Comparison models of the operation of absorption machines using the characteristic equation

Modelos de comparação do funcionamento de máquinas de absocração utilizando a equação característica

Modelos de comparación de la operación de máquinas de absorción utilizando la ecuación característica

DOI: 10.55905/oelv22n6-055

Receipt of originals: 05/03/2024
Acceptance for publication: 05/24/2024

Andres Felipe Lazaro Alvarado
PhD Mechanical Engineering, Absorption Chiller and Refrigeration
Instituição: Universidade Federal de Pernambuco
Endereço: Recife, Pernambuco, Brasil
E-mail: andres.lazaro@ufpe.br

Maria Angelica Gonzalez Carmona
PhD Mechanical Engineering, Absorption Chiller and Refrigeration
Institución: Institucion Universitaria de Barranquilla
Endereço: Barranquilla, Atlántico, Colômbia
E-mail: magonzalezc@unibarranquilla.edu.co

Luis Humberto Martinez Palmeth
Doctor Mechanical Engineering and Manufacturing
Institución: Universidad Surcolombiana (USCO)
Endereço: Neiva, Huila, Colombia
E-mail: luis.martinez@usco.edu.co

Jose Carlos Charamba Dutra
Doctor Mechanical Engineering, Absorption Chiller and Refrigeration
Instituição: Universidade Federal de Pernambuco
Endereço: Recife, Pernambuco, Brasil
E-mail: jose.dutra@ufpe.br

ABSTRACT
The integration of absorption machines in micro-trigeneration systems based on micro-gas turbines is one of the most viable options for the use of waste gases from micro-turbines, increasing the energy efficiency of the systems, for which the analytical model proposed by the authors is used (Malinowski & Lewandowska, 2013) and (Wang, Cai, & Zhang, 2004), which was reproduced, tested, modified and extended to gas micro-
turbines with different power ratings but of the same type, this model is used to heat the activation fluids of the absorption chillers used in these systems, directly influencing the behavior of the chillers according to the load and operating conditions of the micro-turbines. This makes it necessary to develop and apply models of the absorption chillers, with the aim of analyzing the degree of influence that micro-turbines operating at partial load have on the absorption chillers. For this reason, the model selected to obtain the performance of the chillers must be a simple model capable of predicting the behavior of the chillers based on the information from the external currents of the chillers. In the literature, there are a large number of studies focused on the development of absorption chiller models with experimental validation, which take into account specific characteristics of the machine with a greater or lesser degree of detail; this type of model and the literature review.

**Keywords:** Trigeneration, Energy, Efficiency.

**RESUMO**

A integração de máquinas de absorção em sistemas de microtrigeração baseados em microturbinas a gás é uma das opções mais viáveis para o aproveitamento dos gases residuais provenientes de microturbinas, aumentando a eficiência energética dos sistemas, para a qual o modelo analítico proposto pelos autores é utilizado (Malinowski & Lewandowska, 2013) e (Wang, Cai, & Zhang, 2004), que foi reproduzido, testado, modificado e estendido para microturbinas a gás com diferentes potências mas do mesmo tipo, este modelo é utilizado para aquecer os fluidos de acionamento dos chillers de absorção utilizados nestes sistemas, influenciando diretamente o comportamento dos chillers de acordo com a carga e condições de operação das microturbinas, o que torna necessário desenvolver e aplicar modelos de chillers de absorção, com o objetivo de analisar o grau de influência que as microturbinas operando em carga parcial têm nos chillers de absorção. Por esta razão, o modelo selecionado para obter o desempenho dos chillers deve ser um modelo simples, capaz de prever o comportamento dos chillers com base nas informações das correntes externas dos chillers. Na literatura, há um grande número de estudos focados no desenvolvimento de modelos de chillers de absorção com validação experimental, que levam em consideração características específicas da máquina com maior ou menor grau de detalhamento; este tipo de modelo e a revisão da literatura.

