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THERMODYNAMIC STUDY AND EXPERIMENTAL EVALUATION OF THE PROTOTYPE 01 OF A COOLING SYSTEM FOR ABSORPTION USING WATER-LITHIUM BROMIDE PAIR IN RECOGÁS.

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Abstract. *The present study describes a theoretical and experimental analysis of the Prototype 01, this being an absorption cooling machine of simple effect with the pair water-lithium bromide as a working fluid and uses natural gas as an energy source for the steam generator, aiming the simulation of waste heat cogeneration. The unit has been developed and constantly improved in Rede Cooperativa de Pesquisa Norte/Nordeste do Gás Natural RECOGÁS-N/NE building present in Instituto de Energia Sustentável (IES) at the Universidade Federal da Paraíba. This unit has a carbon steel frame, using a stainless steel pipe. One goal of the study is an approximation of the results obtained experimentally in this study with the theoretical results for SANTOS (2005). In order to purpose validation was used Engineering Equation Solver (EES) software to obtain the properties, especially those inherent to the working fluid, using input data obtained experimentally. Still aims to expose inherent and unique aspects of an essentially experimental work, which will be addressed experimental methodology applied by the use of the materials used, the discussions regarding aspects of construction and operation of the unit, problems identified, interventions in the pilot plant and finally proposing solutions to some of the observed problems.*

Keywords: *Absorption cooling, cogeneration, theoretical-experimental, water-lithium bromide.*

1. INTRODUCTION

Unlike refrigeration systems by mechanical compression which use cooling to produce mechanical work generated by an electric motor, the absorption cooling systems use heat as an energy source.

The absorption cooling systems have as their main advantage is the ability to work both by direct combustion of a fuel (natural gas being the most widely used for this purpose) how to work with waste heat from other heating systems would not be used (that would be the case of cogeneration systems), or also exhaust gases from engines, geothermal sources or solar energy. Furthermore, in most systems of absorption the electric energy required for its operation is minimal (especially if compared with the compression systems), since most of these systems use one or two pumps low power.

These systems are classified according to the number of effects, such as single, double or triple effect (systems of double and triple effect are further subdivided due to the flow of the solution and can be connected in parallel or in series). The number of effects in an absorption refrigeration system is related to the number of times that produces steam from the solution by using a single primary source of energy, thus enhancing the flow of refrigerant and refrigerator effect and finally, providing an increase in the coefficient of performance of the unit. Importantly, each of these systems works with different pressure levels, where the simple effect works with two levels of pressure, double effect with three levels of pressure and triple effect with four pressure levels.

For systems in series, the working fluid is pumped directly from the absorber to the steam generator of high-pressure. In the case of the parallel system, the working fluid is pumped simultaneously to all the steam generators in the system.

2. ADVANTAGES AND DISADVANTAGES OF THE SYSTEM

As already mentioned, one of the main advantages of the absorption refrigeration system is that it operates with heat as an energy source, and thus can be used in cogeneration plants making use of waste heat. Other advantages can be pointed out, including some proposed by Dorgan et al. (1995) are as follows:

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• Absorption machines are thermally activated and, therefore, high energy input (shaft) is not required. In this sense, where electricity is expensive or unavailable, or where there is gas, residues, geothermal heat sources and solar available, suction machines can provide cooling with confidence and tranquility, reducing operational costs and avoiding electrical surges due to changes demand;
• One of the main advantages in the absorption cycle is the cost of pumping a liquid instead of steam, from the low pressure region up to high pressure, in which the work is considerably lower;
• Long useful life (20 to 25 years);
• Quiet operation and no vibration;
• While a conventional electrical system has a loss of 65% to 75% of energy for the production of cold, in contrast to this, only about 5% to 10% fuel supply is lost with an absorption system with a gas-powered;
• High reliability;
• Heat recovered can be used as an energy source (replacing the mechanical work) in absorption refrigeration cycles;
• Works with variable load easily and efficiently;
• Low maintenance cost;
• Energy losses due stop and return operations are practically nil;
• Doesn't require the use of CFC's and HCFC's, causing suction machines do not cause damage to the ozone layer and have less impact on global warming;
• Fuel costs are substantially lower than those of electricity, being on average 12-20% of the cost of electricity.

The disadvantages of this system, one can mention:

• Low coefficient of performance (COP), mainly single-acting systems, the system is not competitive compared with the vapor compression refrigeration cycle, which entails higher operating costs in direct-fired systems. Even the double-effect systems are not very profitable in some applications;
• Corrosive action of lithium bromide (on systems with pair water - lithium bromide), thus requiring corrosion inhibitors additives (SRIKHIRIN et al., 2001 Dorgan et al., 1995);
• According KISTLER (1997) absorption systems are larger and heavier compared to vapor compression, he says that the absorption machines require cooling towers with a capacity greater than a 30% compression of the same capacity;
• Because the water acts as a coolant in systems H2O - LiBr, one cannot obtain temperatures lower than 0 ° C due to water freezing suffer this temperature. At temperatures below this, one must use the system ammonia - water;
• The system water - lithium bromide operates at pressures below atmospheric, resulting in inevitable seepages of air into the system which need to be purged periodically. (Dorgan et al, 1995);
• The ammonia-water system has the disadvantage of requiring extra components;
• Ammonia highly toxic and flammable.

