ANALISYS THEORETICAL EXPERIMENTAL FOR A SYSTEM OF REFRIGERATION BY DIFFUSION-ABSORPTION OF WATER AMMONIA OF SIGLE PRESSURE WITH APPLICATION OF COGENERATION BY MINI GENERATORS USING BIODIESEL

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Abstract: *This paper presents mainly an experimental study of absorption cycle of single pressure, represented by the cycles of diffusion-absorption, activated thermically by cogeneration due to exhaust gases from an electric generator, in order to examine not only performance, but also provide its optimization by identifying the components that generate higher irreversibility and costs, and allow support for future studies, with units that can operate at temperatures above 80 °C. It has the intention of assisting isolated communities or other specific applications of refrigeration where the simplicity, lack of maintenance, waste heat recovery and low levels of noise is important. In this study we used a thermodynamic model applied to an absorption refrigeration cycle using water-diffusion-ammonia-hydrogen as working fluids, as water absorbent, the ammonia refrigerant fluid and hydrogen equalizer. An important detail is that the refrigeration cycle operates without the use of mechanical or electrical energy, thermal energy only. The circulation of fluid is due to gravity and a bubble pump. This model was developed in platform EES (Engineering Equation Solver), whose results will be used for simulation and design of system components. The results obtained in this study will be compared with experimental data analysis made in previous studies in which the cycle was thermically activated by the burning of LPG. The thermophysical properties of working fluids are obtained directly involved in the platform. The code constructed allows an analysis by providing the energetic and exergetic performance both in the cycle and for each component. For the experimental studies was obtained through the donation CONSUL, manufacturer in Brazil, a drive to be instrumented and evaluated. The evaluation parameters will be raised based on the theoretical parameters for comparison and adjustments if needed or the model assumptions.*

Keywords: *Refrigeration; diffusion-absorption; cogeneration*

1. INTRODUCTION

Brazil has had for many years cheap and plentiful energy for its economic growth, due to its high hydraulic potential, which produces nearly 83% of all electricity generated in Brazil (ANEEL, 2005). However, in the last decade, electricity consumption grew by an average 4% per annum (MME, 2006), while the generation capacity could not keep up this growth due to decreased investment in building new plants and the continued growth in consumption. It came to a state of collapse, as recorded in 2001 in which the Federal Government decreed a rationing involving a 20% reduction in electricity consumption in the country, based on the year 2000. This meant returning to the consumption levels of the early 90s. It has become urgent, then, the need of using energy in a more rational way, and / or increase supply, using new energy sources (Souza, 2004).

Industrial and commercial sectors that needed to use, during the period of rationing, a cooling system based on vapor compression, whose power consumption is quite high, soured considerable damage in this period, due to the high price of electricity, or by irregular supply .

On the other hand the residential sector, despite being the second largest consumer of electricity in the country, second only to industry, was the largest contributor to the rationalization of consumption in 2001 (ANEEL, 2005). In this sector, refrigerators are present in 88.6% of residences, and in the Northeast the rate fell to 71.8% (IBGE, 2006), but for about 10 million Brazilians who live in rural areas without access to electric energy (ELETROBRÁS, 2005), the use of refrigerators that operate from this source of energy is prevented.

The technologies based on vapor compression, that need and have a high consumption of electricity, and become unviable in isolated communities, have one other drawback is that to use, in general, gases that once released into the atmosphere, collaborate with global warming and attack the ozone layer that protects living beings from harmful ultraviolet rays. As examples of such gases, there are the synthetic refrigerants CFCs, HCFCs and HFCs, which tend to be banned according to international treaties, the Montreal Protocol and Kyoto, for example. For that reason, more ecological and viable cost alternatives are being searched worldwide.

In this scenario, cooling technologies that are thermally activated, such as absorption refrigeration, have become competitively viable, gaining more and more space. Whether for using natural refrigerants that do not affect the ozone layer and do not contribute to global warming, or for the possibility of attending remote communities, in the residential case, as its source of energy may be solar or direct burning of fuel, or for propitiate a more rational use of energy, for industrial and commercial, as they can use: waste heat from a cogeneration process or the direct burning of natural gas, the later strengthened with the increase of the national energy (ANEEL, 2005) . Cogeneration means the simultaneous generation of heat and work from the burning of a fuel (natural gas, wood waste, bagasse, etc.).

