Design And Analysis Of Absorption Refrigeration Systems

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Abstract. *The present study points to the construction of a computational simulator for energetic and exergetic analysis of an Absorption Refrigeration Unit of multiple effects, and design of the expansion devices to ensure the operating conditions of the system under the conditions specified at priori. The simulator is built on the ESS platform, which analyzes the conditions of entry of the cycle such as the condenser and evaporator temperatures, levels of concentration and heat available in the generator. The concept of exergy is extended to an energy analysis and the performance are obtained in the form of rational efficiency and degree of thermodynamics perfection. The ESS platform allows the knowledge of thermodynamic properties at specific points where with the combined use of the equations of continuity, momentum and energy equation is possible to design orifices capable to establish control and pressure balance in the steam generator , absorber, evaporator and condenser. Using the correlation developed for predict the crystallization, depending on orifice diameter to avoid clogging problems during operation of the system. The proper sizing is needed to control pressure levels in the three-cycle system pressure vessels, this control is difficulty to do through valves due to the negative pressure system and the unwillingness of those in the market.*

Keywords*: simulation, absorption refrigeration, ees plataform*

1. INTRODUCTION

The burning of fuels in industrial processes, results in heat that's in many cases is rejected to the neighborhood. This heat can be used as a source of energy in cooling systems using absorption refrigeration Technology.

The fundamental operating principle of the absorption refrigeration cycle is the property that some refrigerant vapors are absorbed by other fluids or saline solutions and may be separated by heating. This heating can be obtained by the energy rejected by some industrial process, which reduces global emissions of CO2 in the atmosphere and thus the greenhouse effect.

With the banning of chloro-fluor-carbons, the search for harmless refrigerants has been driven. In this respect we have vantages in the fluids used for absorption cooling system, because they have have the desirable characteristic of being environmentally friendly because working fluid of the proposed system the is a binary mixture of "water and a salt called lithium bromide, avoiding the problem of fluids used in vapor compression refrigeration systems, which are halogenated fluids and degrade the ozone layer.

To promote the use of absorption refrigeration systems is necessary to raise their performance and reduce its cost. According to Cortez, l.a.b., Mühle, i.n. Silva (1998), in 1950 a system using the mixture water / lithium bromide as working fluid was introduced into industrial applications. Some years later a double effect system was introduced as a standard for a high performance system. However the vapor compression cycle that is about 100 years old is still dominant in the air conditioning in cooling applications, but the cooling systems for absorption of steam are still viable options for certain applications, particularly in the field of industry gas and water coolers on a large scale.

The objective of this papper is to develop a simulator capable of design an absorption refrigeration system, up to 10 Tons of Refrigeration to replace the air conditioners from windows, because they represent the majority of domestic installations for the production of thermal comfort and use traditional systems of vapor compression. These systems are sourced from electricity, so worrying at present mainly in the North and Northeast that has shown a deficit in production. The simulator is developed in ESS platform, due to programming flexibility and ease in obtaining the thermodynamic properties of working fluids involved in the system, the fuel source of the system would be natural gas due to ease of access and according to Carvalho, J.G., (1990) is in crescent expansion.

The absorption refrigeration systems are in essence a set of heat exchangers with phase change, arranged in an organized way to produce cold and the processes of heat and mass transfers occurring in the components of refrigeration systems for vapor absorption are quite complex and the fields of velocity, temperature and concentration that occur in the various components of the absorption refrigeration system are difficult to determine. As a result, obtaining the expressions for the Nusselt numbers are also complex, which serves to determine the heat transfer coefficients used in the design of heat exchangers.

Since the coefficient of heat exchange and the average change in temperature is estimated is needed to determine sufficient area to ensure that the amount of heat gained by the fluid is equal to the amount lost by the hot fluid. In many cases the physical dimensions are important but the exchange coefficient can be small and will need a large surface to ensure that there is an exchange of heat needed. In these cases, to reconcile the need for smaller size and weight with a large surface área, are fixed thin metal plates, they are the fins, which serve to increase the area of heat exchange. The total heat transfer through the finned surface is obtained by adding the portion of the heat transfer through the fins with the portion of smooth surface between the fins.

