EXPERIMENTAL ANALYSIS OF THE UNSTEADY BEHAVIOR OF AN ABSORPTION REFRIGERATION SYSTEM

André Aleixo Manzela, manzela@petrobras.com.br
PETROBRAS, Exploration and Production, Av. Rui Barbosa, 1940 – 3º andar, Zip code 27915-012 – Macaé – RJ, Brazil.

Sérgio de Morais Hanriot, hanriot@pucminas.br
Luben Cabezaas-Gómez, luben@pucminas.br
Cristiana Brasil Maia, cristiana@pucminas.br
José Ricardo Sodré, ricardo@pucminas.br
Pontifical Catholic University of Minas Gerais - Dom José Gaspar Avenue, 500, Coração Eucarístico - Zip code 30535-610, Belo Horizonte, Minas Gerais, Brazil.

Abstract. *This paper presents an experimental analysis of an absorption refrigeration system. The experiments were performed in a domestic refrigerator. Two different energy sources were analyzed: the original energy source (combustion gases of Liquefied Petroleum Gases – LPG) and exhaust gases from an internal combustion engine (ICE). Temperature and humidity were evaluated during experimental tests. The energy requested, the cooling capacity and the coefficient of performance (COP) were determined for the energy sources and the results were compared.*

Keywords*: absorption refrigeration, experimental analysis, unsteady behavior*

1. INTRODUCTION

Technical, economical, strategic and environmental considerations brought a new interest for the refrigeration systems feed by thermal sources, sometimes characterized as residual of processes (Falconi Filho, 2002; Zukowski Júnior, 1999; Lima *et al.*, 2002; Pereira *et al.*, 1998). A considerable research effort has been invested in the study of this kind of refrigeration system in the last years (Aphornratana and Eames, 1995; Cheung *et al.*, 1996; Mcquiston and Parker, 1994; Meunier *et al.*, 1996; Moran and Shapiro, 1999; Pereira *et al.*, 1998; Reis and Silveira, 2002; Santos *et al.*, 2001; Srikhirin *et al.*, 2001; Wylen *et al.*, 1998).

The interest is mainly because of the inferior cost and quality of the energy requested (Aphornratana and Eames, 1995; Horuz and Callander, 2004; Meunier *et al.*, 1996; Pereira *et al.*, 1998; Reis and Silveira, 2002; Santos *et al.*, 2001; Stoecker and Jones, 1985; Varani, 2001).

An important factor to be mentioned while discussing the research development dedicated to the use of absorption refrigeration systems is the necessity of substitution for alternative refrigerants to chlorofluorocarbons (CFC's) used in the compression refrigeration systems, which were convicted, in 1974, as the majors responsible for the ozone layer damage, and that are becoming gradually substituted in response to the Montreal Protocol signed in 1987 by 46 countries that assumed the compromise to reduce the consume of these refrigerants. This Protocol was revised in 1990 when were approved more restrictive measures that anticipated the total elimination to 2000. However, the fast elimination of CFC's would bring a substantial growth in the production costs due to the necessity of new technologies and the abandoning of investments done in technologies for the production of them (Aphornratana and Eames, 1995; Ashrae, 1997; Atwood and Hughes, 1990; Braswell, 1988; Garimella, 2003; Kern and Wallner, 1988; Lorentzen and Pettersen, 1993; Meunier *et al.*, 1996; Moran and Shapiro, 1999; Pereira *et al.*, 1998; Reis and Silveira, 2002; Riffat *et al.*, 1997; Santos *et al.*, 2001; Varani, 2001; Wylen *et al.*, 1998).

It's proper to note that ammonia appears as one of the most potential refrigerants to be used in large scale (Braswell, 1988; Moran and Shapiro, 1999; Pereira *et al.*, 1998; Reis and Silveira, 2002; Wylen *et al.*, 1998).

Recently, many advanced cycles for absorption systems have been investigated. Then, the potential fields of application of absorption systems are growing (Aphornratana and Eames, 1995; Braswell, 1988; Meunier *et al.*, 1996; Reis and Silveira, 2002; Varani, 2001; Ziegler and Riesch, 1993).

Among the several works from literature, some resents works can be commented. Jiangzhou *et al*. (2003) presented an adsorption air conditioning system used in internal combustion engine locomotive driver cabin. The system consists of an adsorber and a cold storage evaporator driven by the engine exhaust gas waste heat, and employs zeolite-water as working pair. The mean refrigeration power obtained from the prototype system was 5 kW, and the chilled air temperature was 18 °C. The authors described the system as simple in structure, reliable in operation, and convenient to control, meeting the demands for air conditioning of the locomotive driver cabin.

