Implementation of the Characteristic Equation Method applied to an Absorption Chiller LiBr/H_2O of Commercial type

Implementação do Método da Equação Característica aplicado a um Chiller de Absorção LiBr/H_2O do tipo Comercial

Recebido em 28/03/2017. Aprovado em 11/04/2017

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RESUMO
Este trabalho tem como objetivo a obtenção da equação característica de um chiller de absorção de simples efeito do tipo comercial (WFC-SC10) de 35 kW de capacidade nominal e utiliza o par LiBr/H2O a partir dos dados nominais e das características dos componentes térmicos. O chiller de absorção em estudo consta de cinco (5) componentes principais; gerador, condensador, evaporador, absorvedor, e um trocador de calor da solução. O método da equação característica está fundamentado na equação de Duhring a qual permite relacionar as temperaturas médias internas dos trocadores de calor do chiller em função dos parâmetros característicos (produto UA, vazões e temperaturas dos circuitos de água fria, quente e gelada). As potências térmicas de ativação (gerador) e de refrigeração (evaporador) do chiller foram encontradas a partir dos dados de operação do mesmo e para toda a faixa de temperatura dos circuitos de água fria (29 a 32 °C), de água quente (75 a 95 °C) e de água gelada (7 a 13 °C). A versatilidade da potência térmica de ativação e de refrigeração foi verificada mediante a comparação dos resultados obtidos pela simulação teórica do chiller de absorção e os resultados calculados pela implementação da equação característica. Os erros apresentados na comparação foram menores que 5%.
PALAVRAS-CHAVE: Chiller de absorção, LiBr/H2O, equação característica.

ABSTRACT
This study aims to obtain the characteristic equation of a single effect absorption chiller of commercial type (WFC-SC10) of 35 kW of cooling capacity and that uses the pair LiBr/H2O as work fluid, from the nominal data and characteristics of the thermal components. The absorption chiller studied consists of five (5) main components; generator, condenser, evaporator, absorber and a solution heat exchanger. The characteristic equation method is based on the Duhring equation that allows correlate the internal average temperatures of the heat exchangers of the absorption chiller as a function of the characteristic parameters (product AU, flow rates and temperatures of cold, hot and chilled water circuits). The thermal activation power (generator) and the cooling capacity (evaporator) of the chiller were found from the same operating data and for the entire temperature range of cold water circuits (29 to 32°C), hot water (75 to 95°C) and chilled water (7 to 13°C). The versatility of the thermal power activation and the cooling capacity was verified by comparing the results obtained by theoretical simulation of the absorption chiller and the results calculated by the implementation of the characteristic equation method. The errors shown in the comparison were lower than 5%.
KEYWORDS: Absorption Chiller, LiBr/H2O, Characteristic equation.

INTRODUCTION

Absorption refrigeration systems present a good alternative in reference to conventional cooling systems since they use waste heat and sustainable sources such as solar energy for its driven, despite the provided coefficient of performance (COP) is relatively low compared to compression systems. These absorption refrigeration systems are strongly linked to cogeneration processes and trigeneration energy due to the amount of heat rejected in these processes (Ochoa et al., 2014; Daghigh & Shafieian, 2016)

The absorption chiller can be analyzed in numerical and/or theoretical way (Labus et al., 2013; Talukdar & Gogoi, 2016) as well as experimentally (Monné, et al., 2011; Zamora et al., 2014). However, to study the energy behavior of these chillers are required various information such as internal temperatures, overall heat coefficients, mass flows and other parameters that usually are not easy to find and/or estimate (Kohlenbach & Ziegler, 2008a 2008b; Zinet et al., 2012). Hence the importance of finding and/or develop simulation tools that enable the prediction of the thermal power of the chiller as function of easy parameters to measure, such as, the temperature of the external circuits; cold, hot and chilled water (Albers, 2014).

The method in characteristic equation applied to absorption refrigeration systems allows to analyze the behavior performance of an absorption chiller and heat pump through algebraic equations, which represent the driven source and cooling capacity of it, as well as the COP as a function of the difference temperature characteristic (Hellmann et al., 1999). This method is based on thermodynamic fundamentals and specific operating characteristics of the equipment, from simple analytical equations that allow their suitability in simulation platforms of the energy plants, such as power Polygeneration plant's, industrial drying processes, cooling and air conditioning processes, among others. Initially, the method was introduced in absorption refrigeration area in Japan (Takada, 1982), as well through the work of Furukawa (1983 and 1987), on characterization of absorption heat pump using the pair LiBr/H_2O depending on the external circuit (temperature of cold, hot and chilled water circuit).

In this context, numerous works are using the method of the characteristic equation for the analysis of the partial load behavior, control strategies in absorption refrigeration systems (Puig et al., 2010; Gutiérrez-Urueta et al., 2012; Helm et al., 2014; Albers, 2014).