Figure 1 shows schematically the basic single effect cycle of absorption refrigeration that it uses as working fluid a solution of Water and lithium bromide.

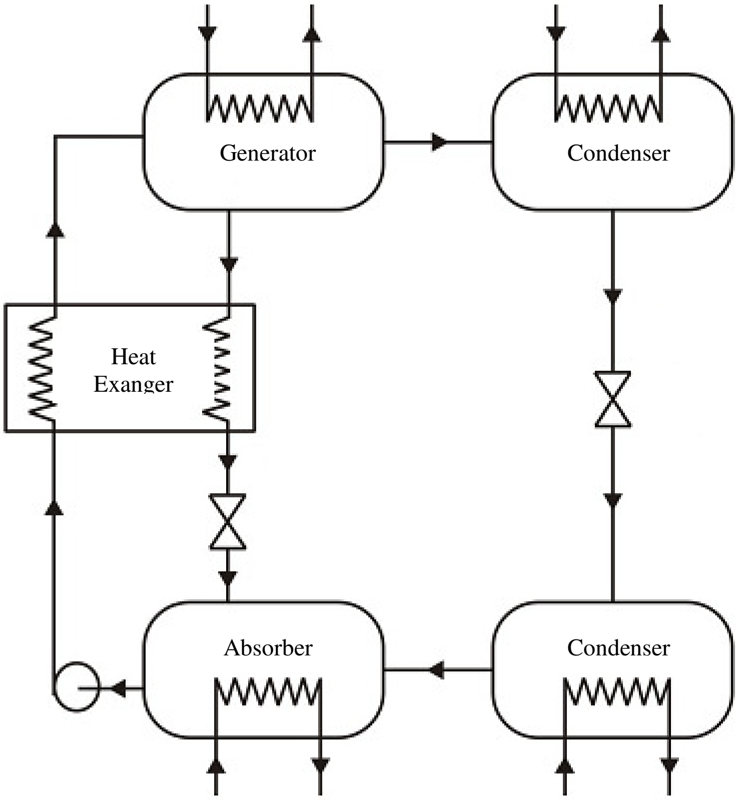


Figure1 Single effect absorption refrigeration system

The operation of this system begins in the steam generator, it is the most important heat exchanger in the cycle because that is where most of the heat exchange of the entire system occurs. After leaving the generator the absorbing solution is heated so that the refrigerant (water) more volatile will suffer desorption. The refrigerant vapor, the at higher pressure, then follow the path: condenser → expansion valve → evaporator, similar to the vapor compression cycle.

The low pressure steam leaving the evaporator is routed to the absorber, where the pressure is kept low thanks to the affinity of the refrigerant vapor. The refrigerant vapor is absorbed by the absorbent in the same way that the condenser this process is exothermic, ie, supplies heat to medium, so you need to cool the absorber in the process or absorption of steam would cease

The refrigerant-absorbent solution is pumped in order to pass through the heat exchanger where it is preheated by the solution coming from the high temperature generator, returning to the generator where the cycle restarts.

The double effect absorption refrigeration system series has higher overall efficiency than the system of simple fact, the double effect is due to recovery of energy contained in the steam coming out of the first generator in a second steam generator that will be at lower pressure and allows more vapor extraction from the solution, the double effect has three levels of concentration and three levels of pressure.