Quin et al. (2006) developed an exhaust gas-driven automotive air conditioning working on a new hydride pair. The results showed that cooling power and system coefficient of performance increase while the minimum refrigeration temperature decreases with growth of the heat source temperature. System heat transfer properties still needed to be improved for better performance. Finally, Huangfu et al. (2007) designed and developed an experimental prototype of an integrated thermal management controller (ITMC) for internal-combustion-engine-based cogeneration system. Based on the principle of variable conductance heat pipe (VCHP), the authors presented the concept of ITMC for IC engine based cogeneration system application. Through the establishment of the ITMC experimental prototype, the working principle of ITMC was verified, providing reference for a future practical device. It was shown that the developed prototype could effectively control the temperature in variable working conditions.

The main objective of the present study is to evaluate the performance of the refrigeration system, considering some variables like the energy requested, the refrigeration cooling capacity, the coefficient of performance (COP) and the general transient behavior of domestic refrigerator internal temperature.

2 - Absorption refrigeration

2.1 - Historical

Before the advent of mechanical refrigeration the water was maintained cold being stored inside of porous ceramic vessels. By infiltration, it penetrated into the ceramic and evaporated. The evaporation caused a dissipation of heat and then the water was refrigerated. The Egyptians and Indians from North America used this system. Many times the natural ice of lakes and rivers was cut during the spring and kept in caves to be used later. The Romans transported snow from Alphes to Rome and it was used to refrigerate the drinks of the imperators (Elonka and Minich, 1978).

Although theses refrigeration methods employed natural phenomena, they were used to keep the temperature lower in a space, being called refrigeration (Elonka and Minich, 1978).

The refrigeration is defined as a branch of science that deals with processes involving temperature decreases and the conservation of a space below the ambient temperature (Dossat, 1961).

The absorption refrigeration was discovered by Nairn in 1777, although the first commercial refrigerator of this type only became constructed and patented in 1823 by Ferdinand Carré, which already got many patents between 1959 and 1962 by the introduction of a machine using the ammonia - water pair (Cheung *et al.*, 1996; Costa, 1982; Pereira *et al.*, 1998; Srikhirin *et al.*, 2001).

The absorption refrigeration system experimented good and bad moments, being antecessor of the compression refrigeration system in the XIX century when the systems using the ammonia - water pair had great application in domestic refrigerators, as well as in chemical and processes industries. The systems that used the water - lithium bromide elements were commercialized in the forties and fifties (Costa, 1982; Perez-Blanco, 1993).

Considering many factors, including the constant growing of energy cost, energetic rejects of low temperature that were left in atmosphere in chemical and processes installations are now frequently used to operate absorption refrigeration systems (Horuz and Callander, 2004; Varani, 2001).

Although the first application of the ammonia - water absorption refrigerator has been in the refrigeration field, as in ice production, actually it founds application predominantly in air conditioning (Lazarrin *et al.*, 1996).

2.2 - Absorption refrigeration system

The absorption and compression refrigeration systems are similar, being different fundamentally by the energy source: the first uses thermal energy and the other electrical energy.

In the absorption refrigeration systems are used two fluids, one of them as refrigerant and the other as absorbent. The most known are the ammonia (NH_3) - water (H_2O) pair (ammonia as the refrigerant and water as the absorbent), and the water (H_2O) - lithium bromide (LiBr) pair (water as the refrigerant and lithium bromide as the absorbent).

The limitation of the water - lithium bromide pair is due to the fact that as water is the refrigerant fluid, the system cannot operate at low temperatures (lower than 0ºC). Besides, the lithium bromide crystallizes in moderated concentrations, and in high concentrations the solution is corrosive to some metals and very expensive (Horuz, 1998; Srikhirin *et al.*, 2001).

Figure 1 shows a diagram of the basic cycle of the ammonia - water absorption refrigeration system. In the next paragraphs it is presented a short description about their working principle.

In this refrigeration system, high-pressure ammonia vapor enters into the condenser and releases heat to the neighborhood, getting condensed. The ammonia, now in liquid phase, but still at high-pressure, pass by a throttling device where its pressure is reduced until the vaporization pressure. So it enters into the evaporator and receives heat from the space to be refrigerated, becoming vapor again, but now at low pressure.