**Palavras-chave:** Trigeração, Eficiência, Energética.

**RESUMEN**

La integración de máquinas de absorción en sistemas de microtrigeneración basados en microturbinas de gas es una de las opciones más viables para el aprovechamiento de los gases residuales de las microturbinas, aumentando la eficiencia energética de los sistemas, para lo cual se utiliza el modelo analítico propuesto por los autores. Se utiliza (Malinowski & Lewandowska, 2013) y (Wang, Cai, & Zhang, 2004), el cual fue reproducido, probado, modificado y extendido a microturbinas de gas con diferentes potencias pero del mismo tipo, este modelo se utiliza para calentar los fluidos de
activación de los enfriadores de absorción utilizados en estos sistemas, influyendo directamente en el comportamiento de los enfriadores de acuerdo con la carga y condiciones de operación de las microturbinas, esto hace necesario desarrollar y aplicar modelos de los enfriadores de absorción, con el objetivo de analizar el grado de influencia que tienen las microturbinas funcionando a carga parcial sobre las enfriadoras de absorción. Por este motivo, el modelo seleccionado para obtener el rendimiento de las enfriadoras debe ser un modelo simple capaz de predecir el comportamiento de las enfriadoras en base a la información de las corrientes externas de las enfriadoras. En la literatura existe una gran cantidad de estudios enfocados al desarrollo de modelos de enfriadores de absorción con validación experimental, que toman en cuenta características específicas de la máquina con mayor o menor grado de detalle; este tipo de modelo y la revisión de la literatura.

**Palabras clave:** Trigeneración, Eficiencia, Energética.

**1 INTRODUCTION**

A basic absorption refrigeration cycle consists of an absorber, a generator, a condenser, and an evaporator, a solution exchanger, expansion valves and a solution pump. In the Figure 1, The diagram of the basic absorption refrigeration cycle is shown, showing the points through which the heat exchange fluids pass.

When refrigerant vapor is produced in the generator by the process of forced boiling by the external hot fluid entering the generator (11), this vapor passes to the condenser (7) at high pressure, being condensed on contact with the external dissipation circuit (15) and entering the liquid state of the condenser (8), subsequently passing through the expansion valve (9), lowering the pressure to reach the evaporator, being evaporated on contact with the external circuit (17) to generate cold water; the refrigerant again in vapor state but with low pressure (10) enters the absorber where it is absorbed by the refrigerant-poor solution coming from the solution expansion valve (6), this refrigerant-poor solution is formed by the absorber-refrigerant pair, this process is given by the temperature decrease given by the dissipation system of the system (13). The liquid refrigerant-rich solution leaving the absorber (1) enters the solution pump, where it is pumped increasing the pressure to the heat exchanger or preheater (2) where the refrigerant-rich solution is preheated to enter at high pressure to the generator (3) to leave...
with low concentration of refrigerant (4), because the refrigerant vapor passed to the condenser. This refrigerant-poor solution leaving the solution exchanger (5) with lower temperature reaches the solution expansion valve, where the pressure is lowered to enter the absorber (6) completing the cycle.

Figure 1. Diagram of a single-effect absorption refrigeration cycle

Source: Authors

2 ABSORPTION CHILLER MODELS

The characterization of absorption chiller equipment is complemented through the development of models that predict the behavior of this equipment under different working conditions, but it is paramount to know how to choose the type of model best suited to the needs of each author, which is why a comparative evaluation by (J. Labus, Bruno, & Coronas, 2013), of different absorption chiller models can serve as a reference when simple but accurate absorption chiller models are needed, for example to integrate these models in complete energy supply and demand models such as trigeneration system configurations. These simple chiller models, characterized by a low number of input parameters, can be used to facilitate annual simulations of complex building systems while providing an adequate level of performance prediction.

Absorption chiller models, both physical and empirical approaches have been studied and presented in the literature by different authors, but in this thesis only a brief
review of the most recent or relevant ones will be given, this review is detailed according to the type of model presented by the author.