In absorption refrigeration, receive more attention systems that operate at two levels of pressure, such as those using the pair water-ammonia or water-lithium bromide as working fluid. But these systems still require electricity or mechanical power to raise the pressure of the solution, being more applicable in industrial and commercial sectors.

Some proposals for a domestic absorption refrigerator are the single pressure refrigeration cycles , such as Carl von Platen Baltzar and Carl Georg Munters' diffusion absorption cycle, and Albert Einstein and Leo Szilard's Einstein cycle (Platen and Munters, 1928, Eintein and Szilard, 1930). Both cycles operate without using electricity or mechanics, just a constant source of thermal energy and uses at least three working fluids to create temperature changes imposing partial pressures in the coolant. The cycle of Platen and Munters uses hydrogen, inert gas, to equalize the pressure throughout the cycle, allowing the movement of fluids and establishing a lower partial pressure for the refrigerant in the evaporator, while maintaining a higher pressure for the refrigerant in the condenser; Ammonia is used as a refrigerant and water as absorbent. While call cycle "single pressure", there is actually a slight variation of global pressure within these cycles due to flow friction and gravity. Thus, although there is no need to pump the fluid to a very high pressure, to create a change in saturation temperature, a mechanism is needed to move the fluid through the cycle against the flow friction and gravity. To eliminate the need for mechanical strength, gravity and a bubble pump driven by heat are used for this purpose. So, as there is no moving part in these cycles (compressor or solution pump), they do not generate noise and vibration during operation, being recommended its implementation in rooms of luxury hotels, offices, hospitals, recreational vehicles, camping and so on. Besides these advantages, the system operates without chlorofluorocarbons, shows good safety, durability, simplicity, portability (the unit can use any heat source, and hence can operate anywhere) and minimum maintenance costs (Chen et al. 1996; Herold et al. 1996; Srikhirin et al. 2001; Koyfman et al., 2003).

Because of low efficiency and high temperature limit, the single pressures cooling cycles have only limited applications, where features like mobility, simplicity, portability, solidity, silent operation and low cost are important. Improved efficiency would open up other potential commercial applications.

2. DIFFUSION-ABSORPTION CYCLE

In 1925, Platen and Munters, students at the Royal Institute of Technology of Sweden, invent the diffusion-absorption cycle. In 1930 Electrolux bought this patent and commercialize it. Currently, the cooling system of absorption-diffusion is manufactured by Consul and Dometic (CONSUL, 2003, DOMETIC, 2004). The original system of Platen and Munters underwent significant changes in its original design, which provided significant improvements in their performance to reach the current commercial configuration, Fig. 2. The main components of this cycle are: steam generator, bubble pump, rectifier, condenser, evaporator, expansion chamber, absorber, solution heat exchanger and gas heat exchanger as follows the Schematic in Fig. 1.

The diffusion-absorption cycle is similar to water- ammonia absorption cycle, being added a third fluid, the equalizing gas, which circulates only through the evaporator, expansion chamber, gas heat exchanger and absorber. Ammonia continues to work as a refrigerant and is the only fluid to run through the entire system. The water acts as absorbent and is restricted to the steam generator, bubble pump, rectifier, absorber and solution heat exchanger. The ammonia-water solution circulates through the generator, bubble pump and absorber. The equalizing gas, which can be non-condensable gases hydrogen and helium, is responsible for standardization of pressures over the cycle and the effect of expansion due to the difference in the partial pressure, allowing the movement of fluids (Koyfman, et al. 2003). The original cycle uses hydrogen as auxiliary gas. It is known that hydrogen can be dangerous in case of leakage. Alternatively, the helium is introduced to replace the hydrogen.

The cooling effect is obtained based on the principle of partial pressure, according to Dalton's Law of Partial Pressures. Due to the auxiliary gas, the partial pressure of ammonia in the evaporator and the absorber is kept low enough to match the required temperature inside the evaporator.

