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CONSTRUCTIVE ANALYSIS OF A REFRIGERATION MACHINE OF THE DOUBLE-EFFECT ABSORPTION IN SERIES USING PAIR WATER / BROMIDE-LITHIUM, WITH THE REFRIGERATION CAPACITY ESTIMATED IN 0.5 TR.

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Abstract. *This paper describes an analysis of some aspects constructive of a machine refrigeration for absorption double-effect in series, using pair the water/ lithium-bromide, with the refrigerating capacity around 0.5 TR. The objective is to develop a machine which operates through a cogeneration system and reuses the heat from the exhaust gases of an engine combustion internal for cooling of the water for human consumption. The methodology consists of the creation of computational code for dimensional analysis and thermodynamics which platform was developed in EES (Engineering Equation Solver), taking advantage of the ease of obtaining the properties, especially of a solution water / lithium-bromide and construction of the prototype, analysis of operation and results obtained. Regarding this, we can report constant blockages in the circulation of the working fluid in the expansion devices thus demonstrating its not functionality; it was not possible to obtain the measurements of the flow of the working fluid through of the ultrasound appliances used; on the other hand, the cogeneration system proved able to supply the necessary energy for the functioning of the prototype constructed.. The machine is under development in the laboratory of the Institute for Sustainable Energy and IES-RECOGÀS, Cooperative Research Network North / Northeast Natural Gas, at the Federal University of Paraíba-UFPB and serve as a basis for studies involving cogeneration and machinery manufacturing small absorption cooling capacity*.

Keywords: *Refrigeration for absorption; dual effect in series; constructive analysis of the prototype*

1. INTRODUCTION

It is known that machines have absorption refrigeration coefficient of performance COP quite below those whose operation is based on compression systems. These, in turn, dominate considerably the market, encompass advantages that range from high yield in comparassion to other systems and a wide range of applicability until bigger ease of maintenance and manufacturing costs are reduced.

The increasing population and production, created the need to expand power generation. Currently, what is sought is the use of alternative and renewable sources of energy as well as cogeneration systems, ie alternatives that can promote the reuse of waste energy.

Aiming to take the heat released by the exhaust system of internal combustion engines for cold production by absorption refrigeration machines, we began the construction of a prototype low cooling capacity (about 0.5 TR) that uses water and bromide lithium as the working fluid and whereupon the function is to cool drinking water.

We propose to present and discuss important points that we found from the results achieved in the construction of our prototype so that they can serve as a basis for further work in this line of research.

For their characteristics construction, the absorption refrigeration machines have several heat exchangers and therefore require physical space most advantaged and have high costs of the manufacturing, particularly those using the solution water / lithium bromide as working fluid. Generally, units are designed for medium or large cooling capacity.

The challenge here is to build and put into perfect operation a low capacity cooling unit, which occupy as little space as possible, with low manufacturing cost and can be used in cogeneration plants.

Therefore, observed which these aspects mentioned above as well as reports inherent of perceived problems of order constructive and solutions to some of these problems and also proposals for new studies, considerable contributions given by this research.

2. METHODOLOGY

The methodological development took place in three stages, namely:

Dimensioning: has been developed based on work of (santos, 2005) in which is presented analysis about thermodynamic and heat transference obtained from the equations established in the literature, resulting in heat and mass fluxes, coefficient of performance,effectiveness,irreversibilities,rational efficiency, area of heat exchange and dimensions of the components.