Physical thermodynamic or more accurate thermodynamic models were reported by many authors, including (Grossman & Zaltash, 2001), who developed a modular simulation tool for absorption systems called ABSIM, with which it is possible to study different absorption cycle configurations with different working fluids. ABSIM calculates the internal cycle state points and thermal loads on each component using a graphically user-constructed cycle configuration, specifying the given working fluid and operation conditions.

(Kaynakli & Kilic, 2006), developed a theoretical study of the performance of a H2O-LiBr absorption system, using a thermodynamic analysis of the absorption cycle; the authors investigated the influences of conduction temperature and heat exchanger efficiency on component thermal loads and COP.

(Yin, Qu, & Archer, 2010), presented the development of a detailed thermodynamic model of a two-stage H2O-LiBr absorption chiller with an output of 16 kW, the steady-state model was based on the relationships of the thermo-physical properties of the working fluids, the mass and energy balances, and the heat and mass transfer relationships for each component of the absorption chiller.

In the thesis presented by (Wu, Zhang, Li, Shi, & Wang, 2012), the authors develop thermodynamic models of different absorption and heat pump cycles, with the aim of testing their applicability with different heat sources, working fluids and in different ranges of cold production. All these thermodynamic models are very demanding as they require a complete knowledge of the absorption cycle including some internal points. These models need a large number of input parameters such as heat transfer coefficients (U) and heat transfer areas (A) of the heat exchangers, the flow rate of the rich solution, the properties and flow rate of the working fluid, the temperatures and some additional assumptions for the convenience of modelling.

A more complete explanation of all these degrees of freedom in the modelling of absorption chillers can be found at (Ayou, Bruno, Coronas, & Bruno, 2012). However, especially with commercial units, the internal parameters of the equipment are not yet
available, which is why thermodynamic models are more suitable during the design stage of the absorption equipment as explained in the article by (Florides, Kalogirou, Tassou, & Wrobel, 2017).

The calculating time in simulation software packages using these models is very long as they require a large number of simultaneous iterations, which is one of the reasons why these models are not very practical.

3 CHARACTERISTIC OF EQUATION METHOD

To obtain the performance of an absorption chiller, (Hellmann H. M., Schweigler C., & Ziegler F, 1999) proposes a method where the cooling capacity and COP are related by linear algebraic expressions with the temperatures of the external fluids of the absorption chillers. The authors (Cudok & Ziegler, 2015), (Kühn, Meyer, & Ziegler, 2008), (Puig-Arnavat, Lopez-Villada, Bruno, & Coronas, 2010), propose a series of expressions similar to the characteristic equation but obtained with a multiple linear regression with experimental data from the chillers. The authors (Lecuona, Ventas, Venegas, Zacarias, & Salgado, 2008), calculate the optimum operation temperature of solar cooling systems by means of the characteristic equation, where the cooling capacity and the COP of the chiller are expressed as functions of the temperatures of the external fluid that exchanges heat with the solution and the refrigerant, using the so-called characteristic temperature difference (ΔΔt), finally the obtained characteristic equation predicts the partial load behavior of the modelled absorption chillers and avoids the need to perform extensive numerical simulations of the internal thermodynamic cycle.

Being the characteristic equation method, a method widely used in the CREVER group, where authors such as (Puig-Arnavat et al., 2010), (López Villada, 2011), (Montero Izquierdo, 2012), (Zamora García, 2012) y (Ochoa & Coronas, 2016), from which the group concludes that the multivariate regression method for QRER and QRG is the most accurate when only information from the external circuits of the chillers is available, as will be detailed in the following section.
3.1 METHODS OF DETERMINING CHARACTERISTIC PARAMETERS

To obtain the parameters used in the characteristic equation, described in general terms in the previous section, the most appropriate method for commercial chillers was also mentioned, for which only the temperature and flow rate information of the chiller's external circuits is available.

These methods include:

1. Determination of the parameters \( B, S_E, \alpha, H_G \) \( \Delta \Delta t \), through the design parameters of the equipment, for which it is necessary to know the internal heat transfer coefficients of each thermal component of the chiller, external flow rates, flow rate of the rich, lean and refrigerant solution, external and internal temperatures of the system. This method is much more extensive and the information needed to apply it is quite extensive and detailed, so many authors turn to method 2 and 3, in which the parameters are determined through reduced and/or experimental parameters.