3. PRINCIPLES OF OPERATION SINGLE-ACTING SYSTEM

The absorption refrigeration cycle transfers heat from low temperature region to high temperature region by absorption and desorption of the refrigerant in the vapor phase by a liquid solution (which is usually a binary mixture composed of refrigerant and another substance, for example, a salt such as lithium bromide). During the absorption process there is heat transfer to the intermediate temperature region (environment for a refrigeration cycle) and during the desorption heat is supplied to cycle from a heat source at high temperature, and a new heat transfer to intermediate temperature region. Note that the refrigerant used in the system is water and LiBr acts as the absorbent, it absorbs water vapor, making the pumping of the absorber to the generator easier and more economical.

The basic refrigeration cycle by single-acting absorption consists of the following components: a condenser, an evaporator, an absorber, a heat exchanger of a solution, a steam generator, a pump and two expansion valves, as shown in Fig. 1.

This cycle has basically four processes, two of which are characterized by exchanges of heat and the other two characterized by simultaneous exchanges of heat and mass.

• Separation (desorption) of the refrigerant in the generator;
• Condensation the refrigerant in the condenser;
• Vaporization of the refrigerant in the evaporator;
• Absorption of the refrigerant solution in the absorber.

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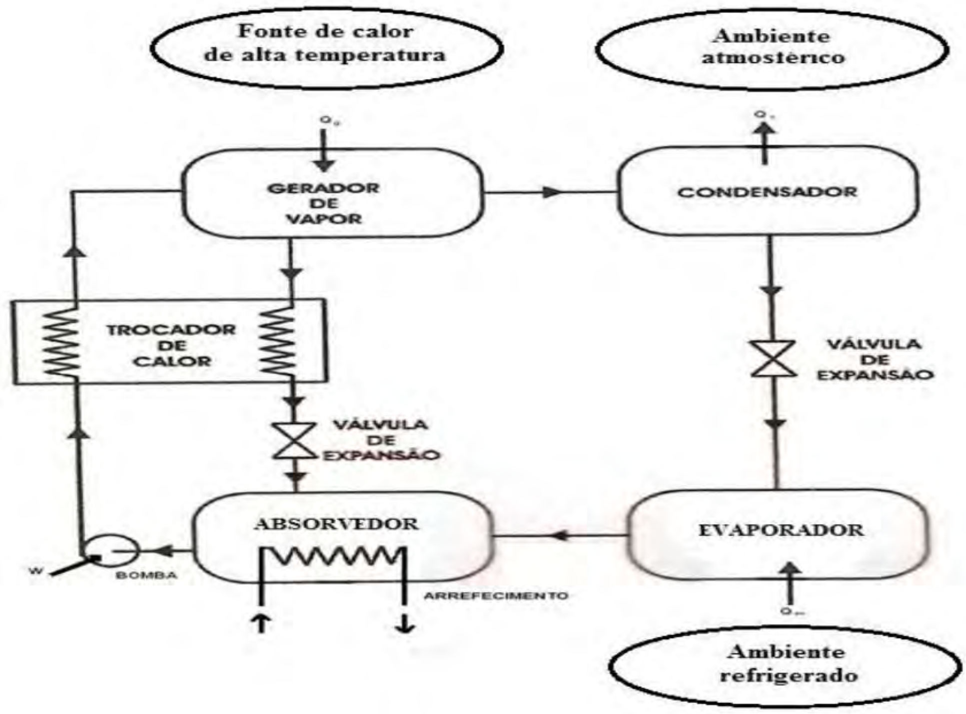

Figure 1. Simplified schematic of absorption cooling system of simple effect.

In Figure 2 is shown a scheme based on the prototype developed at the Instituto de Energia Sustentável of UFPB, there is a recirculating pump, a solution pump of lithium bromide and one pump for recirculation of the coolant.

