TYPE 177: Phönix-Absorption Chiller

General Description

This TYPE simulates the part load behaviour of a single staged H_2O/LiBr-absorption chillers offered by Phönix Sonnenwärme AG. The method of characteristic equations for absorption chillers is used for the calculation by means of a characteristic temperature difference "delta-delta-t-function" ($\Delta\Delta t$) [1]. This method has been improved to account for (small) non-linear effects.

Nomenclature

B	Dühring Parameter	-
COP	Coefficient of performance	-
c_{pAC}	Specific heat of cooling water	kJ/(kg·K)
c_{pE}	Specific heat of chilled water	kJ/(kg·K)
c_{pG}	Specific heat of hot water	kJ/(kg·K)
m_{AC}	Cooling water mass flow rate	kg/h
m_E	Chilled water mass flow rate	kg/h
m_G	Hot water mass flow rate	kg/h
Q_{AC}	Capacity rejected from Absorber and Condenser	kJ/h
Q_E	Evaporator cooling capacity	kJ/h
Q_G	Generator heat capacity	kJ/h
s_X	Slope of a characteristic equation	kJ/(h·K)
T_A	Internal mean absorber temperature	°C
t_{ACi}	Cooling water inlet temperature	°C
t_{ACo}	Cooling water outlet temperature	°C
T_C	Internal mean condenser temperature	°C
T_E	Internal mean evaporator temperature	°C
t_{Ei}	Chilled water inlet temperature	°C
t_{Eo}	Chilled water outlet temperature	°C
T_G	Internal mean generator temperature	°C
t_{Gi}	Hot water inlet temperature	°C
t_{Go}	Hot water outlet temperature	°C
$\Delta\Delta t$	Characteristic temperature difference	K
$\Delta\Delta t_{minX}$	Characteristic loss parameter of a characteristic equation	K

Mathematical Description

The internal temperatures of the four heat exchangers (Generator, Absorber, Condenser, Evaporator) can be combined by using Dühring's rule for the dissolution field of aqueous lithium bromide.

$$(T_G - T_A) = (T_C - T_E) \cdot B \tag{1}$$

Assuming equal heat fluxes inside and outside the absorption chiller (adiabatic heat exchangers) the internal temperatures T_x can be expressed as a function of the external temperatures t_x.

$$T_G = t_G - Q_E\, G/Y_G - Q_{G,x}/Y_G \tag{2.1}$$

$$T_E = t_E - Q_E\, E/Y_E \tag{2.2}$$

$$T_A = t_A - Q_E\, A/Y_A - Q_{A,x}/Y_A \tag{2.3}$$

$$T_C = t_C - Q_E\, C/Y_C \tag{2.4}$$

The coefficients G, E, A and C in equation (2.x) holding for the internal specific enthalpy differences at the corresponding heat exchangers related to the specific enthalpy differences at the evaporator. Y_x are the heat transfer coefficients $Y_x = U_x \cdot A_x$.

By substituting the equations (2) into (1) eliminates the internal temperatures.

$$[\, t_C - t_E + Q_E\, (C/Y_C - 1/Y_E)\,] \cdot B = \ldots$$
$$\ldots = [\, t_G - t_A - Q_E\, (G/Y_G + A/Y_A) - Q_{G,x}/Y_G - Q_{A,x}/Y_A\,] \tag{3}$$

Using the equation of definition for the characteristic temperature difference ($\Delta\Delta$t-function)

$$\Delta\Delta t := (t_G - t_A) - (t_C - t_E) \cdot B \tag{4}$$

and rearranging the enthalpy and heat transfer coefficients into s_E and $\Delta\Delta tmin_E$ leads to the characteristic equation for the cooling capacity.

$$Q_E = s_E \cdot \Delta\Delta t - s_E \cdot \Delta\Delta tmin_E \tag{5}$$

If the gradient (s_E) and axis interval ($s_E \cdot \Delta\Delta tmin_E$) are constant, the part load of an absorption chiller can be expressed as a linear function of $\Delta\Delta t$. It has been shown that under steady state conditions and constant solution flow rates the assumption of constant parameters is permitted at most times [1].

The derivation of the characteristic equation can also be applied to the generator heat flux. Thereby the internal enthalpy differences have to be correlated to the specific enthalpy difference in the generator, which is used to evaporate the cooling agent (H_2O). The remaining

ration (for heating the weak solution) is considered in $Q_{G,x}$ and $\Delta\Delta tmin_G$ respectively.
By means the characteristic equation for the generator heat flux is derived with different slope and axis interval.

$$Q_G = s_G \cdot \Delta\Delta t - s_G \cdot \Delta\Delta tmin_G \tag{6}$$

The same procedure is done for the combined heat flux of absorber and condenser, whereas a serial flow form absorber to condenser with constant mass flow rate is considered. The characteristic equation for the rejected heat from absorber and condenser can be expressed as

$$Q_{AC} = s_{AC} \cdot \Delta\Delta t - s_{AC} \cdot \Delta\Delta tmin_{AC}. \tag{7}$$