Then the ammonia goes to the absorber, where a weak solution of water and ammonia (low ammonia concentration mixture) absorbs this ammonia vapor, rejecting heat to the neighborhood. The solution, now strong (high ammonia concentration mixture), is pumped to the generator where receives heat from the external thermal source. Then, it evaporates getting separated from the water and following to the condenser, running the thermodynamic cycle again. The weak solution that leaves the generator gets back to the absorber to absorb ammonia vapor coming from the evaporator.

Between the absorber and the generator exists a heat exchanger that provides the energy transfer from the weak solution that comes back from the generator to the strong solution that follows to the generator. This device increases the performance of the system due to the fact that the energy necessary from the thermal source to the ammonia vaporization is lower. Experimental studies showed that the coefficient of performance (COP) could be increased in 60% when the heat exchanger is used between the absorber and the generator.

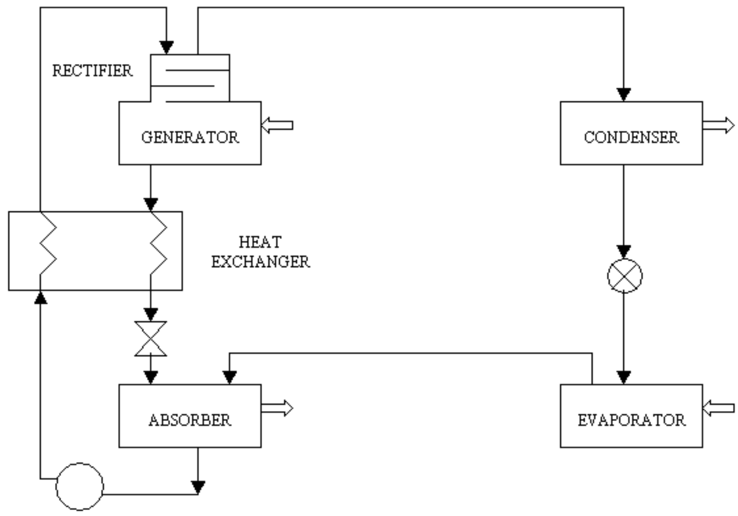

Figure 1. Diagram of the basic cycle of the ammonia - water absorption refrigeration system (Stoecker and Jones, 1985)

Ammonia vapor that follows to the condenser pass before by a rectifier where the water vapor is in part condensed, getting back by gravity to the generator. Being ammonia and water volatile, the cycle needs this rectifier, because without it the water would be accumulated in the evaporator and would reduce the performance of the system. There is yet the possibility of the presence of an analyzer after the rectifier, which works as a heat exchanger that condenses the water vapor that still have not been condensed by the rectifier.

The ammonia - water system has the disadvantage of requiring extra components and the advantage of operating at pressures above the atmosphere. The water - lithium bromide system, in other way, operates below the atmospheric pressure, resulting in air infiltration in the system that has to be periodically purged.

2.3 - Absorption refrigeration versus compression refrigeration

The main difference between the absorption and compression refrigeration systems is related to the energy source that allows the refrigerant to circulate in the circuit. While in the compression system the compressor is used, in the absorption system an absorber and a generator substitute it (Fig. 2). While the energy requested by the compression system is supplied by mechanical work from the compressor, the energy requested by the absorption system is supplied by a thermal source (Dossat, 1961).

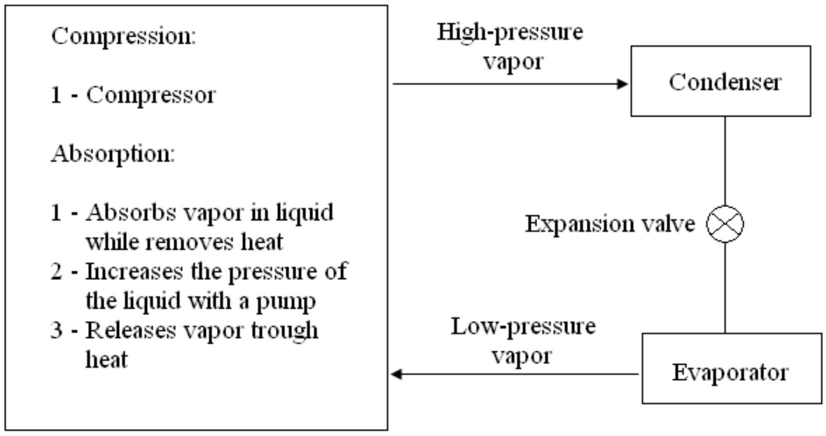

Figure 2. Vapor compression in the compression and absorption systems (Stoecker and Jones, 1985)