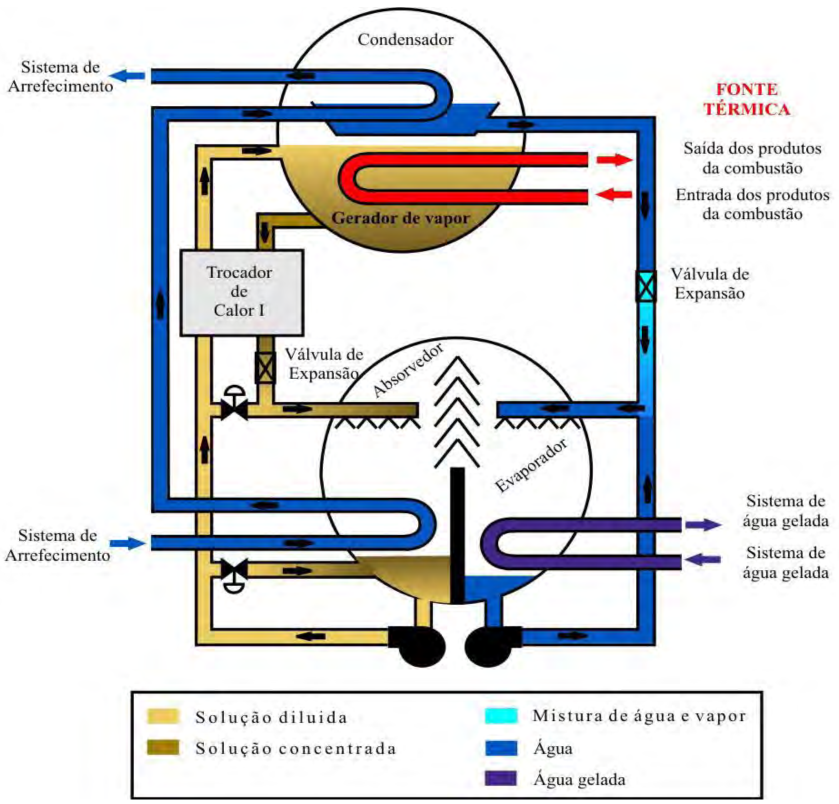

Figure 2. Diagram of absorption cooling system of simple effect with pair water - lithium bromide.
Source: (SANTOS, 2005)

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With reference to that same system can explain how the process works in absorption refrigeration machine. First, the pump lithium bromide solution is turned on, and at this point, it is noted that the solution is rich in refrigerant (ie, water). The temperature of the solution heat exchanger is increased. Once the steam generator, heat energy is added to the system and the refrigerant evaporates, separating from the lithium bromide, being rejected of solution. Thus, of the steam generator out high pressure refrigerant steam and a concentrated solution of lithium bromide.

The refrigerant vapor flows to condenser, where heat is transferred to the environment through the cooling system, causing the refrigerant to condense. Then, the condensed water flows through a flow limiter (expansion valve), thus allowing a decrease pressure (required to maintain the pressure difference between the condenser and evaporator), and causing part of the water evaporates before reaching the evaporator. In the evaporator, the heat evaporates the refrigerant charge remaining, and it flows back to the absorber because it was absorbed by the lithium bromide solution.

As previously mentioned, of the steam generator also leaves concentrated solution of lithium bromide which is a refrigerant-absorbent solution which is cooled in the heat exchanger (note that the temperature of the concentrated solution is greater than the dilute (ie rich in water) which causes the solution coming out of the steam generator supplies heat to the solution coming from the pump, causing it to be pre-heated, which will lead to increased system performance). After passing this solution through the heat exchanger it also goes through a flow limiter (required to maintain the pressure difference between the steam generator and absorber), going to the absorber where, have a concentration of lithium bromide elevated absorb water from the evaporator. This solution again exchanges heat with the cooling system then proceeds to pump, restarting the cycle.

4. CHARACTERISTICS OF THE PROTOTYPE 01 OF A COOLING SYSTEM FOR ABSORPTION USING H_2O – LIBR OF IES - UFPB.

The pilot unit (prototype 01) of absorption cooling system of simple effect is a medium-sized, with a cooling capacity which may vary from 1.5 to 14 TR (5 to 50 kW). It is in the building, Rede Cooperativa de Pesquisa Norte/Nordeste do Gás Natural RECOGÁS-N/NE, present in the IES, and has a structure of carbon steel, using a stainless steel pipe due to the limitations imposed by the use of lithium bromide which is highly corrosive. The main points of the unit can be seen in the following figure (Fig. 3), showing with the entry and exit points of each system component.

