
DTML	7.711 ^oC
Outside coefficient of solution aqua-ammonia	37.59 W/m^2K.
Inside coefficient of water	477.8 W/m^2K
Length of heat transfer	0.75 m
Tube pinth	0.01425 m
Number of baffles	17
Mass flow rate of refrigeration water	0.09144 kg/s
Input mass flow rate of ammonia from evaporator	0.001631 kg/s
Input mass flow rate of weak solution from generator	0.008043kg/s
Output mass flow rate of strong solution	0.009674 kg/s

Using the equations (8), (9) e (10) was determinate the operation of rectifying column. The number of plate necessary to separate the solution is two. The model of column was made in three control volume decrypted in the figure 5.

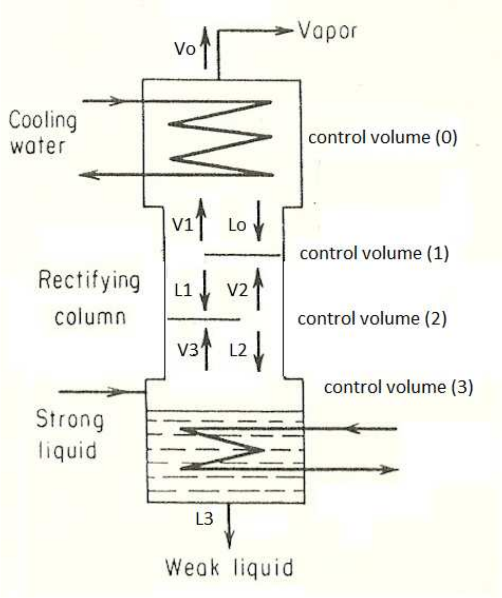

Figure 5. (a) Design of rectifying column

The solution concentration in vapor and liquid face was determinate, show them at figure 6.

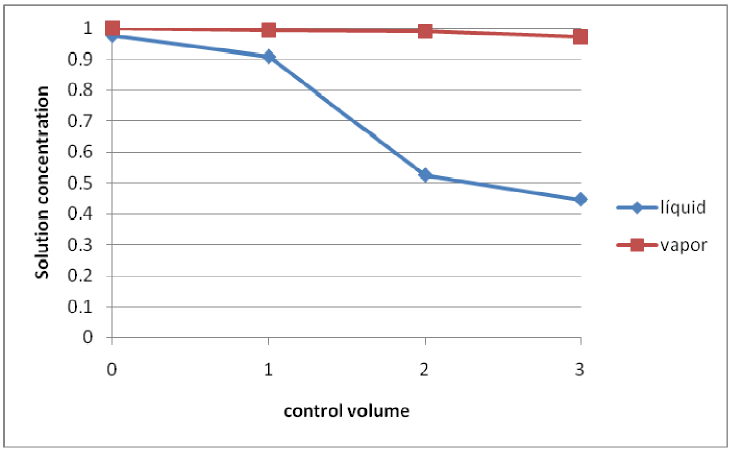

Figure 6. Behavior of solution's concentration at control volume

The ascending vapor, since the control volume (3) toward (0), develops a higher concentration due the increase of mass flow rate of vapor. Further the descending liquid solution, since the control volume (0) toward (3), develops a progressive weake concentration, due the reduction of mass flow rate liquid.

The rate of liquid recirculation (m_{Lo}/m_{Vo}) is 0.2742. The heat transfer of bottom generator is 3.497 kW, the cooling heat of dephlegmator is 0.6879 and the net heat transfer of generator is the diference between of heat transfer of bottom generator minus the cooling heat of dephlegmator, resulting in 2.809 kW.

With the heat transfer of bottom generator and the usefull efficiency of paraboloidal cylindrical collectors that 50%, the area of paraboloidal cylindrical collectors is 4, 68 m^2.

4- CONCLUSION

With data of efficiencies collected at prototype of paraboloidal cylindrical collectors and the modeling developed of generator/retifier was possible design the area of collectors. The usefull efficiency of collector is function of his surface'temperature. The correlation of heat transfer was used to design the absorber. This paper can be progressive study to build a compact absorption system water-ammonia by using solar radiation and evaluated the cost involved.

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