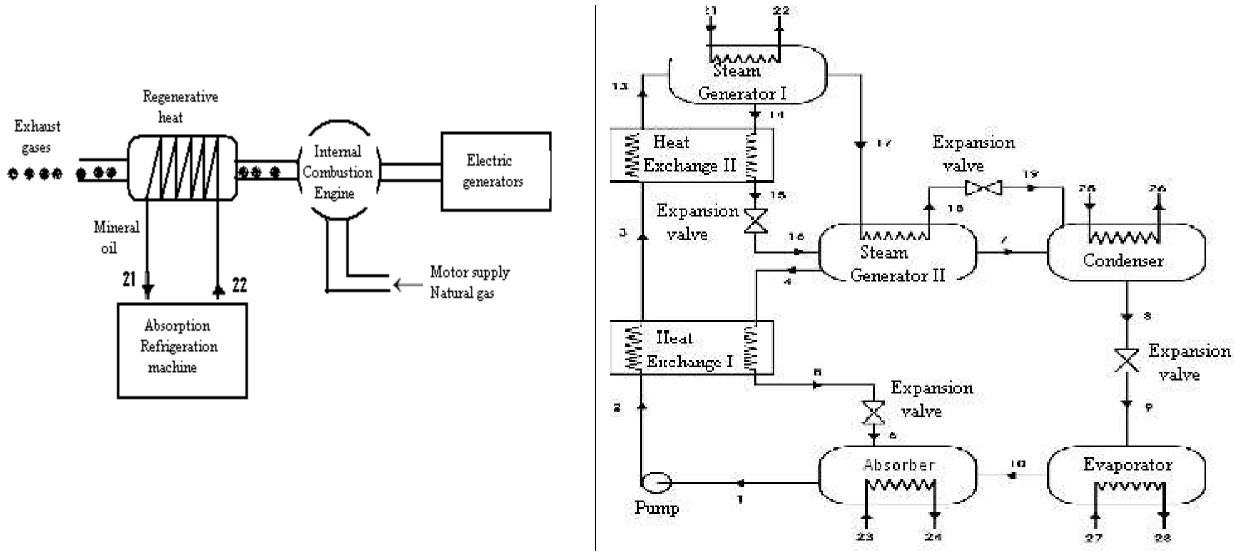
Construction of the pilot unit: monitoring of processes involving the manufacture of machine components, sealing tests of heat exchangers, assembly, selection of points for installation of measuring apparatus, instrumentation of the machine, machine operation test, the adjustments and correction.

Data acquisition and analysis of results: standing the machine in operation and instrumentalized, appropriate readings were made concerning the pressure, temperature and flow at several points of the machine and, in the sequence, analysis of the results.

3. PRINCIPLE OF OPERATION

Figures 1a and 1b illustrate respectively the cogeneration system and the absorption refrigerating machine of double effect in series. The machine comprises two steam generators, two heat exchangers, a condenser, an evaporator, an absorber, a pump for pumping the solution and four expansion valves.

The machine of the refrigeration was coupled to a heat regenerator which, in turn, will receive exhaust gases with high temperature of the internal combustion engine and a mineral oil at a lower temperature. The gases provide heat to the mineral oil and this, in turn, is sent to the steam generator (points 21) which will transfer heat the solution for water/ lithium bromide.



a) Diagram of the cogeneration system

b) Diagram of the absorption machine of double effect in series

Figure 1: Diagrams: a) cogeneration system; b) absorption machine of double effect in series

The working fluid of the absorption machine that is the water / lithium bromide solution is pumped directly from the absorber to the steam generator I, which has the highest pressure level of the system. Before reaching the generator, the fluid is pre-heated twice by passing heat exchanger I and II. Upon reaching the steam generator I, part of water - that in this case is the refrigerant which is in the solution - is vaporized by receiving heat from the mineral oil (points 21 and 22) and if will forward to the steam generator II (point 17).

The solution, whose concentration is on average level in coolant, goes to the heat exchanger II (point 14) transferring heat to the solution that will go to the steam generator I. Soon after, will undergo an expansion device (points 15 and 16) to reduce its pressure level and enters the steam generator II. Meanwhile, the water vapor produced in the steam generator I is sent to the steam generator II (point 17) in an independent circuit. Because the water vapor is at a higher temperature than the solution, it will transfer heat to the solution causing new vaporization.

The vapor coming from the generator I, after ceding heat to the solution, will pass through a expansion device (points 18 and 19) so that its pressure is also reduced to the average level, and then enters the condenser along with the steam coming from the generator II . The solution that remain in the steam generator II (solution with low concentration into refrigerant) goes to the heat exchanger I, where it will preheat the refrigerant-rich solution which goes to the steam generator I and then will be reduced at level low pressure in passing through an expansion device (point 5 and 6) reaching the absorber. The refrigerant, in turn, will condense in the condenser (points 19, 7 and 8) will pass through the expansion device (points 8 and 9) reducing also its pressure to the low level and will achieve the evaporator. Is exactly in the evaporator where the refrigerant will absorb heat from the ambient to the be refrigerated (points 27 and 28), because the ambient is at a temperature level higher than the refrigerant. This then continues to the absorber, where it will be absorbed by the low concentration solution in refrigerant, becoming now a solution of high refrigerant concentration again. Thereafter, the cycle begins once again through the pumping (points 1 and 2) of the high concentration solution to the generator steam I.