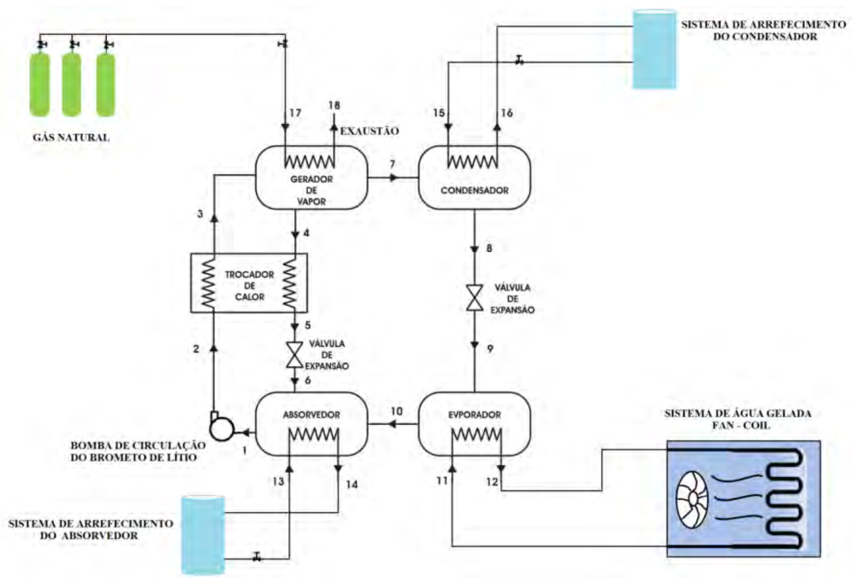

Figure 3. Schematic of the absorption cooling system of simple effect created in IES - UFPB with their own points of entry and exit.

The studied system has five subsystems:

• **Absorption System**: A generator, an absorber, a condenser, an evaporator, a heat exchanger of a solution, two expansion valves (one being coupled to a U-tube), and three pumps, namely: one for the circulation of the solution units, one for recirculation of lithium bromide in absorber, one for recirculating the water in the evaporator;

• **Cooling System:** Two cooling towers, one unique to the absorber and one to the condenser, two pumps, one for suction of each tower;

• **System chilled water / fan coil:** Duct-making outside air, return air duct, box air mixture, a pump for circulating chilled water, and fan coil filter blanket;

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• **Combustion system:** Burner, combustion tunnel, exhaust fan;

• **Data Acquisition System:** The refrigeration unit of RECOGÁS has a data acquisition system that was developed and deployed by MARQUES (2010). The system basically comprises a fieldpoit data acquisition National Instruments, a circuit for signal conditioning of resistive thermometers and sends to the FieldPoint, a computer program made in LabVIEW that receives information from the FieldPoint and transmits it to the computer.

The Following are some photos showing some of the main points of the system under study.

Figure 4 - Side view of the absorption refrigeration system IES-UFPB.

Figure 5 - Front view of the unit.

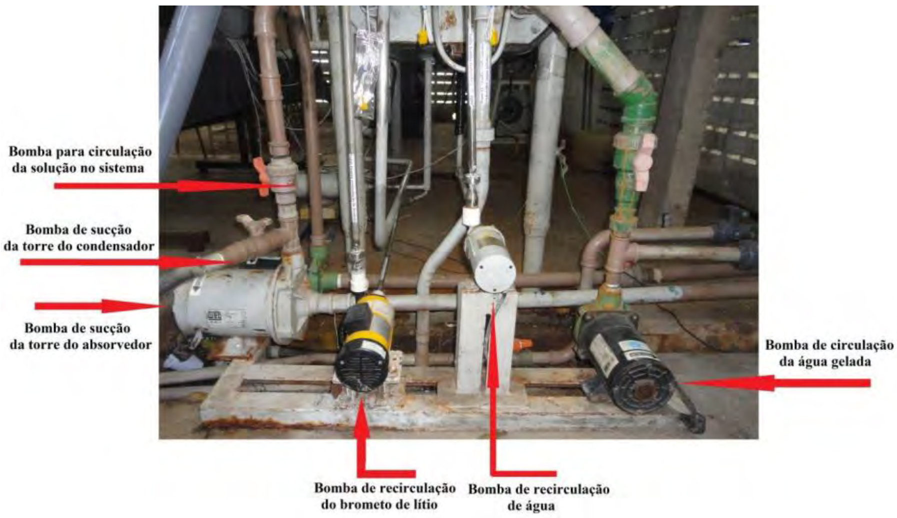

Figure 6 - Pumps used in the system.

The data acquisition system was developed so that they are provided the following actual data:

- High pressure (pressure in the generator);
- Low pressure (pressure in the evaporator);
- Temperature in the generator (which may be equivalent to the point 7);
- Evaporator temperature (equivalent to points 9 and 10);
- Temperature of the condenser (point 8);
- Temperature output of the heat exchanger (point 5);
- Temperature of the absorber (equivalent to 1 point);
- Inlet temperature of the heat exchanger (point 3).

The representation of the measurement of these points can be seen in Fig. 7 below, emphasizing that the values shown in the picture are not real data, as was done with the program off, and thus become merely illustrative.