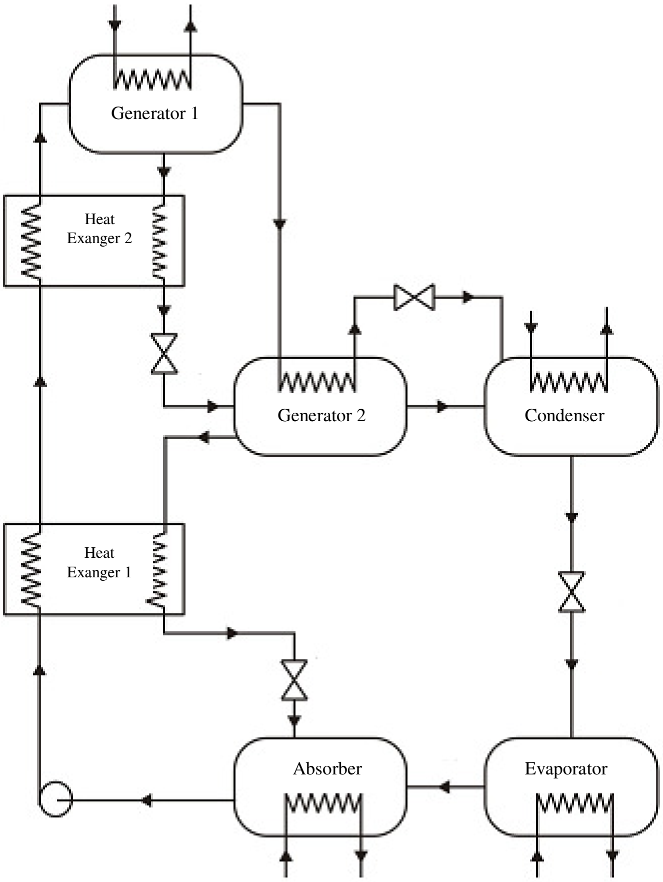


Figure 2 double effect absorption refrigeration system

For the sizing of system components is required before a thermodynamic analysis of the cycle. The thermodynamic analysis was needed to predict the behavior of static points throughout the system and thus predict the locations where there will be the largest irreversibilities as well as to make it possible to evaluate the performance of the cycle, since this depends on the points of entry and exit generator, condenser and evaporator. With the results it was possible to identify levels of temperature and pressure and mass flows that the system will be needed, so select and size components.

For the thermodynamic analysis, was needed the application of conservation laws in each component being el

First Law of Thermodynamics, has show in Wylen, g. Van, Sontag, r., Borgnake (2005)

$$\frac{dE_{O.E.}}{dt} = \dot{Q}_{O.E.} - \dot{W}_{O.E.} + \sum \dot{m}_e\left(h_e + \frac{1}{2}V_e^2 + gZ_e\right) - \sum \dot{m}_s\left(h_s + \frac{1}{2}V_s^2 + gZ_s\right) \tag{1}$$

Second Law of Thermodynamics

$$\frac{dS_{O.E.}}{dt} = \sum \dot{m}_e\, s_e - \sum \dot{m}_e\, s_e + \sum \frac{Q_{O.E.}}{T} + \dot{S}_{ger} \tag{2}$$

The internal and external irreversibilities in each component can be founded by

$$\dot{I}_{\text{int}} = \sum \dot{m}_e b_e - \sum \dot{m}_s b_s - \left(1 - \frac{T_0}{T_{O.E.}}\right)\dot{Q}_{O.E.} \tag{3}$$

$$\dot{I}_{ext} = \sum \dot{m}_s b_s - \sum \dot{m}_e b_e - \left(1 - \frac{T_0}{T_{O.E.}}\right)\dot{Q}_{O.E.} \tag{4}$$

The mass conservation for each component can be expressed br

$$\frac{dm}{dt} = 0 \tag{5}$$

And for last the especies conservation

$$\frac{d(mX)}{dt} = 0 \tag{6}$$

The analysis considers the following simplifying assumptions:

1. All components will operate in steady state;
2. The output of the evaporator and the condenser entrance are in condition of saturation
3. The contributions of variations in kinetic and potential energy are considered negligible;
4. Load losses by friction in heat exchangers and pipes considered negligible.
5. The lithium bromide solution has provided balance in the absorber and exits the steam generator;
6. No heat transfer occurs between the heat exchangers and its neighborhood;

For the construction of the simulator each equation above was applied with appropriate simplifications to each system component and written in EES platform as a result we obtained the thermodynamic states at each point of the cycle, the heat flows in each component and the mass flow rates for the stipulated thermal power input.