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4. ANÁLISE DE TRANSFERÊNCIA DE CALOR E DIMENSIONAMENTO

A análise de transferência de calor toma em consideração os aspectos construtivos de cada componente da unidade. Para fazer o dimensionamento dos diversos trocadores de calor, foi utilizado o método de diferenças de temperatura média logarítmica - DTML. Neste método, a taxa de transferência de calor entre os fluidos que circulam no controle de volume é dada pela fórmula:

$$Q = A_t . U_m . \Delta T_{ml} \tag{1}$$

The following considerations were taken in consideration: negligible heat loss to the surroundings; change in kinetic and potential energies negligible; constant properties; deposition factor in the tube negligible; fully developed flow conditions, fluid properties obtained from the ess, all exchangers operating in counterflow. Furthermore, the heat transfer equations have been derived from (Incropera et al, 2008), except those restriction reported during the equationing.

4.1 SIZING THE CAPACITOR

Internal flow: the fluid flowing in the inner pipes is water whose properties were obtained from ess based on the arithmetic average temperature in relation to the inlet temperature and outlet water tubes. The reynolds number is calculated for fluid flow in a single tube and is determined by:

$$\mathrm{Re}_{(\mathrm{int})} = \frac{4.\left(\dfrac{\dot{m}_{(H_2O)}}{N_T}\right)}{\pi . d_{(\mathrm{int})} . \mu_{(H_2O)}} \tag{2}$$

The nusselt number in the turbulent flow within the tube smooth can be determined from correlations for the convection flow in circular pipe. For re found is valid the using of the equation:

$$Nu_{(\mathrm{int})} = 0{,}023 . \mathrm{Re}_{(\mathrm{int})}^{0,8} . pr^{0,3} \tag{3}$$

where Prandlt number is given by:

$$pr = \frac{Cp_{(H_2O)} . \mu_{(H_2O)}}{k_{(H_2O)}} \tag{4}$$

known the nusselt number, the internal convection coefficient is given using the equation:

$$h_{(\mathrm{int})} = \frac{Nu_{(\mathrm{int})} . k_{(H_2O)}}{d_{(\mathrm{int})}} \tag{5}$$

External flow: the fluid flowing amongst the inner tubes of the condenser and the hull is water vapor, which must be condensed. Whereas the condensation process takes place in the form of film, the convection coefficient can be calculated from the equation:

$$h_{(ext)} = 0{,}729 \left[\frac{g . \rho_l . (\rho_l - \rho_v) . h'_{lv} . k_l^3}{\mu_l . (T_{sat} - T_{\sup}) . N_{T,F} . D_T} \right]^{\frac{1}{4}} \tag{6a}$$

and that (h'lv) is the enthalpy corrected in a phase change, which is determined by the number of jacob which is the ratio between the energy sensible absorbed s and energy latent absorbed in changing the liquid-vapor phase, or

$$Ja = Cp_v \frac{(T_{\sup} - T_{sat})}{h_{lv}} \tag{6b}$$

$$h'_{lv} = h_{lv} (1 + 0{,}68 . Ja) \tag{6c}$$

the properties of the saturated liquid contained in equation (6a) were obtained taking into account the temperature of the film, which can be determined by the equation:

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$$T_{(filme)} = \frac{T_{(sup)} + T_{(inf)}}{2} \quad (7)$$

The temperature of saturation tsat is equal to the temperature of the condensate at the condenser outlet, ie t8. However, like the capacitor has two steam inlet pipes is necessary that the in surface temperatures tsup and in the endless tinf are determined as follows: first was estimated an average temperature of steam entering the condenser based in energy conservation and considering the constant specific heat , resulting:

$$T_{Sat\,(7,19)} = \frac{\dot{m}_7\, T_7 + \dot{m}_{19}\, T_{19}}{\dot{m}_7 + \dot{m}_{19}} \quad (8)$$

Then, estimate the temperature at a point distant from the surface of the tubes called here the temperature at infinity given by:

$$T_{(inf)} = \frac{T_{(7,19)} + T_8}{2} \qquad \text{(temperature at infinity)} \quad (9)$$

The surface temperature of the pipe was considered as the average of the inlet and outlet temperatures of the cooling water inside the tubes, given by:

$$T_{(sup)} = \frac{T_{25} + T_{26}}{2} \qquad \text{(surface temperature)} \quad (10)$$