Basing on the work presented by Hellmann et al., 1998, the refrigerating capacity can be analyzed in terms of the total temperature difference or characteristic temperature function ($\Delta\Delta t$), (Albers & Ziegler, 2010), where the characteristic equation has been used as a tool simulation and analysis to implement a control strategy under solar absorption refrigeration system. In other work (Kunh & Ziegler, 2005), it was discussed and analyzed the influence of three levels of temperature (thermal load, heat dissipation and heat source) and its impact on the behavior of the operation of small scale absorption systems (cooling and/or heating). Other modifications and adaptations were conducted in the calculation method of the characteristic equation in order to improve the prediction of the operating point of single and double effect absorption systems. In this context, Puig-Arnavat et al. (2010) conducted a study on multi effect chiller behavior by using approximation methods through multilinear regressions using experimental and/or manufacturer data. Comparisons between two approaches between these two analysed approaches were carried out. The first refers to the work of Hellmann et al. (1998), based on the energy balances, heat and mass transfer correlations, and the second refers to the work presented by Kunh & Ziegler, (2005), based on characteristic equation methods in which the authors define arbitrary temperature functions to develop multilinear regressions of the data. The results showed that using the first approach those found values provided deviations from 15 to 20% and in the second approach, the results were more favorable, since the errors provided were less than 10%. The applications of the method in more complex systems were conducted specifically in chillers with adiabatic absorbers, as is the case in the work presented by Urueta-Gutierrez et al. (2011). The authors performed an extension of the methodology proposed by Hellmann et al. (1998) to predict the behavior of single effect chillers and heat pumps through simple algebraic equations. This extension is based on the characteristic temperature difference, which can be considered as an improvement of the adjustment of the performance curve of these absorption systems, by including the sub-cooling effect, as well as the evaporated non mass effect in the system. Recently, Albers, 2014 shows an application of the characteristic equation method for monitoring cooling systems of the federal agency of the German environment where a control strategy was developed for solar absorption cooling systems using the characteristic equation as a simulation tools. This new control system was able to reduce costs by 5% when compared with the conventional system used.

The present work aims at the implementation of the characteristic equation method in a single effect absorption chiller of commercial type (Yazaky, 2003) that uses the LiBr/H_2O pair as working fluid with nominal capacity of 35 kW. The thermal power activation (generator) and cooling capacity (evaporator) of the chiller were founded from the same operating data and for the entire temperature range of cold water (29 to 32°C), hot water (75 to 95°C) and chilled water (7 to 13°C) circuits. The results were compared with the results obtained by theoretical simulation of the chiller.

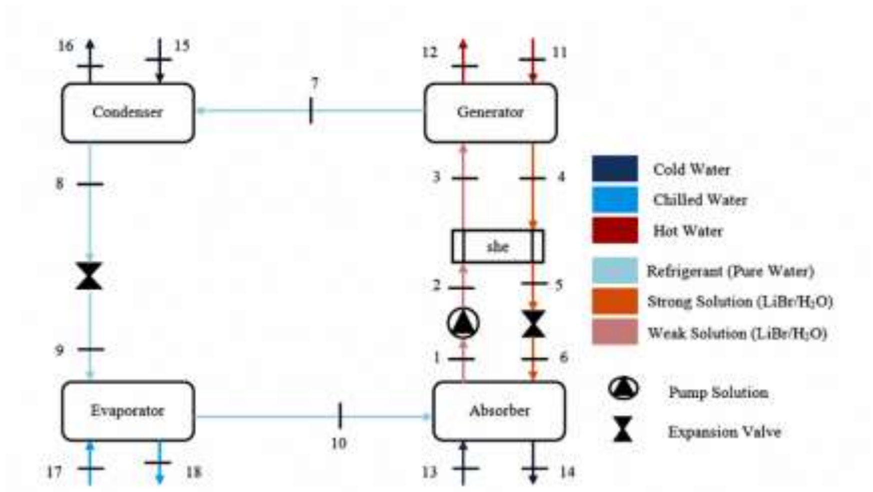
2. MATERIAL AND METHODS

The absorption chiller used in this analysis was a commercial type with nominal capacity of 35 kW of cooling and using LiBr/H_2O as working fluid (Yazaky, 2003; Ochoa et al., 2014b). The absorption chiller consists of five main components (evaporator, condenser, generator, absorber, and a solution heat exchanger).