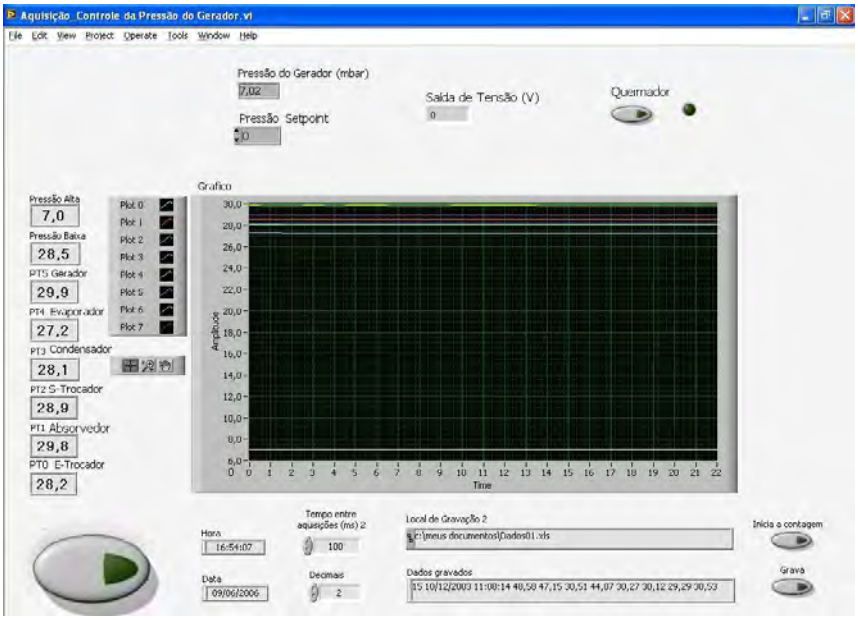

Figure 7 - Visualization of the data acquisition program.

The remaining data were measured using thermocouples, digital thermometers, Schrader valves, pressure gauges, pressure transducers, flow meters.

5. EXPERIMENTAL RESULTS

In this chapter we will show the results of experiments performed highlighting the key parameters that should be taken into consideration. The study aims at approximating the experimentally results obtained in this study with the results obtained theoretically by Santos (2005) for the same prototype.

To try to obtain the same parameters so that one could do the calculations of values such efficiencies it was necessary to use data obtained experimentally (pressure and temperature) with the aid of thermodynamic equations and using the Engineering Equation Solver software (ESS). The software ESS simulates the energetic and exergetic analysis using the results obtained experimentally, where the energetic analysis, determines heat fluxes of each component, the thermodynamic properties of each point of the system and efficiencies (energetic) of each well as a component of the system. The exergetic analysis, in turn, determines the available energy (exergy) of each point of the system, irreversibilities and efficiencies (exergetic) as much of each component of the system.

The reference values for this study are the values obtained in SANTOS (2005). These values can be seen in Tab. 1 below.

Where T (°C) is the temperature at each point, P (kPa) is the pressure, m (kg/s) is the mass flow rate, h (kJ/kg) is the enthalpy, S (kJ/kgK) is the entropy and ex (kJ / kg) is the exergy.

In Table 2 it is possible to enjoy the results of the efficiencies of the First (η) and Second (β) Laws of Thermodynamics, the Degree of Perfection Thermodynamic (ξ), and effectiveness, both for each component and for the complete system, in addition to irreversibilities of the individual values of each component in a work of Santos (2005).

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Table 1. Reference values calculated by Santos (2005)

Pontos	T(°C)	P(kPa)	x(%)	m(kg/s)	h(kJ/kg)	s(kJ/kgK)	ex(kJ/kg)
1	36,8	0,87	56,7	0,0686	93,65078	0,227	30,7
2	36,8	6,28	56,7	0,0686	93,65413	0,227	30,7
3	56,8	6,28	56,7	0,0686	134,09298	0,350	34,2
4	86,2	6,28	62,5	0,0622	215,95842	0,473	79,6
5	62,3	6,28	62,5	0,0622	171,37929	0,345	73,0
6	48,4	0,87	62,5	0,0622	171,37929	0,268	96,1
7	80,8	6,28	-	0,0064	2651,01296	8,563	102,5
8	37,0	6,28	-	0,0064	154,95427	0,532	0,9
9	5,00	0,87	-	0,0064	154,95427	0,558	-6,8
10	5,00	0,87	-	0,0064	2509,71310	9,024	-176,1
11	12,0	-	-	0,7151	50,36183	0,180	1,1
12	7,00	-	-	0,7151	29,41515	0,106	2,3
13	30,0	-	-	1,7250	125,67065	0,437	0,1
14	32,8	-	-	1,7250	137,38306	0,475	0,3
15	32,8	-	-	1,7250	137,38306	0,475	0,3
16	35,0	-	-	1,7250	146,58789	0,505	0,6
17	700,0	-	-	0,0066	10154,56762	17,500	4987,0
18	500,0	-	-	0,0066	6957,40992	13,830	2884,0

Table 2. Efficiency values calculated by Santos (2005)

Componentes	η	β	Efetividade	Irreversibilidades (kW)
Gerador	1,00	0,24	0,3110	10,610
Condensador	1,00	0,71	0,9125	0,185
Evaporador	1,00	0,76	0,7143	0,256
Absorvedor	1,00	0,15	0,6273	2,327
Trocador	1,00	0,59	0,4856	0,169
Sistema (COP)	0,71	0,06	-	-

In the following tables, that is, Table 3 and Table 4, the values of properties are obtained in addition to the efficiency values calculated by such programming.