To calculate the overall coefficient is necessary to use the following equation:

$$U_m = \frac{1}{h_{(int.)}.A_{(int,lat)}} + \frac{\ln\left(D_h / d_{(int)} \right)}{2.\pi.L.K_{aço}} + \frac{1}{h_{(ext.)}.A_{(ext,lat)}.N_T} \quad (11)$$

The calculation of the logarithmic mean temperature difference is made based on heat exchangers in countercurrent. Thus, the equations are used:

$$\Delta T_{ml} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} = \frac{T_{26} - T_{25}}{\ln\left(\frac{T_{26} - T_8}{T_{25} - T_8}\right)} \quad (12)$$

$$\Delta T_1 = T_{q,e} - T_{fr,s} \quad \text{e} \quad \Delta T_2 = T_{q,s} - T_{fr,e} \quad (13)$$

The total area of heat exchange is calculated by the equation:

$$A_t = \pi.D_T.L_T.N_T \quad (14)$$

Substituting equation (14) into equation (1), lie the relationship between tube length and number of tubes which is given by:

$$L_T.N_T = \frac{Q}{\pi.D_T.U_m.\Delta T_{ml}} \quad (15)$$

4.2 SCALING EVAPORATOR

By the evaporator circulates two streams of fluid, whereas circulating water inside the tubes, which must be cooled, while which by the area between the hull and the tubes circulates the coolant which, in this case, too is water. Furthermore, it was considered in the film boiling process.

Internal flow: to obtain the properties of water was adopted the average arithmetic of the temperatures of the inlet and outlet of the water evaporator, since the water temperature varies during its passage through the tubes. To calculate the reynolds number was used to equation (2), while the nusselt number was used to the equation:

$$Nu_{(int)} = 0{,}023.\text{Re}_{(int)}^{4/5}.\text{Pr}^{0,4} \quad (17)$$

After finding nusselt number, one can determine the coefficient of internal convection through equation (5).

External flow: the fluid flowing through the inner tubes of the evaporator and the hull is also water. However, it is intended that she leaves the evaporator as saturated vapor. The convection coefficient can be calculated from the equation (6a), and the properties of the saturated liquid were obtained by taking into consideration the temperature of the film, which can be determined by applying the equation (7), resulting on:

$$T_{(sup)} = \frac{T_{27} + T_{28}}{2} \quad \text{e} \quad T_{(sat)} = T_{10} \quad (18)$$

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To calculate the overall coefficient was made use of equation (11). The calculation of the logarithmic mean temperature difference is made based on heat exchangers in countercurrent. Are used eq (12), (13a) and (13b), resulting in:

$$\Delta T_{ml} = \frac{(T_{28} + T_9) - (T_{27} + T_{10})}{\ln\left(\frac{T_{28} - T_{10}}{T_{27} - T_9}\right)} \tag{19}$$

The total area of heat exchange and the relation of the tube length and number of tubes are given by equation (14) equation (15).

4.3 DESIGN OF EXCHANGERS INTERMEDIARIES

The fluids that will circulate in the intermediate heat exchangers is the solution with water / lithium bromide in different concentrations, and posteriorly will exchange heat between them without any phase change. The solution with low concentration passes through the annular region in both exchangers.

Internal flow: the reynolds number for a single tube is determined by the equation:

$$\mathrm{Re}_{(\mathrm{int})} = \frac{4.\left(\dot{m}_{(LiBr)} / N_T\right)}{\pi . d_{(\mathrm{int})} . \mu_{(LiBr)}} \tag{20}$$

For number reynolds found, is taken up nusselt equal to Nu = 4.36. Knowing the nusselt number, the internal convection coefficient can be determined by:

$$Nu = \frac{h_{(\mathrm{int})}.d_{(\mathrm{int})}}{k_{(LiBr)}} = 4{,}36 \tag{21}$$

Annular flow: the reynolds number was calculated by:

$$\mathrm{Re}_{(an)} = \frac{4.\dot{m}_{(LiBr)}}{\pi . D_h . \mu_{(LiBr)}} \tag{22}$$