A comparison between the absorption and compression systems shows the advantages and disadvantages of the absorption system (Table 1) (Chen *et al.*, 1996; Costa, 1982; Dossat, 1961; Elonka and Minich, 1978; Horuz and Callander, 2004; Mcquiston and Parker, 1994; Moran and Shapiro, 1999; Pirani and Venturini, 2004; Radermacher and Kim, 1996; Reis and Silveira, 2002; Smirnov *et al.*, 1996; Srikhirin *et al.*, 2001; Wylen *et al.*, 1998):

Table 1. Advantages and disadvantages of the absorption system compared with the compression system

Advantages	Disadvantages
1) Inexistence of mobile parts	1) Lower performance
2) Operation with working fluids environmentally friendly	2) Lower applicability
3) Simplicity of operation and control systems	3) Toxicity (ammonia has toxicity)
4) Elimination of electrical supply (use of cheaper and of lower quality energy)	4) Complex installation, being necessary special execution

3 - Experimental setup and procedures

The main objective of this study is to evaluate the performance of the refrigeration system, considering some variables like the energy requested, the refrigeration cooling capacity, the coefficient of performance (COP) and the general transient behavior of the domestic absorption refrigerator internal temperature.

For the experimental tests a domestic absorption refrigerator was considered. The energy source was the combustion gases of Liquefied Petroleum Gases (LPG) and exhaust gases from an internal combustion engine. The refrigerator had 215 liters of internal space. The system worked with the ammonia - water pair as working fluid (Fig. 3).

a) LPG energy source

b) Exhaust gases source

Figure 3. Domestic absorption refrigerator used in the experimental tests.

Temperature inside the refrigerator was monitored through two Pt100 thermometers. A barometer and a liquid-in-bulb thermometer were used to measure ambient pressure and temperature. Ambient pressure was kept at 0.913 ± 0.007 bar, while ambient temperature was maintained at 300 ± 5 K. Air humidity was measured with an uncertainty of $\pm$ 0.06%. Cooling capacity and coefficient of performance were evaluated with uncertainties of $\pm$ 1.84 W and $\pm$ 0.0014, respectively.

3.1 – Experimental set-up using the LPG source

The experiments were carried out with the ambient temperature kept constant during the tests. Initially was installed a rotameter to measure the quantity of fuel consumed by the refrigerator and thermocouples to measure the temperature inside it (Figure 3-a). It was also measured the relative humidity inside the refrigerator. The procedures to the tests are described below.

Approximately 30 minutes before the tests the room air conditioning was connected and the door of the refrigerator was opened to keep the temperature homogeneous with the ambient. After that, the door was closed and the refrigerator was turned-on. The data acquisition acquired the following variables: temperature inside the refrigerator (three sensors), relativity humidity, atmospheric pressure, ambient temperature, LPG flow rate, LPG pressure and LPG temperature. These parameters were taken every 30 seconds. The entire tests took approximately 14.5 hours, and were possible to take parameters during all the time intervals.

3.2 – Experimental set-up using the internal combustion engine

A production 1.6-liter, 8-valve, four-cylinder automotive engine with multipoint electronic fuel injection was used for the tests. The engine also featured compression ratio 9.5:1, 86.4 mm bore and 67.4 mm stroke. The engine was tested in a hydraulic dynamometer of maximum power 260 kW and maximum speed 6000 rev/min. The dynamometer was equipped with a load cell of measuring range up to 2224 N and uncertainty of ± 0.4 N, and a magnetic speed sensor, which uncertainty was ± 3 rev/min. Fuel consumption was measured by a turbine flow meter, of measuring range 0.038 to 100 liters per minute and accuracy of 0.5% of the reading.

A computer-based data acquisition system was used to monitor temperature inside the refrigerator, evaporator inlet and outlet temperatures, and fuel flow rate. All uncertainties of measurements were evaluated according to ABNT/INMETRO [23] (similar to NIST TN 1297), for a confidence level of 95%. Measurement of the exhaust gas temperature was made through two K-type thermocouples installed in the refrigeration system heat exchanger inlet and outlet.

When powering the refrigerator with the engine exhaust gas it was verified that, for engine speeds over 2000 rev/min, the temperature in the refrigerator was increased. At such condition there was excessive energy being transferred from the high temperature exhaust gas to the refrigerant, not allowing its condensation in the condenser due to the elevated sensible heat to be removed. As a consequence, the refrigerant temperature in the evaporator was above that inside the refrigerator. Thus, it was decided to perform the tests at a fixed engine speed of 1500 rev/min to avoid increasing temperature inside the refrigerator. The results were obtained from the absorption refrigeration system using the engine exhaust gas as energy source for wide-open engine throttle valve. More than 800 data points were used to build each curve shown by the figures at Results Section.