Table 3. Data obtained by measuring the experimental values.

Pontos	T(°C)	P(kPa)	x(%)	m(kg/s)	h(kJ/kg)	s(kJ/kgK)	ex(kJ/kg)
1	35,0	0,88	52,93	0,131300	76,94	0,2369	10,87000
2	35,1	6,28	52,93	0,131300	81,92	0,2376	15,64000
3	42,8	6,28	52,93	0,131300	113,50	0,2888	31,95000
4	75,0	6,28	56,87	0,122200	171,40	0,4561	39,95000
5	58,2	6,26	56,87	0,122200	137,50	0,3573	35,47000
6	44,0	0,88	56,87	0,122200	137,50	0,2706	61,34000
7	72,4	6,28	0,00	0,009093	2635,00	8,5170	100,30000
8	36,2	6,28	0,00	0,009093	155,00	0,5320	0,88890
9	10,4	0,88	0,00	0,009093	155,00	0,5576	-6,74300
10	10,4	0,88	0,00	0,009093	2510,00	9,0210	-175,30000
11	20,3	124,20	-	1,347000	85,09	0,3005	0,05738
12	16,5	123,80	-	1,347000	69,19	0,2460	0,41700
13	29,0	153,30	-	7,055000	121,50	0,4227	0,01365
14	30,0	151,30	-	7,055000	125,70	0,4365	0,07608
15	32,0	142,30	-	0,898500	134,00	0,4640	0,24160
16	38,0	142,00	-	0,898500	159,10	0,5455	1,05700
17	600,0	-	-	0,014660	8537,00	15,7500	3892,00000
18	470,0	-	-	0,014660	6491,00	13,2100	2601,00000

Table 4. Data obtained by measuring the experimental values.

Componentes	η	β	Efetividade	Irreversibilidades (kW)
Gerador	1,0000	0,0845	0,2333	17,32
Condensador	1,0000	0,8108	0,8968	0,171
Evaporador	1,0000	0,3161	0,3858	1,048
Absorvedor	1,0000	0,09846	0,6000	4,033
Trocador	1,0000	0,3129	0,4211	1,593
Sistema (COP)	0,6986	0,0256	-	Total = 24,165

In Figure 8, as in Figure 9, it can be noted that there is a concordance between the enthalpy and exergy values measured in Silva (2005) and the present study, with the exception of points 17 and 18 (in and out of the combustion products). This disparity occurs due to temperature difference of input and output of the combustion gases between the two studies.

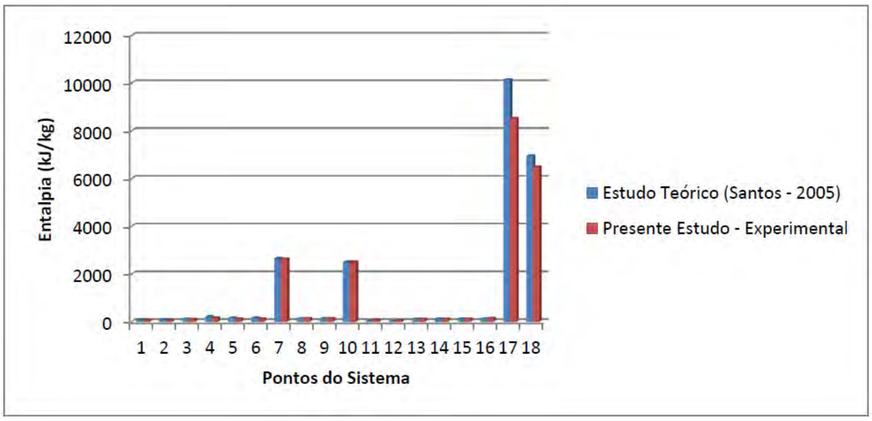

Figure 8. Energetic comparative between the current work and the theoretical study.

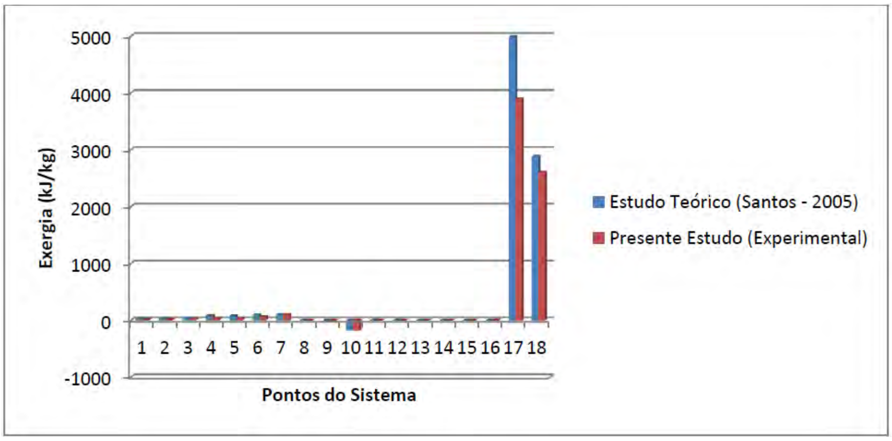

Figure 9. Exergetic comparative between the current work and the theoretical study.