For reynolds found , nusselt Nu = 4.36 is taken. knowing the value of the nusselt number, the external convection coefficient is determined from the equation:

$$Nu = \frac{h_{(ext)}.D_h}{k_{(LiBr)}} \tag{23}$$

The calculation of the overall coefficient is determined using the equation (11) and the logarithmic average of the temperature differences is determined by eq (12), (13a) and (13b), resulting in:

$$\Delta T_{ml} = \frac{(T_{15} + T_{13}) - (T_3 + T_{14})}{\ln\left(\frac{T_{15} - T_3}{T_{14} - T_{13}}\right)} \quad \text{(Trocador de calor de alta)} \tag{24a}$$

$$\Delta T_{ml} = \frac{(T_5 + T_3) - (T_2 + T_4)}{\ln\left(\frac{T_5 - T_2}{T_4 - T_3}\right)} \quad \text{(Trocador de calor de baixa)} \tag{24b}$$

Combining the equations (14) and (15), found is the total area of the heat exchange and relationship between tube length and number of tubes, being given by:

$$\dot{Q} = \dot{m}_3 \left(h_{13} - h_3\right) \quad \text{trocador de alta} \tag{25a}$$

$$\dot{Q} = \dot{m}_3 \left(h_{13} - h_2\right) \quad \text{trocador de baixa} \tag{25b}$$

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4.4 SIZING THE ABSORBER

The absorbing device is responsible for promoting the absorption of the water vapor coming from the evaporator by the lithium bromide solution of the concentration strong coming from the steam generator low, causing retorne concentration of the solution to level weak and, thus, complete the absorption refrigeration cycle. In the process of absorption heat is release, a fact that will make the vapor absorption more difficult if the volume control is not removed. For this purpose, it is necessary that a cooling system in this case is carried out by passing water through the tubes comprising the absorber. The heat that must be removed is determined by the equation:

$$\dot{Q}_{abs} = \dot{m}_{23}\, cp_{(H2O)}(T_{24} - T_{23}) = UA_t \Delta T_{ml} \quad (26)$$

Internal flow: the reynolds number for a pipe is given by equation (2) and the nusselt number is given by equation (3). Already the internal convection coefficient is given by equation (5).
External flow: the refrigerant coming from the evaporator, preferably in the vapor phase, should be absorbed by strong concentration solution coming from the steam generator low. In this case the steam will condense, thus forming a solution of weak concentration. Both the streams will go through between the tubes and the hull of the absorber. For the determination of the external convection coefficient , use is made of equation (6a). To determine the temperature of the film, since it has one inlet flowing strong solution and other water vapor, is calculated as follows: first, determine an average temperature for the entry of steam and the solution concentration strong as if it were a single entry, made through the conservation of energy which resulted in the equation:

$$T_{(6,10)} = \frac{\dot{m}_6 . T_6 + \dot{m}_{10} . T_{10}}{\dot{m}_1} \quad (27)$$

It then calculates the temperature at infinity given by:

$$T_{(\inf)} = \frac{T_{(6,10)} + T_1}{2} \qquad \text{(temperature at infinity)} \quad (28)$$

the surface temperature of the pipe was considered as the average aritmética of the inlet and outlet temperatures of the cooling water circulates through the interior of the tubes, given by:

$$T_{(\sup)} = \frac{T_{23} + T_{24}}{2} \qquad \text{(surface temperature)} \quad (29)$$

The temperature of the film used to determine the properties of solution and steam entering the absorber is given by equation (7), whereas the average concentration is calculated by the equation:

$$x_m = \frac{\dot{m}_6\, x_6 + \dot{m}_{10}\, x_{10}}{\dot{m}_1} \quad (30)$$

To calculate the overall coefficient is made use of equation (11). Applying the equation (12) and (13), is found the average logarithmic of the temperature differences of which is given by:

$$\Delta T_{ml} = \frac{(T_1 - T_{24}) - (T_{(6,10)} - T_{23})}{\ln\left(\dfrac{(T_1 - T_{24})}{(T_{(6,10)} - T_{23})}\right)} \quad (31)$$

The total surface of heat exchange corresponds area of the tubes and relationship between tube length and number of tubes is determined by combining the equation (14), (15) and (26).

4.5 SIZING STEAM GENERATOR HIGH

It is considers too that the process water boiling will realized in the form of film. Since there is no phase change of the mineral oil, heat that will be transferred to the solution of the water / lithium bromide is estimated by using the thermodynamic equation,

$$\dot{Q}_{gI} = \dot{Q}_{óleo} = \dot{m}_{óleo}\, cp_{m,óleo} \Delta T_{óleo} = UA_t \Delta T_{ml} \quad (32)$$

To calculate the average specific heat, use is made of the data supplied by the manufacturer oil. The average specific heat is calculated as the arithmetic average of the specific heats of the oil inlet and outlet of the generator, which is given by:

$$cp_{m,óleo} = 0{,}001675(T_{21} + T_{22}) + 1{,}84175 \quad (33)$$

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We despise the loss heat to the environment because the generator is thermally insulated and we consider that all the heat supplied by the oil will be absorbed by the solution of water / lithium bromide concentration weak that passes between the tubes and the hull of the generator.

