STUDY OF AMMONIA-WATER ABSORPTION TRIPLE EFFECT CYCLE

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Abstract: *The paper presents a study of an ammonia-water absorption triple effect cycle known as the kangaroo cycle, and investigates its limitations. The triple effect absorption processes were modeled and a parametric study was performed*

Key words: *modeling, absorption, triple effect cycle.*

1. Introduction

Vapor compression cycles require electricity to run the compressor that raises the refrigerant's pressure. Absorption cycles accomplish the same task by absorbing the refrigerant into a liquid, pumping the high density liquid mixture up to a higher pressure, and then desorbing the refrigerant by heating. The refrigerants used in absorption systems are naturally occurring, which should reduce the risk of potential problems. Additionally, if higher-efficiency absorption systems can be developed, carbon emissions can be reduced as well.

2. Ammonia Water Absorption Cycles

The simplest type of absorption cycle is the single stage, or basic, cycle. Unfortunately, most of ammonia-water single stage absorption cycles are only able to produce COPs of approximately 0.5, which are well below the 1.0 to 1.3 range necessary for competition with vapor compression cycle efficiencies. Both the operating costs and the equipment costs of a single stage absorption cycle are higher than those of a vapor compression cycle, further demonstrating its lack of commercial economic potential.

One alternative to the basic cycle is the generator-absorber heat exchange (GAX) cycle. The GAX cycle can achieve efficiencies of 0.8 to 1.0, and has been a major research thrust in the absorption area. Despite this effort, however, commercial development has been problematic. New advanced GAX cycles, which may improve upon the basic GAX cycle's performance, are currently under investigation.

This study analyzes the performance characteristics of another multiple effect cycle. Multiple effect cycles are designed by combining single stage components and cycles.

Three triple effect cycles are:

- the three-absorber cycle,
- the three-condenser cycle, and
- the two-absorber/two-condenser, or kangaroo, cycle

Triple effect ammonia water cycles are limited by the nature of the ammonia-water mixture. At generator temperatures above about 200 °C, corrosion becomes a major issue. The kangaroo-type triple effect is so named because it is

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comprised of a single effect cycle that is driven by heat rejected from a coupled high pressure single effect cycle. The low pressure cycle is considered to be within the 'pouch' of the high pressure cycle. The component diagram for the low and high pressure cycles are displayed in Fig. For this cycle, the heat rejected from the high pressure loop condenser, absorber and rectifier is used to run the low pressure cycle. The heat added at the generator is used to create cooling from two evaporators, which can be combined, and to run the low pressure desorber.

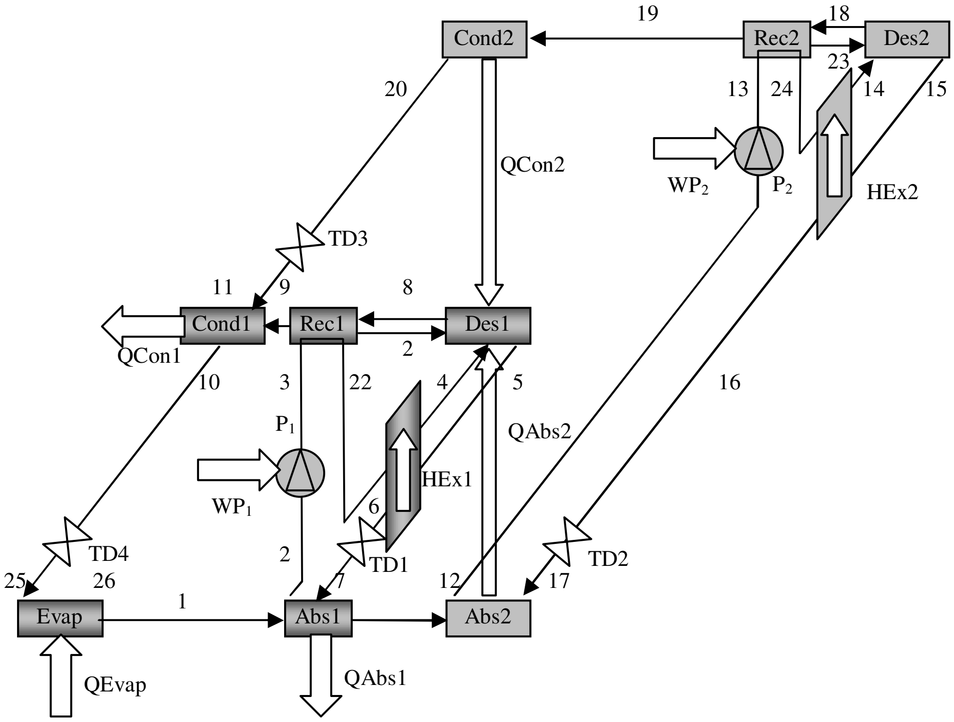

Fig. 1. *Component diagram for the low and high pressure cycles*

3.Modeling the triple effect cycle

a. Introduction

In order to determine the states of the mixture at each point, the designer must examine the cycle requirements, or application operating specifications. The cycle requirements can be used to determine mixture properties at several of the state points. Once these properties are known, other properties can be determined from additional cycle constraints.