By means of the absorber-condenser-combination the equation of definition for the $\Delta\Delta t$-function is reduced to

$$\Delta\Delta t - t_G + (1+B) \cdot t_{AC} - B \cdot t_E = 0. \tag{8}$$

Under normal operation conditions one can use the arithmetic instead of the thermodynamic mean temperature for the heat flux calculation with only a small loss in accuracy. By means the external outlet temperatures of the heat exchangers can be calculated with

$$t_{x,o} = 2 \cdot t_x - t_{x,i} \tag{9}$$

Index $_x$ holds for the Index $_{AC,\ E,\ G}$ according to the heat exchanger. Index $_i$ and $_o$ is used for Input and Output respectively. By substituting equation (9) into the external energy balances leads to

$$Q_x = 2 \cdot m_x \cdot c_{px} \cdot (t_{x,i} - t_x). \tag{10}$$

After equalising the external energy balances with the characteristic equations (5), (6), (7) and using the equation of definition for the $\Delta\Delta t$-function (8) a four dimensional, linear equation system is found.

$$\begin{array}{rcrcrcrcl}
\Delta\Delta t & - & t_G & - & B\, t_E & + & (1+B)\, t_{AC} & = & 0 \\
s_G\, \Delta\Delta t & + & 2\, m_G\, c_{pG}\, t_G & + & 0 & + & 0 & = & 2\, m_G\, c_{pG}\, t_{G,i} + s_G\, \Delta\Delta tmin_G \\
s_E\, \Delta\Delta t & + & 0 & + & 2\, m_E\, c_{pE}\, t_E & + & 0 & = & 2\, m_E\, c_{pE}\, t_{E,i} + s_E\, \Delta\Delta tmin_E \\
s_{AC}\, \Delta\Delta t & + & 0 & + & 0 & + & 2\, m_{AC}\, c_{pAC}\, t_{AC} & = & 2\, m_{AC}\, c_{pAC}\, t_{AC,i} + s_{AC}\, \Delta\Delta tmin_{AC}
\end{array} \tag{11}$$

By solving the linear equation system with the Gaussian elimination algorithm with maximum Pivoting the external mean temperatures (t_g, t_e, t_{ac}) and the $\Delta\Delta t$-function can be calculated. With utilization of equation (9) and (10) all outlet temperatures and heat capacities can be calculated.

For the energy fluxes the following polarity sign convention has to be mentioned: An energy flux into the absorption machine is positive (generator, evaporator); an extracted energy flux from the chiller is negative (absorber, condenser). This has to be noticed when the rejected heat is used e.g. in a cooling tower model, since $Q_{AC} < 0$.

To reduce the possibility of extrapolation errors the part load behaviour can only be simulated in time steps where all inlet temperatures are inside the validity interval of the characteristic equations. Otherwise Output(15) is set to 0. The validity intervals are:

$56°C < t_{Gi} < 95°C$
$19°C < t_{ACi} < 31°C$
$13°C < t_{Ei} < t_{ACi}$

Before the Output(15) is set to 0, a warning is printed to the List-File. This warning is activated, when the difference to the interval border is smaller then 1 K. If one temperature is outside its interval an *** URGENT WARNING *** is printed to the List-File.

Nevertheless, in both cases a capacities value is calculated and the simulation can proceed, but the results have to be used very carefully. So, normally one should use the Output(15) to switch of the pumps.

TRNSYS Component Configuration for Phönix-Absorption Chiller

PARAMETER NO.			DESCRIPTION
1	mode	X -	The value of X depends on the actual version of this Type and the corresponding absorption chiller. More Information is available at http://www.sonnenwaerme-ag.de/ X = 3 is valid from 09. July 2004 on

INPUT NUMBER		DESCRIPTION
1	t_{Gi}	Hot water inlet temperature to generator
2	m_G	Hot water mass flow rate to generator
3	t_{Ei}	Chilled water inlet temperature to evaporator
4	m_E	Chilled water mass flow rate to evaporator
5	t_{ACi}	Cooling water inlet temperature to absorber (and condenser)
6	m_{AC}	Cooling water mass flow rate to absorber (and condenser)

OUTPUT NUMBER		DESCRIPTION
1	t_{Go}	Hot water outlet temperature from generator

2	m_G	Hot water mass flow rate from generator
3	t_{Eo}	Chilled water outlet temperature from evaporator
4	m_E	Chilled water mass flow rate from evaporator
5	t_{ACo}	Cooling water outlet temperature from condenser (and absorber)
6	m_{AC}	Cooling water mass flow rate from condenser (and absorber)
7	Q_G	Generator heat capacity
8	Q_E	Evaporator cooling capacity
9	Q_{AC}	Capacity rejected from Absorber and Condenser
10	COP	Coefficient of performance
11	$\Delta\Delta t$	Characteristic temperature difference
12	c_{pG}	Specific heat used for hot water
13	c_{pE}	Specific heat used for chilled water
14	c_{pAC}	Specific heat used for cooling water
15	ON	= 1 if the operation conditions are suitable = 0 if the operation conditions are outside the rage of validity of the characteristic equations
16	BTR	= 1 if chiller is under operation irrespective of validity, 0 otherwise.

References

1. F. Ziegler, H.-M. Hellmann, C. Schweigler: An approximative method for modeling the operating characteristics of advanced absorption chillers, Proc. of 20th International congress of refrigeration, IIR/IIF, Sydney, 1999, Vol III, Paper 600

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