4. Results and discussion

An experimental study of the behavior of an absorption refrigeration system has been carried out. The prototype was a domestic absorption refrigerator that uses combustion gases of Liquefied Petroleum Gases (LPG). Exhaust gases from an ICE were also evaluated as energy source. In the tests performed, the speed engine was 1500 rpm and the engine throttle valve was wide open.

Figure 4 shows a temporal variation of the temperatures inside the refrigerator. T_1, T_3 and T_4 represent the values of temperature on the top of the refrigerator, below the evaporator and on the bottom of the refrigerator, respectively. T_{av} represents the average of these temperatures.

It can be noticed that the temperature inside the refrigerator decreased until the steady state was reached. At this point, the energy source was turned off and the temperatures started to increase. The temperatures were measured until a new steady state was reached. After the startup of the refrigerator, the temperature inside the refrigerator took 23 minutes to start to decrease. The lower temperature was reached 5 hours and 20 minutes later. After this period, the system took 7 hours and 40 minutes to reach the new steady state condition.

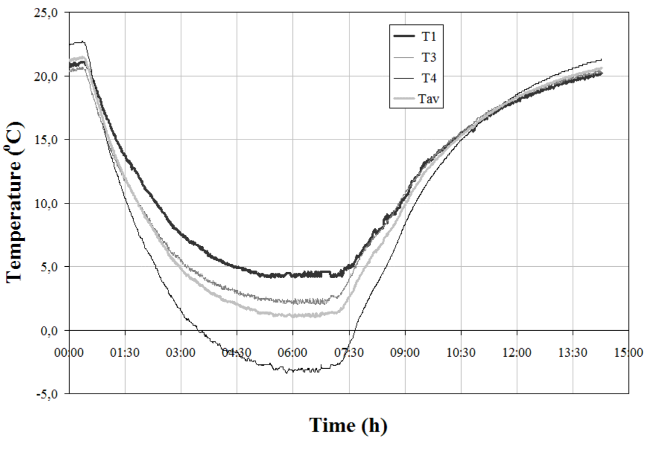

Figure 4 – Temperatures inside the refrigerator using LPG

When the temperatures inside the refrigerator are compared, it can be seen that the lowest temperature occurred below the evaporator, as expected. This is because in the internal space of the refrigerator exist a natural circulation of the air from the top to the bottom region. In fact the air is intensively cooled in the evaporator surface, becoming denser and moving then to the bottom region. In this movement this cold air passes through the sensor positioned below the evaporator, where it is recorded the lowest temperature values.

Figure 5 presents a comparison between the average temperatures inside the refrigerator using LPG and exhaust gases of an ICE as energy source. LPG provided lower temperatures, which where attained in much more time in relation to the ICE system. This phenomenon can be explained due to the fact that heat release from LPG combustion gases was more suitable to the refrigeration system, since this is the original source of energy considered in the project of the employed domestic refrigerator. Since the heat flux from LPG is lower than that from exhaust gases of ICE, the refrigerator operating with exhaust gases as energy source took less time to reach steady state conditions (3 hours and 36 minutes to the first condition and 5 hours and 36 minutes to the second condition).

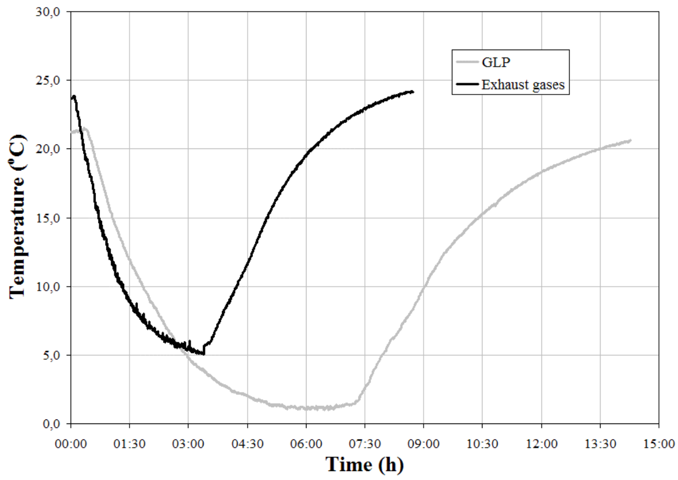

Figure 5 – Comparison between the average temperature inside the refrigerator using LPG and exhaust gases

Figure 6 shows the cooling capacity of the system, calculated according to Manzela (2005). The cooling capacity increases when the temperature inside the refrigerator decreases. The maximum value was 17 W for LPG and 18.4 W for ICE exhaust gases. It can be observed that the system operating with LPG required more time to provide the maximum cooling capacity, justified by the lower heat flux from LPG. It is important to mention that the values obtained agree with those mentioned by Srikhirin *et al.* (2001).