2. Determination of the parameters \( s_E, \alpha, \Delta \Delta t_{\text{min},E} \) from the linear multivariable regression for \( Q_E \), where the term \( \Delta t' \), is coined, which is defined as a new parameter that correlates the behavior of the average temperatures of the external streams of the chillers with the powers. Although the method of the equation has been developed and extended to all types of cycles with different configurations, fluids, flow variation, etc. By different authors, some of these as (Puig-Arnabat et al., 2010), present a study, the authors conclude that obtaining the equations that represent the behavior of the chiller has a better fit by means of linear multivariable regression. The simplicity of the equations that describe the behavior of the absorption chiller make it suitable for implementation in computer simulation tools, but in the same way they conclude that the improvement of the method applies more to the cooling capacity, since the thermal capacity has greater deviation, so for a better fit it is necessary to apply the method 3.\( QR_E \) and \( QR_G \) or method 3.

3. Determination of the parameters \( s_E, \alpha, \Delta \Delta t_{\text{min},E} \) from the linear multivariable regression for \( QR_E \) and \( QR_G \), this method differs from the basic characteristic
equation because the regression is applied for both QRER and for QRGR, without the need to define the characteristic temperature, i.e. it is possible to obtain the characteristic expressions of the chillers through the multivariable regression method for QRER y QRGR.

4. Non-linear multivariate regression method, in this case the equations for the cooling capacity and thermal power of the generator are quadratic polynomials with multiple terms for the external mean temperatures. In order to determine the most significant terms, it is necessary to carry out the analysis of variance of the polynomial terms on several occasions, obtaining the polynomial that best fits the data, which is less used because the implementation of non-linear equations in simulation programs and possible convergence problems during the calculation do not compensate for its greater precision.

5. Extended characteristic equation, in which the effect of the external flows of the thermal chiller has been considered as presented by authors (Gutiérrez-Urueta, Rodríguez, Ziegler, Lecuona, & Rodríguez-Hidalgo, 2012) based on the method proposed by (Albers & Ziegler, 2009).

To obtain the parameters of the characteristic equations of the absorption chillers selected in this thesis, we chose to use the method of multiple linear correlations of QRER y QRGR.

From the average temperature of the thermal fluid circulating through the external circuits of each of the components of the absorption chiller, comparing the experimental data with the theoretical data, which are obtained through the parameters of the general equation (1) of the ΔΔt’, which is replaced in equation (2), finally obtaining the general equation (3).

\[
\Delta\Delta t' = t_G - a * t_{AC} + e * t_E \quad (1)
\]

\[
Q_x = s_x * \Delta\Delta t' + r_x \quad (2)
\]

\[
Q_x = s_x * t_G + sa_x * t_{AC} + se_x * t_E + r_x \quad (3)
\]
Where

“x” corresponds to the analyzed component, \( s_{x,R} \), \( a_{x,R} \), \( e_{x,R} \), \( y_{x,R} \), are the coefficients resulting from the multi-variate correlation of the experimental data.

### 4 APPLICATION OF MODELS IN CASE STUDIES

#### Case I

By means of the linear adjustment of the average capacities and temperatures of the external circuits of each component, the parameters \( s \), \( a \), \( e \), and \( r \) were obtained from the equation (3-4) for \( Q_{E,R} \), (3-5) for \( Q_{G,R} \) y (3-6) for \( Q_{AC,R} \), resulting from the multi-variable regression carried out in Excel, for a 10 kW small power absorption chiller, with ammonia-water as the single-acting working fluid in the thesis. In the Table 1, the values obtained for the parameters given in equation (3-1) are presented.

La Chilii® PSC 12, was tested by varying the temperature of the activation hot water in a range of 75–95 °C at the inlet, a temperature ranges at the inlet of the dissipation water between 20-26 °C, generating cold water with a range between 0-11°C. Annex E shows the tabulation of the data used to obtain the Characteristic Equation of the chiller.