b. Parameters

The following parameters were chosen in order to allow solving of the system and therefore were also varied in order to perform the study:

$\Delta t = 3$ K - pinch temperature (smallest temperature difference between the two streams) for the heat exchangers;

$\Delta X = 0.06$ - concentration difference between rich and poor solution;

$T_{10} = 35$ °C - condensing temperature for Cond1;

$X_{10} = 0.995$ - ammonia vapor concentration;

T_{26} = 4 °C - saturated liquid temperature in;

$T_{10} = T_{26}$ +10 K - vapor temperature at evaporator out;

Parameters of the cycle state points Table 1

State point	**Description**	**Known parameters**	**Flowrate**	**System unknown**
10	Cond1-out	**t**, **X**, q = 0	$\dot{m}_1+\dot{m}_2$	p_{h1}
26	Evap	**t**, $X = X_{10}$, q = 0	$\dot{m}_1+\dot{m}_2$	p_l
25	TD4-out	$p = p_l$, $X = X_{10}$, $h = h_{10}$	$\dot{m}_1+\dot{m}_2$	
1	Evap-out	**t**, $p = p_l$, $X = X_{10}$	$\dot{m}_1+\dot{m}_2$	
9	Rec1-out	$p = p_{h1}$, $X = X_{10}$, q = 1	$\dot{m}_1$	
2	Abs1-out	$t = t_{10}$, $p = p_l$, q = 0	$\dot{m}_1 \cdot fp_1$	X_2
5	Des1-out	$p = p_{h1}$, $X = X_2 - \Delta X$, q = 0	$\dot{m}_1 \cdot (fp_1-1)$	X_5
3	P1-out	$p = p_{h1}$, $X = X_2$, h	$\dot{m}_1 \cdot fp_1$	
21	Rec1-out - Des1-in	$p = p_{h1}$, $X = X_2$, q = 0	$\dot{m}_1 \cdot R_1$	
8	Des1-out - Rec1-in	$t = t_{21}$, $p = p_{h1}$, q = 1	$\dot{m}_1 \cdot (R_1+1)$	X_8
22	Rec1-out	$p = p_{h1}$, $X = X_2$, h	$\dot{m}_1 \cdot fp_1$	
4	HEx1-out	$p = p_{h1}$, $X = X_2$, t(h)	$\dot{m}_1 \cdot fp_1$	
6	HEx1-out	$p = p_{h1}$, $X = X_5$, t(h)	$\dot{m}_1 \cdot (fp_1-1)$	
7	TD1-out	$p = p_l$, $X = X_5$, $h = h_6$	$\dot{m}_1 \cdot (fp_1-1)$	
20	Cond2-out	$t = t_4 + \Delta t$, $X = X_{10}$, q = 0	$\dot{m}_2$	p_{h2}
11	TD3-out	$p = p_{h1}$, $X = X_{10}$, $h = h_{20}$	$\dot{m}_2$	
19	Rec2-out - Cond2-in	$p = p_{h2}$, $X = X_{10}$, q = 1	$\dot{m}_2$	
12	Abs2-out	$t = t_4 + \Delta t$, $p = p_l$, q = 0	$\dot{m}_2 \cdot fp_2$	X_{12}
15	Des2-out - HEx2-in	$p = p_{h2}$, $X = X_{12} - \Delta X$, q = 0	$\dot{m}_2 \cdot (fp_2 - 1)$	X_{15}
13	P2-out	$p = p_{h2}$, $X = X_{12}$, h	$\dot{m}_2 \cdot fp_2$	
23	Rec2-out - Des2-in	$p = p_{h2}$, $X = X_{12}$, q = 0	$\dot{m}_2 \cdot R_2$	
18	Des2-out - Rec2-in	$t = t_{23}$, $p = p_{h2}$, q = 1	$\dot{m}_2 \cdot (1 + R_2)$	X_{18}
24	Rec2-out - HEx2-in	$p = p_{h2}$, $X = X_{12}$, h	$\dot{m}_2 \cdot fp_2$	
14	HEx2-out - Des2-in	$p = p_{h2}$, $X = X_{12}$, t(h)	$\dot{m}_2 \cdot fp_2$	
16	HEx2-out - TD2-in	$p = p_{h2}$, $X = X_{15}$, t(h)	$\dot{m}_2 \cdot (fp_2 - 1)$	
17	TD2-out	$p = p_l$, $X = X_{15}$, $h = h_{16}$	$\dot{m}_2 \cdot (fp_2 - 1)$	

c. Model equations (selected)