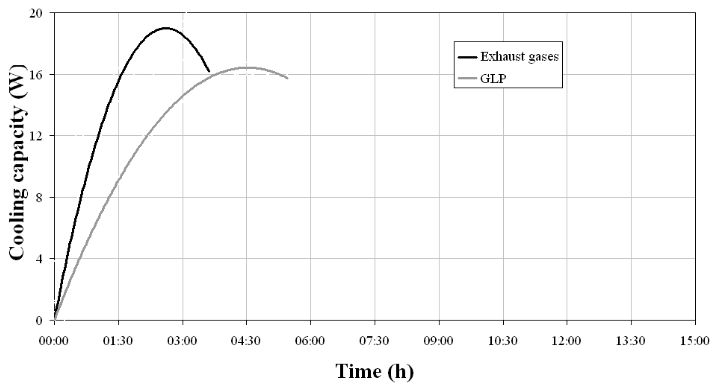

Figure 6. Comparison between the cooling capacity of the refrigerator using LPG and exhaust gases

Figure 7 shows the coefficient of performance (COP) of the refrigerator, calculated according to Manzela (2005). The general behavior of the COP is similar to the cooling capacity general behavior. The maximum COP value was 0.047 for LPG and 0.011 for exhaust gases. According to Chen et. al. (1996), the very low COP of an absorption refrigeration system can be explained because the temperatures of the source energy are about 200ºC, while the evaporator operates with temperatures around -20ºC (resulting in a low Carnot COP), the auxiliary gas requires a portion of the refrigeration load and because the rectifier losses heat directly to the environment. The great difference between the COP of the refrigerator is possibly explained by the fact that the temperature of the exhaust gases was not suitable for the system.

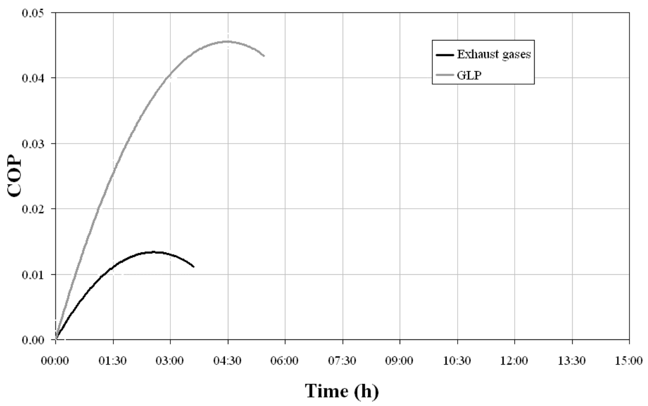

Figure 7. Comparison between the COP of the refrigerator using LPG and exhaust gases

5. Conclusions

It was performed an experimental analysis of a domestic refrigerator operating with two energy sources: the original (LPG) and energy of exhaust gases from an internal combustion engine. It was observed that the exhaust gases provided an amount of energy greater than the required. The main consequences of this exceeded energy were the higher values of temperature and relative humidity inside the refrigerator and the time required to reach the minimum temperature.

Regarding the available energy, the exhaust gases from an internal combustion engine represent an interesting potential to be used as energy source for absorption refrigeration systems. A specific project of a heat exchanger involving the refrigeration system and the exhaust gases pipes could improve the results.

6. Acknowledgements

Financial support of this research was provided by CNPq (National Council for Scientific and Technological Development) with additional assistance from the *Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG).*

7. References

Aphornratana, S.; Eames, I. W., 1995, "Thermodynamic Analysis of Absorption Refrigeration Cycles Using the Second Law of Thermodynamics Method", International Journal of Refrigeration, v. 18, n. 4, pp. 244 - 252.

Ashrae - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1997, Ashrae Handbook - Fundamentals, Atlanta.

Atwood, Theodore; Hughes, H. Michael, 1990, "Refrigerants and Energy Efficiency", International Journal of Refrigeration, v. 13, n. x, pp. 270 - 273.