It is easily found in the literature (Chen et al., 1996, Srikhirin et al., 2002, Zohar, et al., 2005), the operation description of the diffusion-absorption refrigeration cycle. To facilitate understanding of the operating principle of this cycle, we adopted the reservoir system as a starting point of operation, like is shown in Fig. 2. Inside the tank, there is a strong solution of ammonia-water (rich in ammonia) with a concentration of 34% (34% ammonia and 66% water in mass). This solution, weak absorber, flows and feeds the generator, where it is heated to 183 ° C causing the ammonia to evaporate. The vapor forms bubbles that push columns of weak solution of ammonia-water liquid in the bubble pump. The weak solution (low in ammonia), with a concentration of 15% is sent by gravity to the solution heat exchanger and then to the absorber, while the ammonia vapor continues to rise toward the rectifier (liquid-steam separator). The steam that usually leaves the bubble pump contains a quantity of water.

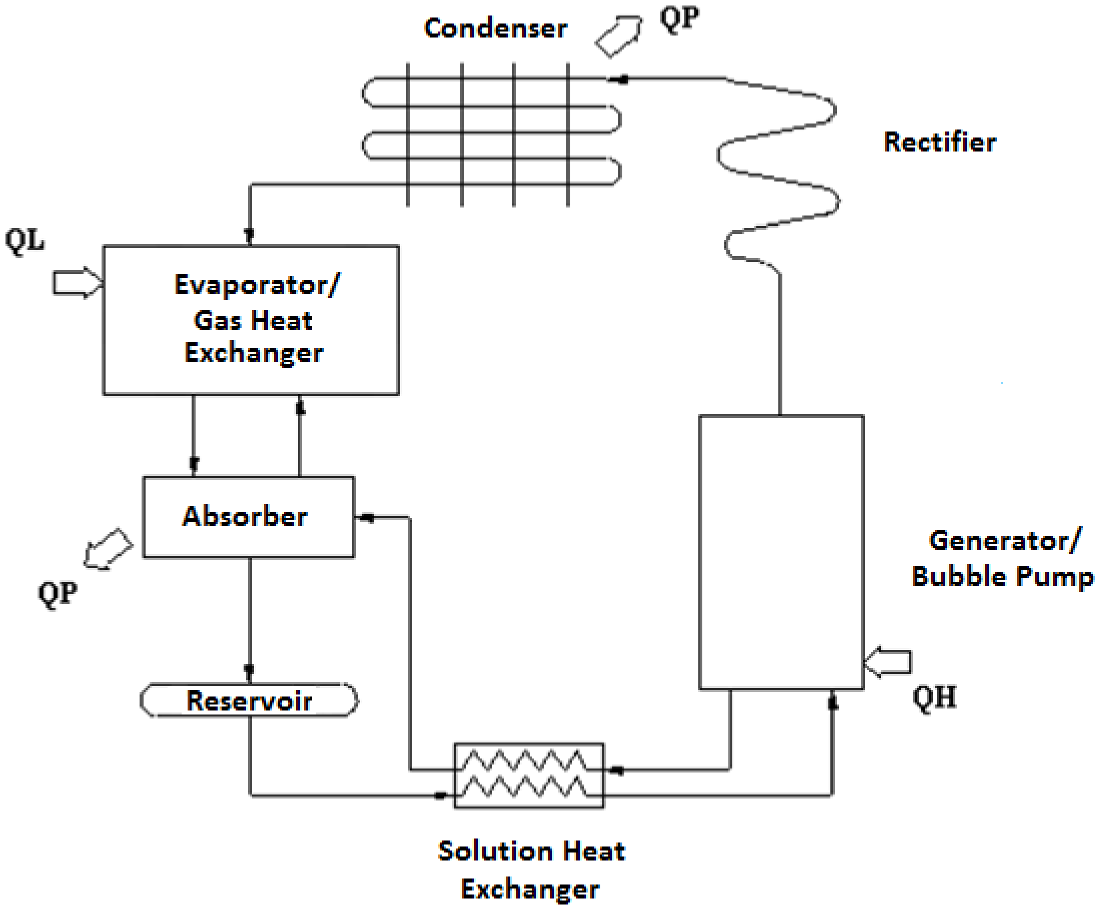

Figure 1. Schematic of diffusion-absorption cycle.