Internal flow: for the determination of the properties of mineral oil, was adopted its operating of temperature would be given by the arithmetic mean of the inlet and outlet temperatures of the steam generator. The reynolds number for a pipe is given by:

$$\mathrm{Re}_{(\mathrm{int})} = \frac{4\left(\dot{m}_{(óleo)} / N_T\right)}{\pi . d_{(\mathrm{int})} . \mu_{(óleo)}} \tag{34}$$

For re found nusselt is determined by equation (17) and the number of prandlt given by:

$$\mathrm{Pr} = \frac{cp_{(m,óleo)} . \mu_{(óleo)}}{k_{(óleo)}} \tag{35}$$

Known nusselt number, the internal convection coefficient is determined by:

$$h_{(\mathrm{int})} = \frac{Nu_{(\mathrm{int})} . k_{(óleo)}}{d_{(\mathrm{int})}} \tag{36}$$

External flow: the steam generator of the high will receive a solution with concentration weak and will have as output streams water vapor and solution with concentration average coming out by for different tubes. Thus, there has one input and two outputs. In this case, it becomes necessary to identify an optimum temperature in order to obtain the properties of solution and steam considering that there is two outputs instead of only one. To do so, was determined an average temperature for the steam and the solution of medium concentration as if it were a single output. This was done through the conservation of energy which resulted in the equation:

$$T_{(14,17)} = \frac{\dot{m}_{14} . T_{14} + \dot{m}_{17} . T_{17}}{\dot{m}_{13}} \tag{37}$$

Then determines the temperature at a point distant from the surface of the tubes, ie the temperature at infinity which is given by

$$T_{(\inf)} = \frac{T_{(14,17)} + T_{13}}{2} \tag{38}$$

The surface temperature of the pipe was considered as the average of the inlet and outlet temperatures of the mineral oil in the tubes, given by:

$$T_{(\sup)} = \frac{T_{21} + T_{22}}{2} \tag{39}$$

The temperature of the film used to determine the properties of the solution and of the vapor leaving the generator is set according to Eq (7). The average concentration is calculated by the equation:

$$x_m = \frac{\dot{m}_{14}\ x_{14} + \dot{m}_{17}\ x_{17}}{\dot{m}_{13}} \tag{40}$$

Having the values of temperature of the film and of the solution of concentration average and making use of the EES, we found the necessary properties to be continue the other calculations involved in sizing. The calculation of external convection coefficient in the film boiling process for horizontally disposed cylinder has been developed based on Eq. (41), Bejan (1948).

$$\frac{h_{(ext)} . D_T}{k_v} = 0{,}62\left[\frac{D_T^3 . g . (\rho_l - \rho_v)\, h'_{lv}}{k_v . v_v \left(T_{(filme)} - T_{sat}\right)}\right]^{\frac{1}{4}} \tag{41}$$

To calculate the overall coefficient was made use of Equation (11). The calculation of the logarithmic mean of the temperature differences is made based on heat exchangers in counter-current, resulting in:

$$\Delta T_{ml} = \frac{(T_{21} - T_{13}) - (T_{22} - T_{(14,17)})}{\ln\left(\frac{(T_{21} - T_{13})}{(T_{22} - T_{(14,17)})}\right)} \quad (42)$$

The total area of the heat exchange, corresponde to surface of the tubes and the relationship between tube length and number of tubes is determined by combining the equation (14), (15) and (32).