Braswell, A., 1988, "Impact of CFC Regulations on the Air Conditioning and Refrigeration Industry", International Journal of Refrigeration, v. 11, n. x, pp. 385 - 388.

Chen, J.; Kim, K. J.; Herold, K. E., 1996, "Performance Enhancement of a Diffusion Absorption Refrigerator", International Journal of Refrigeration, v. 19, n. 3, pp. 208 - 218.

Cheung, K.; Hwang, Y.; Judge, J. F.; Kolos, K.; Singh, A.; Radermacher, R., 1996, "Performance Assessment of Multistage Absorption Cycles", International Journal of Refrigeration, v. 19, n. 7, pp. 473 - 481.

Costa, Ênnio Cruz da, 1982, Refrigeração, 3ª edição, São Paulo, Edgard Blücher.

Dossat, Roy J., 1961, Princípios de Refrigeração, tradução da 1ª edição, São Paulo, Hemus.

Elonka, Stephen Michael; Minich, Quaid Walton, 1978, Manual de Refrigeração e Ar Condicionado, tradução da 2ª edição, São Paulo, McGraw-Hill do Brasil.

Falconi Filho, Aldo, 2002, Análise Experimental de um Ciclo de Refrigeração por Absorção Operando em Regime Transiente, Dissertação de Mestrado, Departamento de Engenharia Mecânica, PUC Rio, Rio de Janeiro, Rio de Janeiro, Brasil.

Garimella, Srinivas, 2003, "Innovations in Energy Efficient and Environmentally Friendly Space - Conditioning Systems", Energy, v. 28, n. x , pp. 1593 - 1614.

Horuz, I., 1998, "A Comparison Between Ammonia - Water and Water - Lithium Bromide Solutions in Vapor Absorption Refrigeration Systems", Int. Comm. Heat Mass Transfer, v. 25, n. 5, pp. 711 - 721.

Horuz, I.; Callander, T. M. S., 2004, "Experimental Investigation of a Vapor Absorption Refrigeration System", International Journal of Refrigeration, v. 27, n. x, pp. 10 - 16.

Huangfu, Y., Wu. J. Y., Wang, R. Z., Xia, Z. Z., Li, S., 2007, "Development of an experimental prototype of an integrated thermal management controller for internal-combustion-engine-based cogeneration systems", Applied Energy, v. 84; pp. 1356-1373.

Jiangzhou S., Wang R. Z., Lu Y. Z., Xu Y. X., Wu J. Y., Li Z. H., 2003, "Locomotive driver cabin adsorption air-conditioner", Renewable Energy, v. 28; pp. 1659-1670.

Kern, J.; Wallner, R., 1988, "Impact of the Montreal Protocol on Automotive Air Conditioning", International Journal of Refrigeration, v. 11, n. x, pp. 203 - 210.

Lazarrin, R. M.; Gasparella, A.; Longo, G. A., 1996, "Ammonia - Water Absorption Machines for Refrigeration: Theoretical and Real Performances", International Journal of Refrigeration, v. 19, n. 4, pp. 239 - 246.

Lorentzen, Gustav; Pettersen, Jostein, 1993, "A New, Efficient and Environmentally Benign System for Car Air - Conditioning", International Journal of Refrigeration, v. 16, n. 1, pp. 4 - 12.

Manzela, A.A., 2005, "Estudo Experimental da Utilização dos Gases de Exaustão de um Motor de Combustão Interna como Fonte de Energia de um Sistema de Refrigeração por Absorção, Master Degree Thesis, Pontifícia Universidade Católica de Minas Gerais", Belo Horizonte, Brazil.

Mcquiston, Faye C.; Parker, Jerald D., 1994, Heating, Ventilating and Air Conditioning - Analysis and Design, 4ª edição, New York, John Wiley & Sons.

Meunier, F.; Kaushik, S. C.; Neveu, P.; Poyelle, F., 1996, "A Comparative Thermodynamic Study of Sorption Systems: Second Law Analysis", International Journal of Refrigeration, v. 19, n. 6, pp. 414 - 421.

Moran, Michael G.; Shapiro, Howard N., 1999, Fundamentals of Engineering Thermodynamics, 4ª edição, New York, John Wiley & Sons.

Pereira, José Tomaz Vieira; Milanés, Rafael Lincoln Pratts; Silverio, Rodolfo de Jesús Rodriguez, 1998, "Avaliação Energética e Exergética de um Sistema de Refrigeração por Absorção Água - Amônia", Mercofrio - Congresso de Ar Condicionado, Refrigeração, Aquecimento e Ventilação do Mercosul, Porto Alegre, xxx., pp. x - x.