In the rectifier, due to cooling, the water in the steam is condensed, going back and joining the weak solution. The ammonia vapor goes to the condenser, air cooled, where heat is removed causing the condensation at the total pressure of the system, but a part of the ammonia vapor is not condensed and flows directly from the condenser to the reservoir. The condensed ammonia goes to the evaporator, passing first through the expansion chamber. A fluid retainer interposed between the condenser and the evaporator prevents the hydrogen from entering the condenser. Hydrogen gas enters the lower section of the evaporator and flows upwards in counter with liquid ammonia flowing down. The hydrogen flowing upward in the evaporator tends to mix with the ammonia vapor, favoring more evaporation with successive removal of heat from the environment in which the evaporator is located. It is this process of evaporation that produces cooling. The liquid passes through the evaporator, which is divided into two sections: a freezer and a food chiller. Since evaporator is loaded with hydrogen, the partial pressure of liquid ammonia is reduced and this reduction allows the liquid ammonia evaporates at a lower temperature.

Considering that ammonia continues to evaporate, there is an increase in its partial pressure in the food chiller. The density of ammonia is considerably greater than that of hydrogen. Steam (ammonia- hydrogen / helium) becomes heavier with the continuous evaporation of ammonia, thus it goes down by gravity from the freezer to the food chiller and passes through the hot gas exchanger entering the absorber, while at the same time, a continuous stream of weak ammonia-water solution, strong absorber, enters through the air cooled top section of the absorber, also by gravity.

At the absorber, the weak solution of ammonia-water, which was previously cooled in heat exchanger solution allowing the ammonia vapor to be absorbed, causes the vapor to become lighter and rise to the evaporator (a residue of ammonia vapor returns the evaporator, dragged by hydrogen which is lighter) This causes a movement of hydrogen in the evaporator and the absorber. The movement of hydrogen has little effect on the rate of evaporation in the evaporator and the rate of absorption in the absorber. The movement of hydrogen not only affects the rate of mass transfer, but also reduces the cooling capacity, since the gas is warm when leaving the absorber and must be cooled (Srikhirin et al., 2002). A gas heat exchanger is used for the purpose of exchanging heat between the cool gas (evaporator outlet) and hot gas (the evaporator inlet). The ammonia vapor absorbed by the weak solution in the absorber is routed to the reservoir, thus completing the cycle.