Comparing the values of Table 2 and 4, we note that, as was to be expected, the first law efficiency is not enough to qualify the heat transfer because it only quantifies, not taking into account losses, or how heat transfer occurs. On the other hand, by the second law efficiency represents in an appropriate way these parameters, and Fig. 10 it can be seen comparison with the theoretical results.

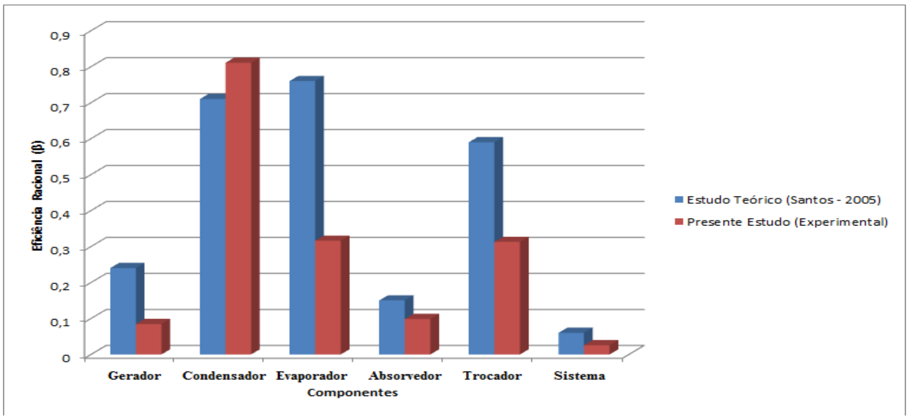

Figure 10. Rational comparison of the efficiency of each component.

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For the comparative we note that the components of the experimental system are still wasting lots of energy available, and not taking advantage of its exergy. The exception is with regard to the condenser, but this can be explained because for the calculation of Santos (2005), it took into consideration that there would only be a cooling tower to the condenser and absorber, causing the temperature of the point 14 and 15 were equal, which does not occur in practice because there are two towers and each works in a different regime, with different flow rates and temperatures.

Another important point of comparison are the values of the irreversibility in the system. These values can be seen in Fig. 11.

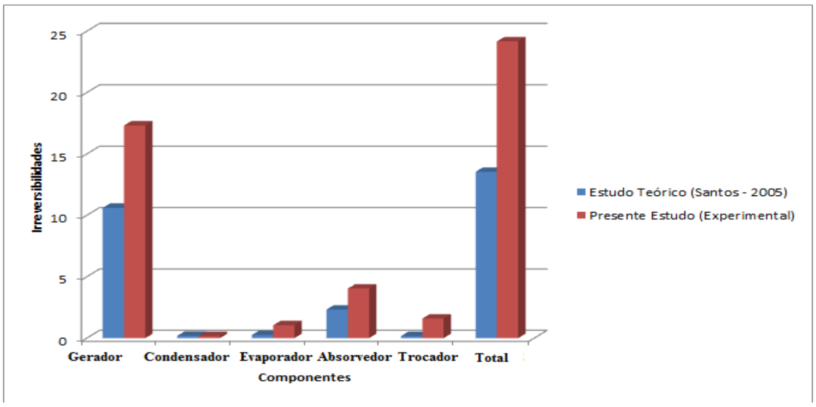

Figure 11. Comparison of the irreversibility of each component in addition to the full.

Looking at Figure 11 we note that as stated earlier, there is a good gap between data irreversibilities. This was expected, because irreversibility, it is loss of energy, or energy badly used, and these higher losses in a system occur due to factors such as friction, the mixture of two different substances, chemical processes, hysteresis effects, etc. This cannot be sized just theoretically, so this difference.

However, as the experimental results, we note that the greatest losses occur in the generator, followed by the absorber, as also observed Varani (2001) and Moreira (2004). In addition, the generator has a low effectiveness and the reduced efficiency 2nd law.

6. CONCLUSIONS

The present study aims to present an experimental analysis of the Prototype 01 developed in the building of RECOGÁS-N/NE UFPB, being an absorption refrigeration system that uses a working fluid as the binary pair of water and lithium bromide.

Through a study about the technology improved, it was possible to understand the constructive aspects and functional of the unit. Futhermore, it was made the instrumentation of the unit, and therefore leading to obtaining data from the current project.