The need for construction of the simulator on ESS platform was due to the possibility of obtaining thermodynamic properties and thermo physical properties of lithium bromide-water mixture with subroutines from the program, the properties obtained by the software was compared with Kaita, Y (2001)

Measurement Cycle Performance coefficient is obtained by the ratio of the desired product and what is paid to obtain it, we have the heat removed from the refrigerated environment as an input in the evaporator and the heat available in the generator.

$$COP = \frac{Q_{evap}}{Q_{ger}} \tag{7}$$

2. COMPONENT DESIGN

The sizing of components is done with a heat transfer analysis which seeks to ensure quantification of the heat transfer taxes resulting from the thermodynamic analysis on each physical component of the system, takes into consideration, so the aspects constructive order of system devices and their capabilities. In general, it considers the real possibility of physical implementation of the thermodynamic model through the design of physical devices

2.1Heat Exchangers

To allow for the sizing of heat exchangers is necessary to know for each component of the mass flow reates and the thermodynamic states at each point, which was obtained in thermodynamic analysis. To obtain the outer area of the heat exchanger is used the method of DTML. In this method, the total rate of heat transfer between fluids is given by:

$$Q = A_{ext} U_{global} DTML \tag{8}$$

Where the heat involved in the process was calculated in the thermodynamic analysis, DTML can be calculated based on the temperature of the fluid at the entrances and exits of the component Global heat trahsfer coeficient depends on the overall Nusselt number with specific expressions for each component in the study, sothe outside area is possible to be determined.

The configuration of the exchanger was chosen as a hoof-tube and the outer area of the exchanger and determined by summing areas of the tubes in the exchanger and the total area is given by

$$A_{ext} = \pi d_{ext} l_{tube} \tag{9}$$

In the simulator the user determines a particular setting to the heat exchanger and the simulator appoints if the rate of heat transfer achieved with the actual configuration, is enough if compared with the calculated heat trahsfer on the thermodynamic analysis of cycle, user will noticed if the area is sufficient or if is necessary to increase with greater length or number of tubes or modifications to the external diameter of the tubes of the exchanger.

To obtain the global coefficient of heat transfer we use the expression

$$U = \frac{1}{A_{int} h_{int} + A_{ext} h_{ext} + \frac{\ln\left(\frac{De}{Di}\right)}{2 L_{tubes} \pi N_{tubes}} h_{cond}} \tag{10}$$

The coefficients of convection can be found via the Nusselt number through the relation:

$$Nus = \frac{h}{D_{tube} K_{fluid}} \tag{11}$$

The Number of Nussel is function of the type of flow and working fluid to flow in circular pipes is given to $Nus = 0.023 \mathrm{Re}^{0.8} \mathrm{Pr}^{0.4}$ for turbulent flow and $Nus = 4.36$ for laminar flow.

However the system settings where there is phase changes and mass transfer involved in the systems they are the condenser, evaporator, absorber and the steam generator.

To the evaporator the convection coefficient is obtained directly by oh Bromley correlation for film boiling on a horizontal cylinder

$$h = C_{pel} \left[\frac{g K \rho_v (\rho_v - \rho_l)(h_{fg} + 0{,}4 CP_v)(T_s - T_{sat})}{visc_v D_e (T_s - T_{sat})} \right]^{1/4} \tag{12}$$

Where :

Cpel is the coefficient of film
K is the conductivity of the fluid
ρ is the fluid density
hfg is the enthalpy of vaporization
visc is the viscosity of the fluid
Ts is the surface temperature of the tube
Tsat is the saturation temperature of the fluid pressure component
D_e Is the diameter of the tube

For the condenser there's phase change in the flow and heat transfer coefficient where the vapor condenses on the condenser tube bundle can be estimated by Incropera, F. P.; Dewitt, d. P (2008)

$$h = 0.729\left[\frac{\left(gK\rho_l(\rho_l - \rho_v)\right)\left(h_{fg} + 0{,}68CP_v\right)\left(T_s - T_{sat}\right)\right)\frac{K^3}{visc\left(T_{sat} - T_s\right)D_e}}{\frac{N_{tubes}}{3}}\right]^{1/4} \tag{13}$$