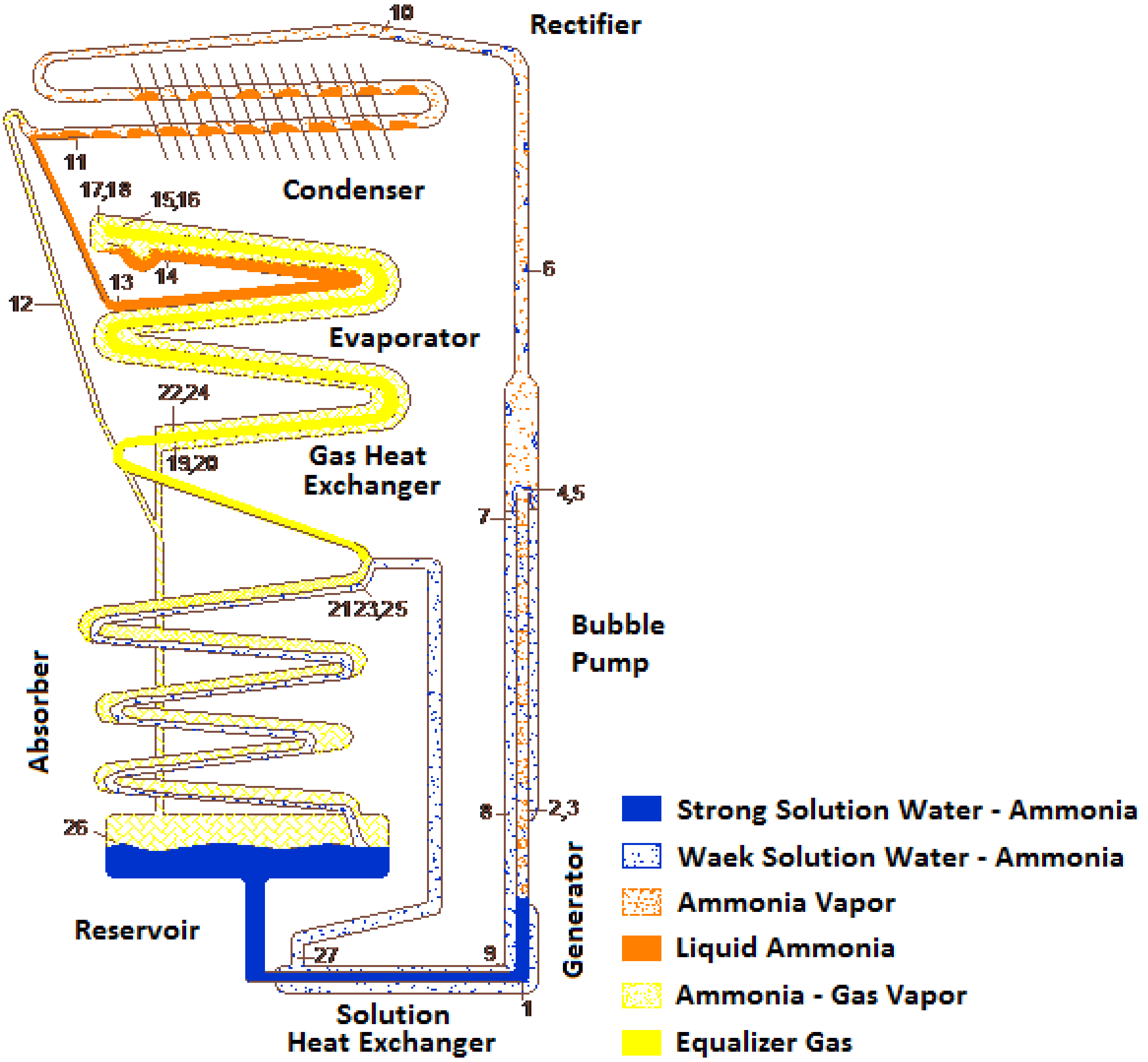

Figure 2. Current domestic diffusion-absorption cycle.

3. INSTRUMENTATION

The instrumentation of the entire cooling unit was done, based on the thermodynamic model developed in the ESS (Engeneering Equation Solver) for an absorption refrigeration cycle-diffusion, acquiring experimental data according to the input parameters of the program, identifying the theoretical points in the components of the refrigerator.

Thereafter thermocouples were placed in appropriate points of the components of the cooling unit to obtain the temperature, where the lectures were made by a digital thermometer with inputs for the outputs of the thermocouples. In some moments a laser thermometer was used for comparison with the data acquired. The heat needed to drive the cooling unit was supplied by the exhaust fumes of an electric generator.

Figure 3. Thermocouple and thermometer.

Figure 4. Laser thermometer.

Figure 5. Electric Generator.

4. EXPERIMENTAL SECTION

The cycles of absorption-diffusion only need thermal energy for their activation, thus to provide the thermal drive to the cooling unit it was attached to an electric generator, whose exhaust gases provided the heat for it. The generator ran for approximately six hours and thirty minutes without interruption, providing heat to the refrigerator, on March 25, 2011 starting at 15 hours and 19 minutes, with an ambient temperature of 32 ° C, and there was the acquiring of the following data:

Table 1. Temperature data of the cooling unit driven by the exausting gases of the electric generator.

Lecture - Hour	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
1° - 16h25min	126,7	112,7	42,0	30,0	31,9	31,6	33,4	33,8	32,4	31,1	31,4
2° - 17h50min	122,9	118,8	37,8	28,4	29,6	28,1	30,6	30,9	30,2	29,4	29,7
3° - 19h18min	128,1	123,8	44,6	32,9	32,5	29,8	32,3	32,4	31,1	29,4	30,0
4° - 21h01min	127,1	118,7	39,5	28,5	27,3	28,4	30,6	30,7	30,3	29,0	29,3
5° - 22h04min	128,3	117,5	34,1	26,6	26,1	28,1	29,9	29,2	26,2	27,2	27,7

*Temperatures in °C

The data shown represent some of the input parameters of the thermodynamic model, the other served as the basis for the possibility of verification of the stabilization time of the cooling unit and comparison with points on the program that could not be measured directly.