2.1. Absorption refrigeration cycle

The single effect absorption refrigeration system is similar to the compression refrigeration cycle. Its fundamental difference is the compression process, replaced by thermal unit (generator, solution heat exchanger and absorber), represented by the process 1-6, and showed in Figure 1. The cycle initiated from the driving force supply to the absorption chiller through the hot water, shown by points 11 and 12, in Figure 1. Heat is exchange with the LiBr/H_2O solution (process 3-4), by heating it and spraying it through the generator. The generated steam (point 7) is condensed by the heat exchange with cold water (process 15-16), and passes through an expansion valve (process 8-9), thus lowering the temperature and pressure. Then, moves on to the evaporator, which allows the cooling effect of the chilled water as it passes through it (process 17-18). In the absorber, the solution becomes stronger and is mixed with the saturated steam coming from the evaporator (point 10), and pumped to the generator (process 1-2), where the whole process initiated again. The heat exchanger between the generator and absorber (process 2-3 and 4-5) is usually uses to improves the efficiency of the chiller (COP - coefficient of performance), by preheating the weak solution that returns to the generator (Ochoa et al., 2014b).

Figure 1. Scheme of the absorption refrigeration cycle used for the complete modeling.



For the analysis of this system the following assumptions were considered:

- The pressure variation occurs only in the expansion components;
- The process of pumping of the solution is considered isentropic;
- The heat exchange with the surroundings is negligible;
- The variations in kinetic and potential energy are negligible;
- The entire process occurs in steady state;
- The refrigerant circuit, i.e. states 7, 8, 9 and 10, is driven only by water (0% LiBr);
- The overall heat coefficients are assumed constant through the process.

2.2. Equation Characteristic Method

The application of the characteristic equation is based on thermodynamic fundamentals and nominal characteristics of the chiller (Hellman et al., 1999; Albers & Ziegler, 2005). The main objective of the characteristic equation is to determine the behavior of the absorption chiller from the average temperatures of external circuits (cold, hot and chilled water), taking into account the specific characteristics of the chiller, its overall heat transfer coefficients and flow rates. The method is based on the Duhring rule, which relates the internal average temperatures of each heat exchanger of the chiller, the strong and weak concentrations of the system (at the same vapor pressure) and the solution saturation temperatures from a linear equation with slope β and intersection α, expressed as:

$$T_{sat,sol} = \beta \cdot (X_{sol}) \cdot T_{sat,ref} + \alpha(X_{sol}) \quad (1)$$

Considering the four main components of the system (Absorber, Evaporator, condenser e generator), and calculating the heat flow as a function of the overall heat transfer coefficient and heat exchanger area, product (UA_X), and the average logarithmic difference ($\Delta T_{lm,X}$) as:

$$\dot{Q}_X = UA_X \Delta T_{lm,X} \tag{2}$$

where:

$$\Delta T_{lm,X} = \frac{(t_{X,in} - T_{X,in}) - (t_{X,out} - T_{X,out})}{Ln\left\{\frac{(t_{X,in} - T_{X,in})}{(t_{X,out} - T_{X,out})}\right\}} \tag{3}$$

The subscript *X* represented the chiller components (absorber, evaporator, condenser and generator). The temperature of the external water circuit (hot, cold and chilled) are represented by the letter (*t*) and the temperatures of the internal circuit of the chiller are represented by the letter (*T*). The subscript (*in*) and (*out*) represent the inlet and outlet of each circuit.

In heat exchangers, the temperature difference achieved between the hot fluid and cold fluid ($\Delta T = T_{hot} - T_{cold}$), varies with the type of fluid flow being greater for flow parallel flow than countercurrent flow (Çengel, 2009). For this reason the average logarithmic temperature difference is commonly used for the entrances and exits of hot and cold fluids of the exchanger. However, according to the literature consulted for heat exchangers analysis of absorption refrigeration systems (Ziegler, 1998; Myat et al., 2011; Kohlenbach & Ziegler, 2008a and 2008b), the term (ΔT_{lm}) of the characteristic equation can be replaced by a mean temperature difference between the hot and cold fluids ($\Delta Tlm_X \approx |t_X - T_X|$).

Whereas t_X is the average temperature of the external fluid and T_X is the average temperature of the internal fluid, the heat exchanger flows can be expressed as:

$$\dot{Q}_E = UA_E(t_E - T_E) \tag{4}$$

$$\dot{Q}_A = UA_A(T_A - t_A) \tag{5}$$

$$\dot{Q}_G = UA_G(t_G - T_G) \tag{6}$$

$$\dot{Q}_C = UA_C(T_C - t_C) \tag{7}$$

Applying the first law of thermodynamics to the absorption refrigeration system, Fig. 1, and considering the steady-state in the energy and mass balance of the system, each heat flow can be expressed according to the enthalpy difference and mass flow rate of the cycle as:

$$\dot{Q}_E = \dot{m}_{ref} \cdot (h_{10} - h_8) \tag{8}$$

$$\dot{Q}_C = \dot{m}_{ref} \cdot (h_7 - h_8) \tag{9}$$

$$h_8 = h_9 \tag{10}$$

$$\dot{m}_{ref} = \frac{\dot{Q}_E}{(h_{10} - h_8)} = \frac{\dot{Q}_C}{(h_7 - h_8)} \tag{11}$$

$$\dot{Q}_C = C \cdot \dot{Q}_E \tag{12}$$

$$C = \frac{(h_7 - h_8)}{(h_{10} - h_8)} \tag{13}$$

For the thermal compressor (Generator - solution heat exchanger - Absorber), it can be express as:

$$\dot{Q}_A = \dot{m}_{ref} h_{10} + \dot{m}_{strong} h_6 - \dot{m}_{weak} h_1 \quad (14)$$

$$\dot{m}_{strong} h_6 = \dot{m}_{strong} h_4 - \dot{Q}_{she} \quad (15)$$

$$\dot{Q}_A = A \cdot \dot{Q}_E + \dot{Q}_{max} - \dot{Q}_{she} \quad (16)$$

where:

$$A = \frac{(h_{10} - h_4)}{(h_{10} - h_8)} \quad (17)$$

$$\dot{Q}_{max} = \dot{m}_{weak}(h_4 - h_1) \quad (18)$$

$$\dot{Q}_{loss} = \dot{Q}_{max} - \dot{Q}_{she} \quad (19)$$

Hence: $\dot{Q}_A = A \cdot \dot{Q}_E + \dot{Q}_{loss}$ (20)

Analogously to the generator, it can be express as:

$$\dot{Q}_G = \dot{m}_{ref} h_7 + \dot{m}_{strong} h_4 - \dot{m}_{weak} h_1 - \dot{Q}_{tcs} \quad (21)$$

$$\dot{Q}_G = G \cdot \dot{Q}_E + \dot{Q}_{loss} \quad (22)$$

$$G = \frac{(h_7 - h_4)}{(h_{10} - h_8)} \quad (23)$$

Combining equations 4 - 7 of heat exchangers, and the equations of internal circuit of the chiller (equations 12, 20 and 22), it can be find a system of equations depending on the cooling capacity of the chiller and the temperature difference between the external circuits and internal, expressed as:

$$\dot{Q}_E = UA_E(t_E - T_E) \quad (24)$$

$$C \cdot \dot{Q}_E = UA_C(T_C - t_c) \quad (25)$$

$$A \cdot \dot{Q}_E + \dot{Q}_{loss} = UA_A(T_A - t_A) \quad (26)$$

$$G \cdot \dot{Q}_E + \dot{Q}_{loss} = UA_G(t_G - T_G) \quad (27)$$

Applying Eq 1. of the Duhring rule for two temperature levels (high and low), one can find the following relationships:

$$T_G = \beta \cdot (X_{sol}) \cdot T_C + \alpha \cdot (X_{sol}) \quad (28)$$

$$T_A = \beta \cdot (X_{sol}) \cdot T_E + \alpha \cdot (X_{sol}) \quad (29)$$

Finally, it can be determinated the equation 30, as:

$$T_G - T_A = \beta(X_{sol}) \cdot (T_C - T_E) \quad (30)$$

The β term of equation 30 is given by the slope Duhring diagram, commonly estimated to the solution of LiBr/H_2O between 1.1 to 1.2 (Ziegler & Albers, 2009). By combining the equations 24 to 27 and considering the equations 29 and 30, the average external temperature of the cold, hot and chilled water circuit are determined, expressed as:

$$t_G - t_A - \beta \cdot (t_C - t_E) = \dot{Q}_E \cdot \left(\frac{G}{UA_G} + \frac{A}{UA_A}\right) + \dot{Q}_{loss} \cdot \left(\frac{1}{UA_G} + \frac{1}{UA_A}\right) + \beta \cdot \dot{Q}_E \cdot \left(\frac{C}{UA_C} + \frac{1}{UA_E}\right) \quad (31)$$

The term on the left can be represented by the characteristic temperature difference ($\Delta\Delta t$), as:

$$\Delta\Delta t = t_G - t_A - \beta \cdot (t_C - t_E) \quad (32)$$

Where Eq. 32, may be interpreted as the difference between the temperature thrust (Δt_{thrust}) and temperature lift (Δt_{lift}), as:

$$\Delta\Delta t = \Delta t_{thrust} - \beta \cdot \Delta t_{lift} \quad (33)$$

Where:

$$\Delta t_{thrust} = (t_G - t_A) \quad (34)$$

$$\Delta t_{lift} = (t_C - t_E) \quad (35)$$

The characteristic difference can also be defined in terms of the design parameters, such as:

$$\Delta\Delta t = \dot{Q}_E \cdot \left(\frac{G}{UA_G} + \frac{A}{UA_A}\right) + \dot{Q}_{loss} \cdot \left(\frac{1}{UA_G} + \frac{1}{UA_A}\right) + \beta \cdot \dot{Q}_E \cdot \left(\frac{C}{UA_C} + \frac{1}{UA_E}\right) \quad (36)$$

$$\Delta\Delta t = \left\{\dot{Q}_E + \frac{\dot{Q}_{loss} \cdot \left(\frac{1}{UA_G} + \frac{1}{UA_A}\right)}{\left[\frac{G}{UA_G} + \frac{A}{UA_A} + \beta \cdot \left(\frac{C}{UA_C} + \frac{1}{UA_E}\right)\right]}\right\} \Big/ \left\{\frac{1}{\left[\frac{G}{UA_G} + \frac{A}{UA_A} + \beta \cdot \left(\frac{C}{UA_C} + \frac{1}{UA_E}\right)\right]}\right\} \quad (37)$$

This fraction of the characteristic temperature difference can be simplified in function of two parameters; (S_E) representing the proportion of the global coefficient of each component of the chiller (evaporator, condenser, absorber and generator) and (α_E) which represents the distribution of the overall heat transfer coefficient inside the equipment, such as:

$$S_E = \frac{1}{\left[\frac{G}{UA_G} + \frac{A}{UA_A} + \beta \cdot \left(\frac{C}{UA_C} + \frac{1}{UA_E}\right)\right]} \quad (38)$$

$$\alpha_E = \frac{\left(\frac{1}{UA_G} + \frac{1}{UA_A}\right)}{\left[\frac{G}{UA_G} + \frac{A}{UA_A} + \beta \cdot \left(\frac{C}{UA_C} + \frac{1}{UA_E}\right)\right]} \quad (39)$$

$$\Delta\Delta t = \frac{\dot{Q}_E + \alpha_E \cdot \dot{Q}_{loss}}{S_E} \quad (40)$$

There is a relationship between the parameters (S_E, α_E and $\dot{Q}_{loss}$) called the minimum total temperature difference, expressed as:

$$\Delta\Delta t_{minE} = \frac{\alpha_E \cdot \dot{Q}_{loss}}{S_E} \quad (41)$$

The characteristic temperature difference is defined as:

$$\Delta\Delta t = \frac{\dot{Q}_E}{S_E} + \Delta\Delta t_{minE} \tag{42}$$

Hence, the thermal power activation (generator) and cooling capacity (evaporator) of the absorption chiller can be expressed as:

$$\dot{Q}_E = S_E \cdot (\Delta\Delta t - \Delta\Delta t_{minE}) \tag{43}$$

$$\dot{Q}_G = G \cdot [S_E \cdot (\Delta\Delta t - \Delta\Delta t_{minE})] + \frac{S_E}{\alpha_E} \cdot \Delta\Delta t_{minE} \tag{44}$$

3. DISCUSSION AND RESULTS

Applying the characteristic equation method, described in the previous section, the equations of thermal power activation and cooling capacity of the absorption chiller were determinated according to the parameters S_E, $\Delta\Delta t$, G, $\Delta\Delta t_{minE}$, α_E. These equations represent two straight lines that describe the general behavior of the absorption chiller.

3.1 Nominal Conditions of the Absorption Chiller - WFC-SC10:

The nominal temperature conditions of cold, chilled and hot water of the absorption chiller (WFC-SC10) were 31°C, 7°C and 88°C respectively. The mass flow rate were 5.08, 1.52 and 2.40 $kg.s^{-1}$, for the cold, chilled and hot water respectively. The mass flow rate for the LiBr/H_2O solution was 0.22 $kg.s^{-1}$ (Yazaki, 2003). The values of the products *UA*, needed to obtain the coefficients of thermal power absorption chiller were extracted from the literature (Yazaky, 2003; Ochoa et al., 2016), Table 1.

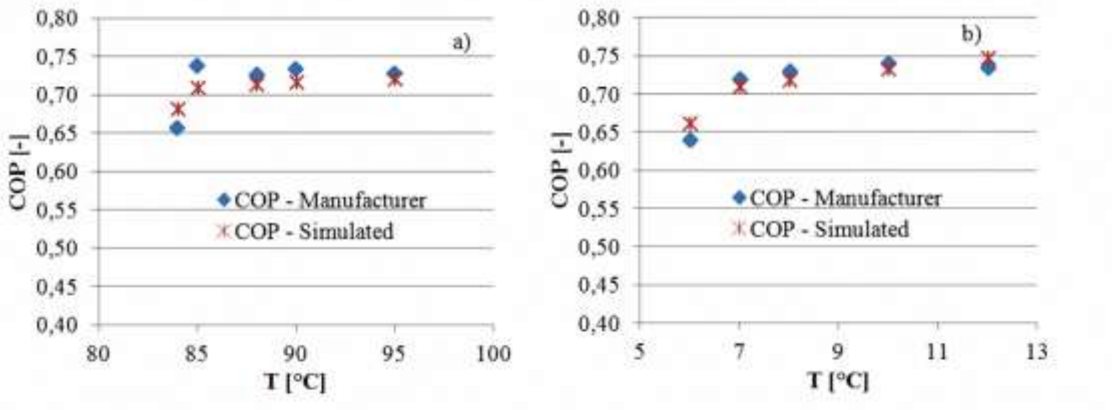
Table 1. Product AU of Chiller heat exchangers WFC-SC10 absorption.