<table>
<thead>
<tr>
<th></th>
<th>Evaporador</th>
<th>Generador</th>
<th>A/C disipación</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s )</td>
<td>0.3084</td>
<td>0.6174</td>
<td>0.9882</td>
</tr>
<tr>
<td>( a )</td>
<td>-2.6513</td>
<td>-2.0015</td>
<td>-2.2861</td>
</tr>
<tr>
<td>( e )</td>
<td>1.9240</td>
<td>1.1204</td>
<td>1.3982</td>
</tr>
<tr>
<td>( r )</td>
<td>1.0750</td>
<td>-5.9867</td>
<td>-2.8406</td>
</tr>
</tbody>
</table>

Source: Authors

From equation (1) for the overall \( \Delta \Delta t' \) the parameters \( s \), \( a \), \( e \) and \( r \), are replaced by the parameters in Table 1, obtained respectively for each component of the experimental data.

\[
Q_E = 0.3084 \times t_G + (-0.81772) \times t_{AC} + 0.59341 \times t_E + 1,0750 \quad (4)
\]
\[ Q_G = 0.6174 \times t_G + 1.2358 \times t_{AC} + 0.69180 \times t_E + (-5.9867) \]  \( (5) \)

\[ Q_{AC} = 0.9882 \times t_G + 2.2591 \times t_{AC} + 1.3817 \times t_E + (-2.8406) \]  \( (6) \)

In the Figure 2, Figure 3 and Figure 4, the results of the "fitting" performed with the experimental data Vs. the data calculated by equations (2), (3) and (4) are presented, observing that they have a good fit, with an error of ± 10%.

**Figure 2.** Experimental cooling capacity Vs. calculated using linear multi-variable regression \( \Delta t' \)

**Figure 3.** Experimental thermal power Vs. calculated using linear multivariate regression \( \Delta t' \)
Figure 4. Experimental dissipation capacity Vs. calculated using multivariate regression

In the Figure 5 and Figure 6, the good adjustment of the thermal power and the experimental cooling capacity as a function of the calculated $\Delta \Delta t'$ is clearly visualized, the good adjustment with the cooling capacity is observed, and it is also observed that it has a greater dispersion with the thermal power.
Case II

By means of the same linear adjustment of the average capacities and temperatures of the external circuits of each component as explained in the previous section, the parameters $s$, $a$, $e$, and $r$ were obtained from equation (7) for QRER and (8) for QRGR, resulting from the multi-variable regression performed in Excel, for a 17 kW absorption chiller, with ammonia-water as the single-acting working fluid. In the Table 2, the values obtained for the parameters given in equation (1) are presented. The ROBUR ACF 60-00 TK was tested by varying the temperature of the cold water produced up to 8ºC, dissipated directly by air, and activated with thermal oil at 217ºC. Annex E shows the tabulation of the data used to obtain the Characteristic Equation of the chiller.

Table 2. Parameters $s$, $a$, $e$, $r$ for the E. characteristic of ROBUR ACF 60-00 TK.

<table>
<thead>
<tr>
<th></th>
<th>Evaporador</th>
<th>Generador</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>0,1022</td>
<td>0,1478</td>
</tr>
<tr>
<td>$a$</td>
<td>1,0074</td>
<td>-0,4283</td>
</tr>
<tr>
<td>$e$</td>
<td>-7,0668</td>
<td>0,5173</td>
</tr>
<tr>
<td>$r$</td>
<td>-5,1855</td>
<td>-9,5880</td>
</tr>
</tbody>
</table>

$Q_E = 0,1022 \cdot t_G + 0,129 \cdot t_{AC} + 0,72194 \cdot t_E + (-5,1855)$ (7)

$Q_G = 0,1478 \cdot t_G + 0,0633 \cdot t_{AC} + 0,07641 \cdot t_E + (-9,588)$ (8)
In Figure 7 and Figure 8, show the results of the fitting of the experimental data versus the data calculated by equations (5) and (6), observing that they have a good fit, with an error of ± 10%.