For comparative purposes, the refrigerator was also thermally activated by a flame. The Table 2 shows the data obtained from the cooling unit, having a flame fed by a residential gas canister as heat source, also in order to move closer to reality, i.e. to show the applicability of the cooling unit in everyday life.

Table 2. Temperature data of the cooling unit driven by a flame.

Lecture – Hour	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
1° - 09h53min	355	30	31	31	30	33	33	31	33	27	28
2° - 10h13min	359	183	59	59	34	38	34	32	34	27	27
3° - 10h33min	356	193	123	60	34	39	43	35	38	20	25
4° - 10h53min	348	197	132	62	35	44	49	41	45	9	23
5° - 11h13min	344	197	132	61	34	46	49	41	47	0	22
6° - 11h33min	352	197	132	61	34	47	50	42	48	-1	21
7° - 11h53min	355	198	135	61	34	49	51	42	49	-2	20
8° - 12h13min	346	198	135	60	34	49	51	42	49	-6	19
9° - 12h33min	385	198	136	60	35	50	52	43	50	-8	17
10° - 12h53min	332	197	136	60	39	50	52	43	50	-10	14
11° - 13h13min	364	198	137	61	35	50	53	43	50	-10	13
12° - 13h33min	337	197	136	60	34	50	52	43	49	-11	10
13° - 13h53min	354	198	134	60	36	50	52	42	49	-12	8
14° - 14h13min	362	198	134	61	37	51	53	43	50	-12	9
15° - 14h33min	347	198	137	60	37	50	52	42	50	-12	7
16° - 14h53min	337	197	137	60	36	50	52	42	49	-13	6
17° - 15h13min	372	198	134	60	36	50	52	42	49	-14	4
18° - 15h33min	366	197	139	59	37	50	53	42	48	-14	3
19° - 15h53min	356	197	137	60	35	50	52	41	48	-15	3
20° - 16h13min	369	197	137	60	34	50	52	40	48	-15	2
21° - 16h33min	333	196	137	59	37	49	52	40	47	-15	1
24° - 16h53min	351	197	137	59	34	48	52	40	47	-16	0
25° - 17h13min	344	197	133	59	34	49	51	39	46	-16	0
26° - 17h33min	348	197	136	59	34	49	51	40	47	-16	0
27° - 17h53min	349	197	136	59	34	48	51	39	46	-17	0
28° - 18h13min	337	197	137	59	34	48	51	39	45	-17	-1
29° - 18h33min	339	196	137	58	35	48	51	39	46	-17	0
30° - 18h53min	341	197	137	59	34	48	51	39	45	-18	-1
31° - 19h13min	364	198	138	60	35	50	52	40	47	-16	0
32° - 19h33min	353	197	137	58	33	48	51	38	45	-18	-2
33° - 19h53min	369	198	137	58	33	48	51	38	45	-18	-3
34° - 20h13min	367	198	139	60	34	49	52	39	49	-18	-2
35° - 20h33min	342	199	136	58	34	49	52	40	47	-17	-2
36° - 20h53min	333	198	137	58	33	47	50	38	45	-18	-3
37° - 21h13min	347	198	138	60	33	48	51	38	46	-19	-4
38° - 21h33min	355	198	138	58	33	47	50	38	45	-18	-3
39° - 21h53min	331	197	134	58	34	47	50	37	45	-19	-4

*Temperatures in °C

The description of the temperatures in Tab.1 and Tab 2 are described below:

- T1 – temperature of the cycle's heat supply (for Table 1, temperature of exhaust gases, for Table 2, the flame temperature);
- T2 - temperature of the generator / bubble pump;
- T3 - inlet temperature of the rectifier;
- T4 - inlet temperature of the condenser;
- T5 - outlet temperature of the condenser;
- T6 - inlet temperature of weak solution in the absorber;
- T7 - outlet temperature of the gas heat exchanger to the tank;
- T8 - outlet temperature of the absorber;
- T9 - outlet temperature of the reservoir;
- T10 - evaporator temperature;
- T11 - temperature of the wings of the fridge (inside).

Figure 6 shows schematically the points in the components of cooling unit, except for T10 and T11 which are inside the unit.