Component	Evaporator	Condenser	Absorber	Generator	Solution heat exchanger
UA [$kW.K^{-1}$]	6.5	12.0	7.6	13.5	0.45

3.2 Comparison of Thermodynamic results and manufacturer's data:

Initially, a comparison of the results obtained from the thermodynamic model and the manufacturer's data was performed in order to verify the versatility of nominal data in the application of the characteristic equation method. The thermodynamic model was based on energy and mass balance equations (Ochoa et al., 2014b). Figures 2a and 2b show a comparison of COP as a function of temperature of the hot water inlet and chilled water outlet of the absorption chiller (Yazaki, 2003; Ochoa et al., 2014b).

Figure 2. Comparison the COP of the absorption chiller WFC-SC10. (a) Depending on the inlet water temperature. (b) Depending on the outlet chilled temperature.



Fonte: Ochoa et al., 2014b

As can be seen in Figures 2a and 2b, the relative errors were less than 4% for all chillers operating range. These errors can be associated with uncertainties in the manufacturer's data, in addition to simplifying assumptions of the thermodynamic model. Depending on the available data supplied by the manufacturer (Yazaki, 2003), such as: hot, cold and chilled water temperatures and mass flow rates, and also the *UA* products of heat exchangers, the characteristic equation method can be used without applied the whole thermodynamically modeling of the absorption chiller, since it would be necessary to know the concentrations and pressures throughout the whole process, which is not provided by the manufacturer. Therefore, this method could be introduced as an alternative tool in the simulation of single-effect absorption chillers that uses the LiBr/H_2O pair as working fluid.

3.3 Application of the characteristic Equation method in the absorption chiller WFC-SC10:

The values of the characteristic equation parameters that define the cooling capacity (equation 43) and the thermal power activation (equation 44) of the absorption chiller from the nominal data were: $S_E = 1.921\ kW.K^{-1}$, $\alpha_E = 0.4016\ kW.K^{-1}$; $G = 1.037$, $\Delta\Delta t_{minE} = 3.2913\,K$ and the coefficient of Duhring (B) selected was 1.2 (Ziegler & Albers, 2009).

3.4 Comparison of theoretical results and the data obtained by the characteristic equation:

The implementation of the characteristic equation method allowed to predict the absorption Chiller behavior along all operating temperature range (7-12°C chilled water, 75-95°C hot water, and 29-32°C cold water). Fifty four (54) operating conditions of the absorption chiller were selected according to the manufacturer's operating data, shown in Table 2 (Yazaki, 2003).

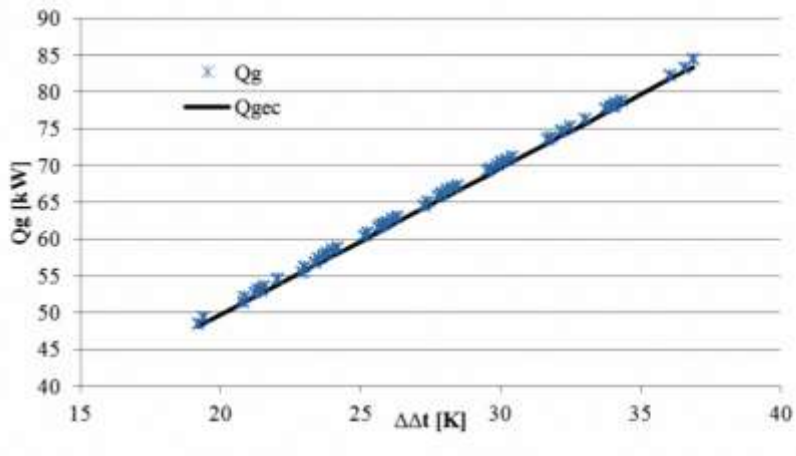
Table 2. Operating conditions of absorption Chiller WFC-SC10.