For the process in the steam generator and the absorber phase change exists that can be evaluated with the correlations above however should be added the share of combined heat transfer due to mass transfer. From the coefficient of heat transfer is possible to estimate the coefficient of mass transfer through the Chilton-Colburn analogy that relates the two quantities by the number of Lewis

$$h_{heat} = h_{mass}\rho_{solution}CP_{solution}Lewis^{2/3} \tag{14}$$

Where the lewis number is the relation betwen the Heat Difusibility and Mass Difusibility

2.2 Expansion Devices

The sizing of expansion devices was necessary due to the difficulty of market expansion valves in the pressure range desired and the working fluid cycle the problem was solved with the use of low diameter coils where the pressure drop occurs in distributed and expansion through holes where the pressure drop occurs in a localized way.

For sizing is necessary the pressure before and after the device, the flow rate and pipe diameter of the equipment, it was done by applying the energy equation in the device and adding the pressure drop over it in order to obtain the orifice diameter that would produce the desired pressure drop, then the ESS shows another advantage in its programming because there is no need to isolate the unknown variable of the equation or system of equations there is only the necessity that the number of equations equals the number of unknowns, even in transcendental equations as in this case the program is able to get the result instantly.

According to J.R. Simões Moreira (2003), the process of expansion in nozzles and orifices have more complex characteristics including phase change and supersonic flow, in a next analysis these effects could be included in the model.

2.3 Recirculation Pumps

The sizing of the power of the recirculation pump is obtained in thermodynamic analysis of the cycle, the type of pump chosen to be the final decision is taken based on the manufacturer's catalogs with the flow and head at the pump will work.

3. Results

As a result we have the thermodynamic analysis of the cycle that can be remade with a simple mouse click to a different operating condition like change in pressure or concentration, which are validated by the work of Herold, k.e., r. Radermacher, s. Klein. (1996), coinciding with an error of less than 3%

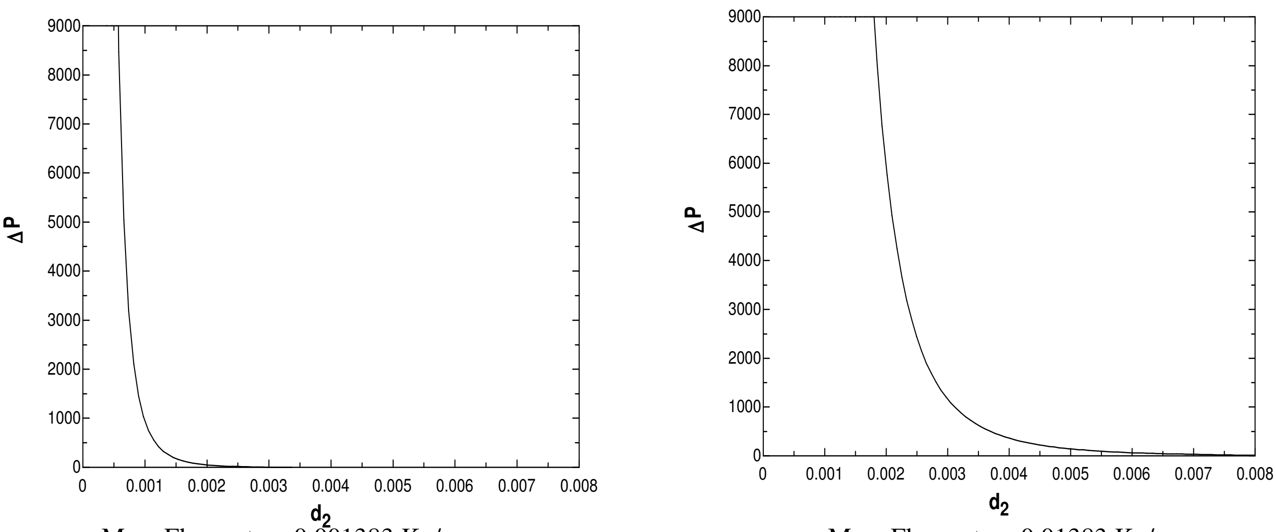
Table 1. Results of thermodynamic analysis for the double effect system