In Figure 9 and Figure 10, shows the good fit of the experimental thermal power and cooling capacity as a function of the calculated ΔΔt'.
Case III

With the experimental data from the 35 kWt WFC-SC10 Yazaki single-acting chiller, connected to the test bench of the GET group laboratories at the Federal University of Pernambuco, the chiller's characteristic equation was obtained by applying the linear multivariable regression method for Qe and Qg, calculating the parameters s, a, e, and r, presented in the Table 3 and applied in equation (9) for QRER and (3-10) for QRGR, the result of the regression carried out in Excel.

The tests were performed leaving the water flow rates of the external currents fixed, as well as the temperatures of the water entering the absorber (27 °C) and the condenser (12 °C), and varying only the temperature of the hot water entering the
generator in a range of 75 - 95 ºC. The flow rates used for these tests were: 2.39 [kg/s] for the generator; 1.52 [kg/s] for the evaporator; 5.08 [kg/s] for the absorber - condenser, which are connected in series. The data have a repeatability of 5, i.e. 5 tests were performed under the same conditions to improve the reliability of the data. The Ciatessa 10 kW prototype was tested by varying the temperature of the cold water produced to 6 ºC, indirectly dissipated by air, and activated with hot water at 90 ºC. Annex E shows the tabulation of the data used to obtain the chiller's Characteristic Equation.

Table 3. Parameters s, a, e, r for the E. characteristic of the WFC-SC10 Yazaki

<table>
<thead>
<tr>
<th></th>
<th>Evaporador</th>
<th>Generador</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>-23,03157</td>
<td>-37,67905</td>
</tr>
<tr>
<td>s</td>
<td>-0,00915</td>
<td>2,32758</td>
</tr>
<tr>
<td>a</td>
<td>-128,28059</td>
<td>-2,38727</td>
</tr>
<tr>
<td>e</td>
<td>-103,52943</td>
<td>0,28981</td>
</tr>
</tbody>
</table>

Source: Authors

\[
Q_E = -0,00915 \times t_G + 1,17345 \times t_{AC} + 0,947044 \times t_E + (-23,0315) \tag{9}
\]

\[
Q_G = 2,32758 \times t_G + (-5,5565) \times t_{AC} + 0,67454 \times t_E + (-37,679) \tag{10}
\]

\[
Q_E = 0,3084 \times t_G + (-0,81772) \times t_{AC} + 0,59341 \times t_E + 1,0750 \tag{11}
\]

In the Figure 11 and Figure 12 show the results of the comparisons made with the experimental data Vs. data calculated by equations (7) and (8), observing that they have a good fit, with an error of ± 10%. Where the thermal power and cooling capacity of the WFC-SC10 Yazaki chiller from the data taken in the laboratory were compared with the data generated by the characteristic equation obtained.
Figure 11. Experimental thermal power Vs. calculated using linear multivariate regression

![Graph showing experimental thermal power vs. calculated thermal power with a linear equation and R² value.]

Source: Authors

Figure 12. Experimental cooling capacity Vs. calculated using linear multivariate regression

![Graph showing experimental cooling capacity vs. calculated cooling capacity with a linear equation and R² value.]

Source: Authors

In the Figure 13 and Figure 14, shows the good fit of the experimental thermal power and cooling capacity as a function of the calculated $\Delta\Delta t'$. 

y = 0.9054x + 2.6879

$R^2 = 0.9422$

y = 1x

$R^2 = 0.9976$
Caso IV

Using the multivariate linear regression method applied in the previous cases on the experimental data obtained by (Zamora García, 2012), parameters s, a, e, and r were obtained from equation (12) for QRER and (13) for QRGR, resulting from the regression performed in Excel, for a Ciatesa 10 kW single-acting absorption chiller, with lithium ammonia-nitrate as the thesis fluid. Table 4, shows the values obtained for the parameters used in the equation (11). The Ciatesa 10 kW prototype was tested by varying the temperature of the cold water produced up to 6°C, indirectly dissipated by air, and activated with hot water at 90°C. Annex E shows the tabulation of the data used to obtain the Characteristic Equation of the chiller.
$Q_E = 0.3771 \times t_G - 1.0155 \times t_{AC} + 0.6714 \times t_E + (3.98317)$ \hspace{1cm} (12)