4.6 Sizing Generator of the Low

The heat provided to the operation of the steam generator of lower is originating from water vapor coming from the generator of high. It is considered that all the heat supplied by the vapor will be absorbed by the solution of water / lithium bromide

$$\dot{Q}_{gII} = \dot{m}_{17}(h_{17} - h_{18}) = UA_t \Delta T_{ml} \quad (43)$$

Internal flow: Water vapor passing through the tubes will yield heat to the solution found between the tubes and the hull of the generator. There is a trend, so that part of this steam undergoes a phase change during draining. For low speeds of the flow steam, are valid the eq. (44) and (45). Çengel (2009, p.591).

$$\mathrm{Re}_{v,e} = \left(\frac{\rho_v . u_{(m,v)} . D_T}{\mu_v}\right) < 35000 \quad (44)$$

$$\overline{h_{(\mathrm{int})}} = 0{,}555\left[\frac{k_l^3 . g.(\rho_l - \rho_v) h'_{lv} . \rho_l}{\mu_l .(T_{(sat)} - T_{(\mathrm{sup})}) D_T}\right]^{\frac{1}{4}} \quad \text{sendo} \quad h'_{lv} \equiv h_{lv} + \frac{3}{8} . cp_l .(T_{sat} - T_{\mathrm{sup}}) \quad (45)$$

External Flow: The procedure for dimensioning should be similar to previously developed for generator of high. The temperature of the flow of the generator output is given by:

$$T_{(4,7)} = \frac{\dot{m}_4 . T_4 + \dot{m}_7 . T_7}{\dot{m}_{16}} \quad (46)$$

The temperature at a point distant from the surface of the pipe, is given by;

$$T_{(\inf)} = \frac{T_{(4,7)} + T_{16}}{2} \quad (47)$$

The surface temperature of the pipes was considered as the average of the inlet and outlet temperatures of the steam from the generator of higt which pass inside the tubes, being given by:

$$T_{(\mathrm{sup})} = \frac{T_{17} + T_{18}}{2} \quad (48)$$

The temperature of the film is then determined by Equation (17), whereas the average concentration is calculated by the equation:

$$x_m = \frac{\dot{m}_{16}\ x_{16} + \dot{m}_4\ x_4}{\dot{m}_{16} + \dot{m}_4} \quad (49)$$

The calculation of external convection coefficient in the film boiling process for cylinders arranged horizontally has been developed based on Equation (41) and the calculating of the global coefficient was made with the use of Equation (11). The calculation of the mean logarithmic of the temperature differences is made based on heat exchangers in counter-current, resulting in:

$$\Delta T_{ml} = \frac{(T_{24} - T_{(4,7)}) - (T_{23} - T_{22})}{\ln\left(\frac{(T_{24} - T_{(4,7)})}{(T_{23} - T_{22})}\right)} \quad (50)$$

The area total of heat exchange corresponds to the surface of the tubes and the relationship between tube length and number of tubes is determined by combining the equation (14), (15) and (43).

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5. RESULTS

For acquisition of data on temperature were installed at appropriate points and of form noninvasively type thermocouples "MTK-01" and Digital Thermometer MT-525 (manufacturer: Minipa) ". We were careful to use folder and thermal insulation during installation of the thermocouples in order to obtain the most accurate results possible.

Table 1 shows the measured values at intervals of about fifteen minutes. Only four readings were made, since from that instant, it was found that there was blocking the circulation of the working fluid.

Table 1 - Temperature values obtained in several points of the machine.

Temperature em (ºC)	1º reading	2º reading	3º reading	4º reading
T_3	32,0	37,1	57,5	50,2
T_8	32,8	37,5	40,4	42,3
T_{13}	33,6	65,5	76,0	59,9
T_{14}	33,6	78,4	84,0	56,4
T_{15}	34,8	44,9	72,8	52,4
T_{17}	34,5	66,8	76,8	78,5
T_{21}	33,8	111,8	156,5	162,8
T_{22}	33,8	105,7	149,4	157,9
$T_{23}=T_{25}$	31,8	32,3	39,7	40,7
T_{24}	31,9	32,3	41,8	40,9
T_{26}	31,9	33,4	41,6	43,1
T_{27}	30,9	30,3	31,7	31,2
T_{28}	30,7	29,7	30,8	29,9
Note: The values shown in subscript in column number one, corresponds the place of installation of the thermocouples as shown in the diagram in Figure 1.				

From the values of the temperatures shown in "Tab.1" You can say that there was movement of fluid in the pipes and the occurrence of heat exchange between the solutions of form check the functioning of the heat exchanger of the high. According Khaliq and Kumar (2007), the operating temperature of the generator of the steam of the high to an machine coolant vapor absorption double effect in series should be around 160 ° C, temperature that is compatible with the fourth reading, points 21 and 22. The effectiveness of the heat exchanger of the high determined experimentally and building on the values of the third reading of "Tab 1" is 0.698, while the estimated value of the work of Santos (2005) is 0.7. Temperatures T_{27} and T_{28} also show a small effect fridge, but far short of what you wish to achieve.