Description	Entalphy [KJ/Kg]	Mass flowrate [Kg/s]	Pressure [Kpa]	Temperature [C]	Concentration
1	167,5	0,002046	7,381	40	0
2	167,5	0,002046	0,87	4,959	0
3	2510	0,002046	0,87	4	0
4	66,06	0,01314	0,87	29,9	52,9
5	66,11	0,01314	77	29,9	62,66
6	140,4	0,01314	77	64,9	52,9
7	300,3	0,01212	77	138,4	57,33
8	219,9	0,01212	77	98,38	57,33
9	219,9	0,01212	7,381	78,19	57,33
10	2674	0,001015	77	97,46	0

11	70.61	0,01109	7,381	90,2	62,66
12	70.61	0,01109	0,87	48.69	62,66
13	240,1	0,001015	77	57,49	0
14	2583	0,001031	7,381	45	0
15	240,1	0,001015	7,381	40,15	0

Table 2. Results of thermodynamic analysis for the single effect system

Description	Entalphy [KJ/Kg]	Mass flowrate [Kg/s]	Pressure [Kpa]	Temperature [C]	Concentração
	168,3	0,001349	7,46	40,2	0
	168,3	0,001349	0,8109	3,955	0
	2508	0,001349	0,8109	4	0
	91,34	0,01454	0,8109	35,7	56,7
	91,34	0,01454	7,46	35,7	56,7
	131,8	0,01454	7,46	55,7	56,7
	223	0,01319	7,46	90,05	62,5
	178,5	0,01319	7,46	66,07	62,5
	178,5	0,01319	0,8109	47,18	62,5
	2583	0,001349	7,46	45,02	0

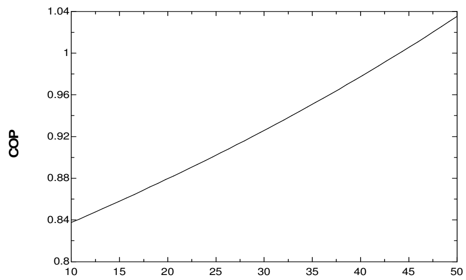


Mass Flow rate = 0.001383 Kg/s Mass Flow rate = 0.01383 Kg/s

Figure 3 Diagram of Pressure Drop vs Orifice Diametrer for different mass flow reates

It is observed that the behavior of pressure drop is critical to the diameter of the orifice mainly for low flow rates becomes difficult to control the process and the machining tolerances are very tight.

Cop variation of the system as a function of temperature difference in the heat exchanger



ΔT Heat Exchanger

Figure 4. Diagram of COP vs Temperature Difference in heat exchanger

It is noticed that system performance increases with increasing temperature difference in the heat exchanger before the steam generator but there is a limitation of area of the exchanger which increases exponentially with it.