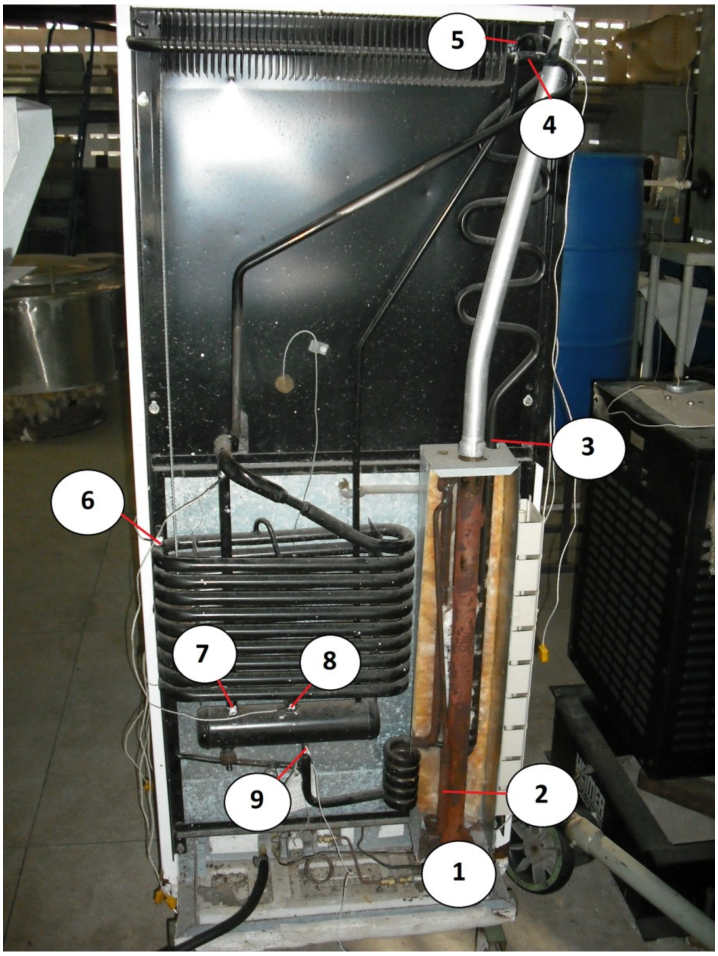

Figure 6. Representation of points in the refrigerator.

5. RESULTS

As can be seen in Tab. 1, the cooling unit was not put in operation, because the temperatures T10 and T11 which are related to the interior of the refrigerator, freezer and food chiller, respectively, did not caused refrigeration effect. Unlike when looking at Tab. 2, when the cooling unit was thermally activated by a flame and it was reached much higher temperatures in the generator / bubble pump, being this a point to be emphasized and crucial to the functioning of the machine, and that within some hours there have been the refrigeration effect.

Continuing to look at Tab. 1, it is notable that even though the ammonia evaporates in the vicinity of the generator/bubble pump, right after in T3 there is already a very abrupt drop in temperature, which does not occur with the flame drive.

Finally, there was not the implementation of the input data obtained in the model developed in the ESS, with the experiment of thermal cooling unit driven by exhaust gases from the electric generator, because the refrigerator did not caused refrigeration effect, as aforesaid, that allowed the determination of the experimental COP and a comparison between the theoretical (Souza, 2004) and the experimental data.

6. CONCLUSIONS

The attempt to apply the co-generation in the diffusion-absorption cycle, using the waste heat from an electric generator, was not successful, because as shown by the data acquired by the instrumentation applied to the cooling unit, ammonia vapor does not reaches the condenser, in fact, even before the rectifier the ammonia is already condensed, thus not circulating through the single pressure refrigeration cycle, and so there is no refrigeration effect. The exhaust from the electric generator does not provide enough heat to have the refrigerator operational, so there is not the versatility as expected for applications such as cogeneration or solar power, for the diffusion absorption cycle, unless it is reached higher heat supply temperatures, i.e., it would be required a more powerful electrical generator or engine, in which the exhaust gases could reach higher temperatures.

Another detail of the applicability of this experiment is the fact that the noises generated by electrical generator are quite high, something that conflicts with some of the advantages of diffusion-absorption cycle, so it would be required the installation of this system with distance between the electrical generator and cooling unit, but this configuration is not feasible because there would be a significant loss of heat in the exhaust pipe that connects to the generator/bubble-pump, even with insulation.

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