For the case of pressure measurement in the system, were used pressure transducers TM25/100 / manufacturer-Hytronic, one installed on the evaporator / absorber (low pressure) and other in generator of the steam II (intermediate pressure) and a pressure gauge PIEZOVAC PV20 installed in the steam generator I (high pressure) along with the pressure indicator HM204 / manufacturer-Hytronic. Table 2 shows the values obtained by these devices.

Table 2 - Values for the pressures in the system.

Pressure (mBar)	1º	2º	3º	4º
High	43,0	335,0	479,0	483,0
Average	33,4	55,2	71,9	75,5
Low	8,8	23,1	62,4	61,9

The pressures indicated by Santos (2005) is 0.87 kPa, 4.42 kPa and 77.52 kPa for low, medium and high, respectively. Observing the values obtained in "Tab.2", you can check an equalization between the three pressure levels achieved mainly at the beginning of the operation. However, with the passage of time, the low pressure showed a elevated value.

As for the measures of flow of the working fluid, were used Flow Meter Ultra Sonic UFM140 / manufacturer-FMS Plandata CSI Ltda and Flowmeter PORTAFLOW Ultra Sonic X / Manufacturer-Fuji Electric. These devices were used to measure the flow rate of the working fluid at the inlet and outlet of the steam generator I (points 13 and 14 of the diagram of Fig 1b) and the output of the solution in steam generator II (point 4 of the diagram of Fig.1b). The values obtained were unstable and have suffered swings and constant dropouts. It is believed that the fact preponderant for that episode is in tubing diameter below the indicated minimum specification for the use of equipment that is 13 mm, supplied by the manufacturer. On the other hand, the flow of mineral oil the enter in steam generator I (point 21 in the

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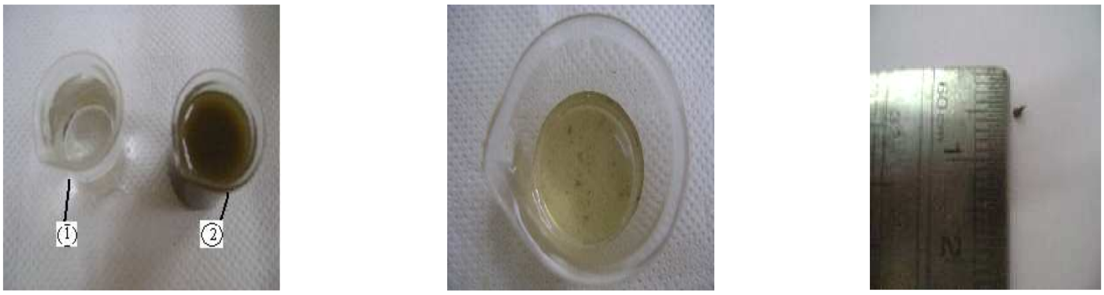
diagram of Fig 1b) was obtained without any problems, seeing that the tubing used was 19 mm, remained completely full and no waste particles solid and also air bubbles that might interfere in reading. The value found was 0.08 l / s.

6. CONCLUSION

Was observed a deficiency in machine operation. The flow rate of the working fluid was blocked several times during the tests, and also at the time of acquisition of the data shown in the tables. Display devices installed in the machine indicated that solid particles were settled in the holes of expansion and blocked the passage of fluid, even after several cleaning processes which were conducted by washing with water jet, injection of compressed air and argon gas. It is believed that the lithium bromide, for being extremely corrosive, chemically reacted with residues from the welding and thus particles in suspension in the working fluid have been observed as shown in Figure - 2.



1 – New solution
2 – Solution withdrawal of the machine

a) Solution LiBr / H_2O b) Solid particles in the solution c) size of the solid particle

Figure 2 - Solution contaminated with solid particles

What is being proposed to try to solve this problem is to make the replacement of the orifice by expansion tubes "U", because the costs to buy valves for this finality would be quite high.

The theoretical results obtained by analyzing thermodynamics and heat transfer are consistent with the literature and, therefore, do not cease to be validated by experimental results obtained in the pilot plant. Actually cause, make with which continuity occurs in absorption refrigeration cycle to the machine reach the steady state is only the starting point so that if can achieve results futures and indicate the satisfactory operation of the unit built from new interventions.

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8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.