Perez-Blanco, H., 1993, "Conceptual Design of a High - Efficiency Absorption Cooling Cycle", International Journal of Refrigeration, v. 16, n. 6, pp. 429 - 433.

Pirani, Marcelo José; Venturini, Osvaldo José, 2004, Disseminação de Informações em Eficiência Energética: Eficiência Energética em Sistemas de Refrigeração Industrial, 1ª edição, Itajubá, FUPAI.

Quin F., Chen J., Lu M., Chen Z., Zhou Y., Yang K., 2006, "Development of a metal hydride refrigeration system as an exhaust gas-driven automobile air conditioner", Renewable Energy, doi: 10.1016/j.renene.2006.10.014.

Radermacher, R.; Kim, K., 1996, "Domestic Refrigerators: Recent Developments", International Journal of Refrigeration, v. 19, n. 1, pp. 61 - 69.

Reis, Joaquim A. dos; Silveira, José L., 2002, "Análise Exergética de um Sistema de Refrigeração por Absorção Usando Calor Recuperado de um Motor de Combustão Interna", Mercofrio - Congresso de Ar Condicionado, Refrigeração, Aquecimento e Ventilação do Mercosul, Florianópolis, xxx., pp. x - x.

Riffat, S. B.; Afonso, C. F.; Oliveira, A. C.; Reay, D. A., 1997, "Natural Refrigerants for Refrigeraton and Air - Conditioning Systems", Applied Thermal Engineering, v. 17, n. 1, pp. 33 - 42.

Santos, Afonso Henriques Moreira; Simões, Alexandre Augusto; Martins, André Ramon Silva; Viana, Augusto Nelson Carvalho; Bortoni, Edson da Costa; Lora, Electo Eduardo Silva; Teixeira, Flávio Neves; Haddad, Jamil; Cortez, José Antônio; Nogueira, Luiz Augusto Horta; Almeida, Manuel da Silva Valente de; Pirani, Marcelo José; Venturini, Osvaldo; Gama, Paulo Henrique Ramalho Pereira; Yamachita, Roberto Akira; Silva, Valberto Ferreira da, 2001, Conservação de Energia: Eficiência Energética de Instalações e Equipamentos, 2ª edição, Itajubá, EFEI.

Smirnov, G. F.; Bukraba, M. A.; Fattuh, T.; Nabulsi, B., 1996, "Domestic Refrigerators with Absorption - Diffusion Units and Heat Transfer Panels", International Journal of Refrigeration, v. 19, n. 8, pp. 517 - 521.

Srikhirin, Pongsid; Aphornratana, Satha; Chungpaibulpatana, Supachart, 2001, "A Review of Absorption Refrigeration Technologies", Renewable and Sustainable Energy Reviews, v. 5, n. x, pp. 343 - 372.

Srikhirin, Pongsid; Aphornratana, Satha, 2002, "Investigation of a Diffusion Absorption Refrigerator", Applied Thermal Engineering, v. 22, n. x, pp. 1181 - 1193.

Stoecker, Wilbert F.; Jones, Jerold W., 1985, Refrigeração e Ar Condicionado, tradução da 2ª edição, São Paulo, McGraw-Hill do Brasil.

Tozer, Robert; James, Ron W., 1998, "Heat Powered Refrigeration Cycles", Applied Thermal Engineering, v. 18, n. x, pp. 731 - 743.

Varani, Celina Maria Ribeiro, 2001, Avaliação Energética e Exergética de uma Unidade de Refrigeração por Absorção Água / Brometo de Lítio Utilizando Gás Natural, Tese de Doutorado, Centro de Tecnologia, Universidade Federal da Paraíba, João Pessoa, Paraíba, Brasil.

Wylen, Gordon J. Van; Sonntag, Richard E.; Borgnakke, Claus, 1998, Fundamentos da Termodinâmica, tradução da 5ª edição, São Paulo, Edgard Blücher.

Ziegler, F.; Riesch, P., 1993, “Absorption Cycles. A Review with Regard to Energetic Efficiency”, Heat Recovery Systems and Combined Heat and Power, v. 13, n. 2, pp. 147 - 159.

Zukowski Júnior, Joel Carlos, 1999, Estudo de Sensibilidade em um Sistema de Refrigeração por Absorção Água - Amônia, Tese de Doutorado, Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, Campinas, São Paulo, Brasil.

8. Responsibility notice

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