Thus the following considerations can be made:

• There is a good agreement between the energy and exergy values obtained, and compared with the literature values with the exception of points 17 and 18 (in and out of the combustion products). This disparity occurs due to temperature difference at the inlet and outlet of the combustion gases between the two studies;

• The efficiency of the 1st law of thermodynamics is not sufficient to analyze correctly the efficiency of the components and the system as a whole. As required analysis by the second law;

• In relation the comparison with the data from Santos (2005), we note that the components of the experimental system are still wasting lots of energy available, and not taking advantage of its exergy. The exception is the condenser, because the theoretical study considered base is just a cooling tower for heat exchange with the absorber and condenser;

• The system has great total irreversibility, as in theory it is evident that the steam generator is the component that has the highest irreversibilities, if necessary a redesign of the components, particularly the steam generator so that it presents a lower temperature output, or better use of the energy that is supplied.

7. REFERENCES

BEJAN, A., 1996, Entropy Generation Minimization, [S.I]: CRC. Printed the U.S.A.

BOSNJAKOVIC, F. & BLACKSHEAR JR. , P. L. , 1965, Thecnical Thermodynamic, editado por Holt, Rinehart and Winston, Inc. , N.Y.

ISSN 2176-5480

ÇENGEL, Y.A., BOLES, M. A., 2006, “Thermodynamics - An Engineering Approach”, 5ª Edition, McGraw-Hill.

DENG, S.M.; MA, W.B., 1998. Experimental studies on the characteristics of an absorber using LiBr/H2O solution as working fluid.

DORGAN, C. B., DORGAN, E. C., LEIGHT, S. P., 1995, Application Guide for Absorption Cooling / Refrigeration Using Recovered Heat. Atlanta, USA, America Society of Heating, Refrigeration and Air-Conditioning Engineers,Inc.

FOX, Robert W.,2006 – Introdução à Mecânica dos Fluidos. -6. Ed.- Rio de Janeiro, LTC.

HEROLD, K. E.., RADERMACHER, R ; KLEIN, A. S., 1996, “Absorption Chillers and Heat Pumps”, CRC Press, Printed in the U.S.A.

INCROPERA, F. P. , et al , 2008, Fundamentos de Transferência de Calor e Massa. 6ª ed. Rio de Janeiro: LTC.

KAITA, Y., 2001. Thermodynamic properties of lithium bromide water solutions at high temperatures. International Journal of Refrigeration.

KALOGIROU, S.; FLORIDES, G.; TASSOU, S.; WROBEL, L., 2001. Design and Construction of a Lithium Bromide Water Absorption Refrigerator.

KOTAS, T. J. , 1995, The Exergy Method of Thermal Plant Analysis. Krieger Publishing Company, Reprint Edition.

MARQUES, João Erivando Soares. Aplicação da lógica fuzzy no Controle da cristalização de um sistema de refrigeração por absorção com par água – brometo de lítio. Tese (Tese de doutorado) – Universidade Federal da Paraíba, João Pessoa, 2010.

MOREIRA, H. L. Análise Termoeconômica de Sistemas de Refrigeração por Absorção com o Par Água-Brometo de Lítio. Tese (Tese de Doutorado) — Universidade Federal da Paraíba, João Pessoa – Pb, 2004.

NAPOLEÃO, D. A. S., 2003. Determinação da Entropia de Mistura Amônia e Água para Aplicações em Processos de Refrigeração. Tese de D.S.c, - UNESP, Guaratinguetá – SP.

ROCHA, M. A., 2010, Estudo Teórico-Experimental de um Sistema de Refrigeração por Absorção de Duplo Efeito em Série usando o par Água/Brometo de Lítio. Dissertação (Dissertação de mestrado) – Universidade Federal da Paraíba, João Pessoa – PB.

SANTOS, Paulo Henrique Dias Dos. Análise Exergética de sistemas de refrigeração por absorção de múltiplos efeitos com um par água – brometo de lítio. Dissertação (Dissertação de mestrado) – Universidade Federal da Paraíba, João Pessoa, 2005.

SRIKHIRIN, P.; APHORNRATANA, S.; CHUNGPAIBULPATANA, S.; 2001. A review of absorption refrigeration technologies.

SZARGUT, J.; MORRIS, D. R.; STEWARD, F. R. Exergy Analysis of Thermal, Chemical, and Metallurgical Processes. [S.l.]: Hemisphere Publishing Corporation, 1988. Print edition.

TSATSARONIS, G., 1993. Thermoeconomic analisis and optimization of energy systems. Energy Combust.

VARANI, C. M. R. Avaliação Energética e Exergética de uma Unidade de Refrigeração por Absorção Água/Brometo de Lítio Utilizando Gás Natural. Tese (Tese de Doutorado) — Universidade Federal da Paraíba, João Pessoa – Pb, 2001.

WYLEN, V.; SONNTAG; BORGNAKKE. Fundamentos da Termodinâmica. São Paulo: Edgard Blucher, 2003.