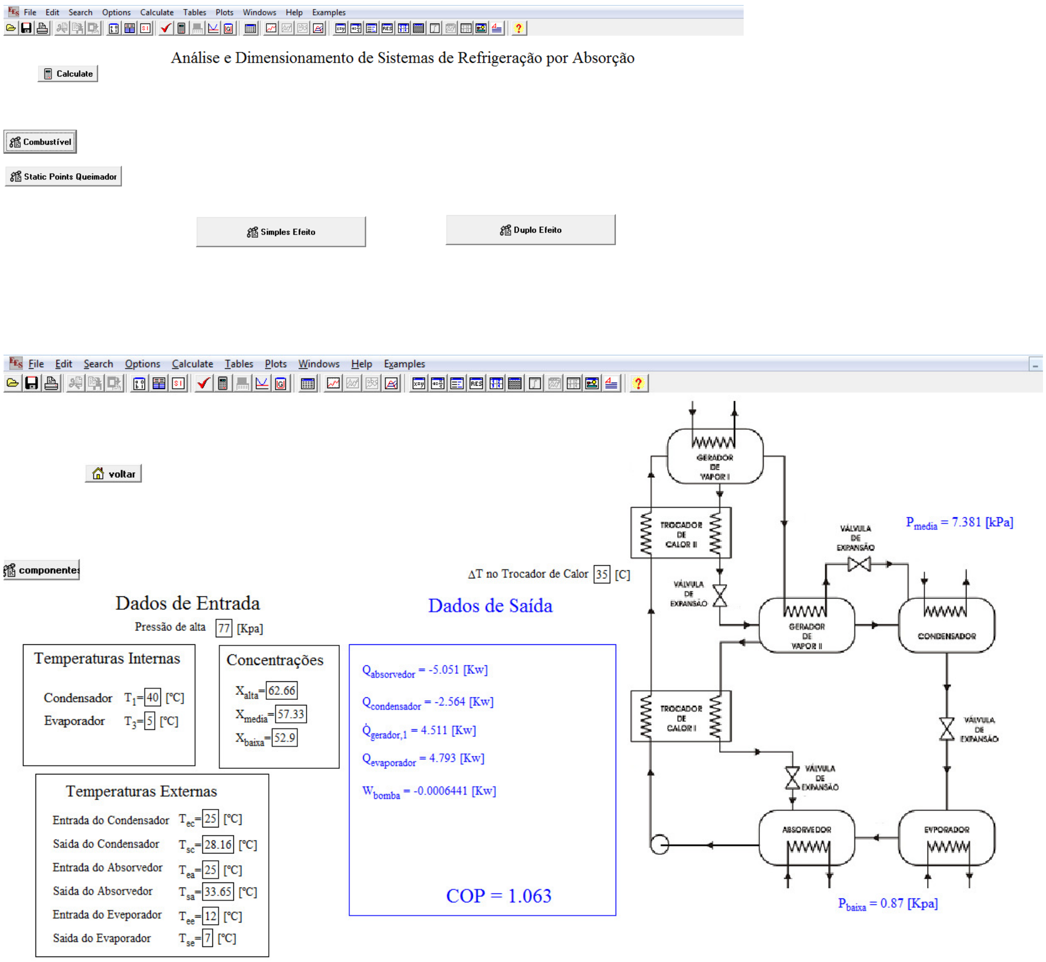


Figure 5. Data imput Windows of the simulator

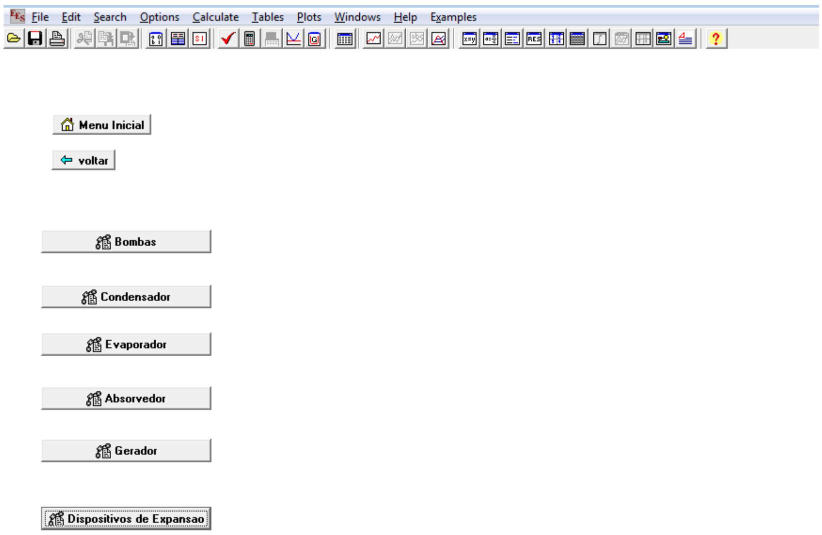


Figure 6. Component Design Window

Figure 7. Prototype built based from the result of the simulation

4. Conclusions

The simulator proved to be a great tool to aid in the design of absorption refrigeration systems with the pair water-lithium bromide, only feeding the program with some input data you can get all the energy and exergetic analysis of the cycle to different input parameters, with respect to the components although the final decision on the size and geometry has been taken based on CFD analysis via a finite element method, the simulator provides a great starting point as regards the area of heat exchangers, number and length of tubes.

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