Hot water [°C]	Cold water [°C]	Chilled water [°C]
75/80/85/88/90/95	29/30/31/32	7
75/80/85/88/90/95	29/30/31/32	8
75/80/85/88/90/95	29/30/31/32	9
75/80/85/88/90/95	29/30/31/32	11
75/80/85/88/90/95	29/30/31/32	12.5

The criteria used to select the 54 operating conditions of the absorption chiller were the hot and cold water inlet temperatures and the chilled water temperatures as external parameters necessary for the implementation of the characteristic equation method, since this method is based on the mean temperatures of the hot, cold and chilled water circuits.

Figures 3 and 4 show the comparison of thermal power activation (generator) and the cooling capacity (evaporator) over the results obtained by the thermodynamic model and the results obtained by applying the characteristic equation method for the operating conditions of the absorption chiller.

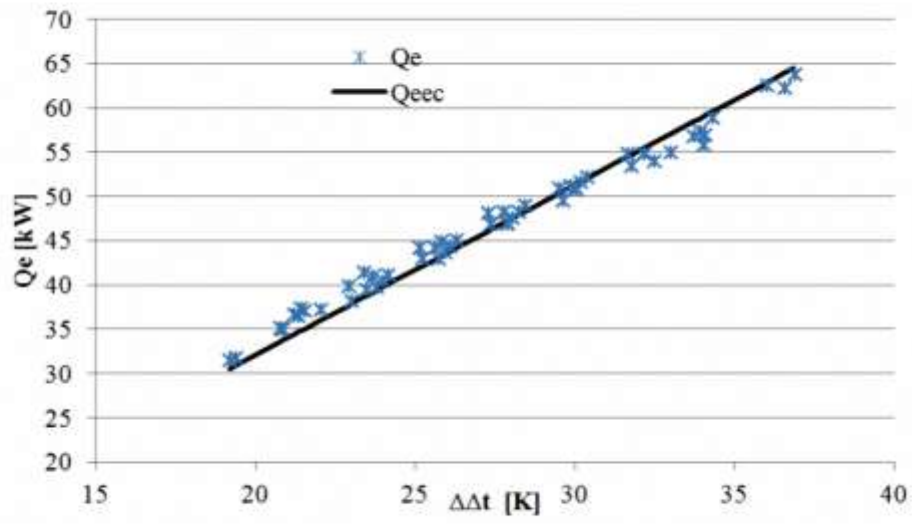
Figure 3. Comparison of the calculated thermal power activation (generator) with the thermodynamic model (Qg) and data obtained using the characteristic equation (Qgec) versus ΔΔt.



It can be seen in Figure 3 that the values obtained by the characteristic equation of the thermal power activation (generator) set well along the operating range of the absorption chiller.

In Figure 4, the comparison of the results of thermodynamic models and those obtained by the characteristic equation for the cooling capacity was presented (evaporator).

Figure 4. Comparison of the calculated cooling capacity (evaporator) with the thermodynamic model (Qe) and data obtained using the characteristic equation (Qeec) versus ΔΔt.



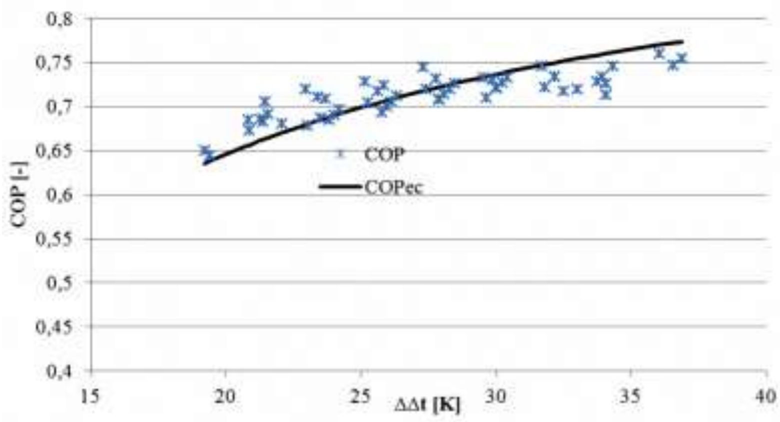
Like the thermal power activation (generator), the comparison between the theoretical results and the ones obtained by the characteristic equation was very good throughout the operating range; however, there is a slight discrepancy between the results, which do not exceed the error of 5%.

The results of thermal power activation (generator) and the cooling capacity (evaporator) obtained with the application of the characteristic equation method have shown relatively small deviations, less the 5% with the theoretical data for the most ΔΔt range analyzed. Despite this, there are at least five conditions where this error is greater at the 5% in the cooling capacity (evaporator) which may be attributed to the deviation of the nominal operation conditions of the absorption chiller, as well as the simplifying assumptions used in the analysis.