$Q_G = 0.5883 \times t_G - 1.2947 \times t_{AC} + 0.8202 \times t_E + (0.43861)$ \hspace{1cm} (13)

Table 4. Parámetros s, a, e, r para la E. característica de la enfriadora Ciatesa de 10 kW

<table>
<thead>
<tr>
<th></th>
<th>Evaporador</th>
<th>Generador</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>0.377170311</td>
<td>0.58838068</td>
</tr>
<tr>
<td>a</td>
<td>-2.692429163</td>
<td>-2.200523291</td>
</tr>
<tr>
<td>e</td>
<td>1.780263643</td>
<td>1.394142791</td>
</tr>
<tr>
<td>r</td>
<td>3.983175609</td>
<td>0.438618438</td>
</tr>
</tbody>
</table>

Source: Authors

The results of the comparison between the experimental data and the data calculated by equations (3-9) and (3-10) are presented in Figure 15 and Figure 16, showing that they have a good fit, with an error of ± 10%.

Figure 15. Experimental thermal power Vs. calculated using the characteristic equation
Figure 16. Experimental cooling capacity Vs. calculated using the characteristic equation

In the Figure 17 and Figure 18 clearly show the good fit of the experimental thermal power and cooling capacity to the calculated $\Delta \Delta t'$. 

Figure 17. Adjustment of the cooling capacity according to $\Delta \Delta t'$
Figure 18. *The setting of the thermal output is according to* $\Delta\Delta t'$

5 CHARACTERISTIC EQUATION FOR COMMERCIAL MACHINES

There are a large number of authors, who have applied obtained the characteristic equations of different single and double effect absorption chillers with $\text{HR}_2\text{O-LiBr}$, using the linear multivariable regression method $\Delta\Delta t'$, many of these theses are presented by the authors (López Villada, 2011), (Zamora García, 2012) and summarized in Table 5.

<table>
<thead>
<tr>
<th>Nombre</th>
<th>Potencia [kW]</th>
<th>Fluido de trabajo</th>
<th>Parámetros características</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotativa</td>
<td>Simple efecto</td>
<td>4,5</td>
<td>H$_2$O-LiBr</td>
</tr>
<tr>
<td>Broad</td>
<td>Simple efecto</td>
<td>15</td>
<td>H$_2$O-LiBr</td>
</tr>
<tr>
<td>Broad</td>
<td>Simple efecto</td>
<td>786</td>
<td>H$_2$O-LiBr</td>
</tr>
<tr>
<td>Broad</td>
<td>Doble efecto</td>
<td>1163</td>
<td>H$_2$O-LiBr</td>
</tr>
</tbody>
</table>

Source: Authors

In addition, the double and triple effect direct flame chillers presented by (Montero Izquierdo, 2012) are used with the extended characteristic equation method.
6 CONCLUSIONS

The characteristic equation method was selected as a simplified method with which it is possible to obtain the performance of single, double and triple effect absorption chillers.

Comparing the characteristic equation method with the multivariate regression methods, these give better results when only information on the external currents of the absorption chillers is available.

The multivariable linear regression method for \( QR_e R \) and \( QR_c R \), is the best fitting method for this type of data with a maximum error percentage ±10 %, which is why it was the method selected to obtain the 4 characteristic equations for the 4 cases studied in this chapter.

The methods explained above are not valid for modelling the dynamic behavior of chillers. This aspect is of special relevance in the start-up and shut-down moments of the equipment. If these units are in permanent operation under more or less stable conditions, the stationary model is fully valid.

ACKNOWLEDGMENTS

The authors thank the Universities participating in the development of this article, the Institución Universitaria de Barranquilla in Colombia and the Universidade Federal de Pernambuco in Brazil.
REFERENCIAS