It is important to note that despite the deviations (smaller to 5%) found in the thermal power activation (generator) and the cooling capacity (evaporator), the characteristic equation method allowed to predict clearly the operation of the absorption chiller at partial conditions.

In figure 5 it is shown the comparison of the COP results obtained by the theoretical model and the results obtained through the characteristic equation.

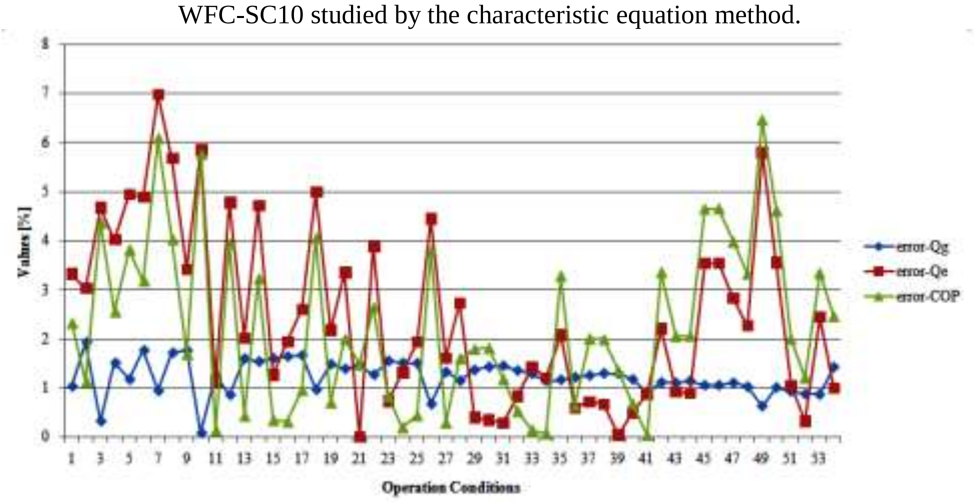
Figure 5. Comparison of the calculated COP with the thermodynamic model and data obtained using the characteristic equation (COPec) versus ΔΔt.



It can be observed that there are differences between the theoretical results and those obtained by the equation characteristics. These deviations are the product of the error propagation in thermal activation power (generator) and cooling capacity (evaporator), which again were attributed to uncertainties in the manufacturer's data and also to simplifying assumptions. However it should be noted that these deviations were not larger than 5% in most operating conditions, especially for nominal operating conditions of the absorption chiller of 88°C, 7°C and 31°C at the hot, chilled and cold water temperatures, respectively represented by a ΔΔt of 24K where the deviation was not greater than 1%.

Finally, Figure 6 shows the variation of the error obtained from the thermal power activation and cooling capacity, as well as the COP as a function of the fifty four (54) operating conditions.

Figure 6. Error variation of the thermal power activation and cooling capacity, as well of the COP absorption chiller WFC-SC10 studied by the characteristic equation method.



As already mentioned, Figure 6 shows the good agreement between the theoretical results and the results values from the characteristic equation. For the most chiller operating range, including the nominal condition, the deviations were lower by 5%. Only four conditions achieved an error higher than 5% but less than 8%. This confirms the versatility of the characteristic equation method to predict the absorption chiller behavior from the average temperature and flow rates of the chilled, hot and cold water circuit, as well as the overall heat transfer coefficients and the areas of heat exchange (UA product). By two simple algebraic equations (straight lines) it can be found the thermal power activation and the cooling capacity of the absorption chiller, which is a good alternative as a simulation and analysis tool in cogeneration and/or trigeneration plants, or any process that's presents an absorption chiller.

4. CONCLUSION

The characteristic equation obtained from the nominal data of the absorption chiller allowed to predict its behavior. The most significant results of this study are:

- Comparison of the results of thermal power activation (generator) and the cooling capacity (evaporator), obtained by the characteristic equation and the theoretical values were good, since the mean relative deviations found were lower than 5% for most operating conditions examined, except for four conditions where the error was higher than 5% but lower than 8%;
- The thermal activation power and cooling capacity found from the characteristic equation method calculated for the nominal condition showed excellent agreement with a smaller error of 1%;
- Despite these deviations, the characteristic equation allowed to reproduce the single effect absorption Chiller behavior of commercial type WFC-SC10;

5. ACKNOWLEDGEMENT

The first author thanks the program science without border - Cnpq-Brazil, for the scholarship of the Post-doctoral study (PDE:203489/2014-4), and also the FACEPE/Cnpq for financial support for research project APQ-0151-3.05/14. Moreover, the authors are also grateful to FADE/FINEP/PETROBRÁS/COPERGAS/UFPE for financial support for research project Proc. 21010422. The first author thanks also Professor Alberto Coronas for his support during the Post-doctoral study at the Rovira and Virgili University and also the Staff from the same university, specially the CREVER group.

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