Circulation factors (1: Baby stage, 2: Mother stage):

$FP_1 =$ **Error!**; $FP_2 =$ **Error!** (1)

Reflux coefficients:

$R_1 =$ **Error!**; $R_2 =$ **Error!** (2)

Loads:

$$\Phi_{des1} = \dot{m}_1 \cdot ((R_1 + 1) \cdot H_8 - R_1 \cdot H_{21} + (FP_1 - 1) \cdot H_5 - FP_1 \cdot H_4) \quad (3)$$

$$\Phi_{abs1} = \dot{m}_1 \cdot (H_1 + (FP_1 - {}_1) \cdot H_7 - FP_1 \cdot H_2) \quad (4)$$

$$\Phi_{cond1} = \dot{m}_1 \cdot (H_9 - H_{10}) + \dot{m}_2 \cdot (H_{11} - H_{10}) \quad (5)$$

$$\Phi_{evap1} = \dot{m}_1 \cdot (H_1 - H_{25}) \quad (6)$$

$$\Phi_{des2} = \dot{m}_2 \cdot ((R_2 + 1) \cdot H_{18} - R_2 \cdot H_{23} + (FP_2 - 1) \cdot H_{15} - FP_2 \cdot H_{14}) \quad (7)$$

$$\Phi_{abs2} = \dot{m}_2 \cdot (H_1 + (FP_2 - 1) \cdot H_{17} - FP_2 \cdot H_{12}) \quad (8)$$

$$\Phi_{cond2} = \dot{m}_2 \cdot (H_{19} - H_{20}) \quad (9)$$

$$\Phi_{evap2} = \dot{m}_2 \cdot (H_1 - H_{25}) \quad (10)$$

Work of pumps:

$$W_{P1} = \dot{m}_1 \cdot FP_1 \cdot (P_{H1} - P_{\_Low}) \cdot V_2 \quad (11)$$

$$W_{P2} = \dot{m}_2 \cdot FP_2 \cdot (P_{H2} - P_{\_Low}) \cdot V_{12} \quad (12)$$

Check energy balance:

$$\Phi_{chk12} = (\Phi_{des1} - \Phi_{cond2} - \Phi_{abs2}) - \Phi_{abs1} - \Phi_{cond1} + \Phi_{evap1} + W_{P1} + (\Phi_{des2} + \Phi_{evap2} + W_{P2}) \quad (13)$$

Internal heat exchange between first and second stage:

$$\Phi_{des1} = \Phi_{cond2} + \Phi_{abs2} \quad (14)$$

COPs for cooling/heating mode:

$COP_{c12} =$ **Error!** (15)

$COP_{h12} =$ **Error!** (16)

Remarks:

- Absorber1 and Condenser1 are cooled with the same cooling media: $t_2 = t_{10}$
- in order to perform heating of Des1, Cond2 and Abs2 have the same output temperature: $t_{20} = t_{12} = t_4 + \Delta t$
- equilibrium is assumed between states 8 and 21, and 18 and 23.

d. External Cycle Constraints

We assume that the application considered in this study for the ammonia-water triple effect cycle is space cooling. This dictates the condenser and absorber heat sink and the evaporator external heat source.

e. Design Parameters

The upper loop is coupled to the lower loop by the rejection of heat from the condenser, rectifier and absorber to the lower loop desorber. The mass flow rate of the refrigerant on the upper loop is not a design variable, as it is in the lower loop. This is the result of requiring that the heat required to drive the lower loop desorber be equal to the total heat rejected from the upper loop. Designation of the refrigerant mass flow rate is replaced by this heat transfer constraint.

Higher COPs are achieved with higher desorber exit temperatures, but the upper loop desorber temperature is constrained to 200 °C by the maximum temperature of an ammonia-water mixture that can be achieved without incurring undue corrosion problems. The refrigerant concentration in the refrigeration loop should be as high as possible, as the increased concentration reduces the temperature glide in the evaporator and raises the evaporator/absorber pressure, which maximizes the COP.

Results

In order to assess the system behavior some of the input parameters (ΔX_1, ΔX_2, T_{10}, T_{26}, X_{10}) were varied and their influence on COP is presented below.

The increase of condensing temperature of the baby cycle T_{10} leads to an almost liniar increase of the corresponding condensing pressure PH1 and of the condensing temperature of mother cycle T_{20} (but to a steeper increase of corresponding condensing pressure PH2) (see Fig. 1). The increase of evaporation temperature leads to a decrease of the condensing temperature of mother cycle T_{20} (and of corresponding condensing pressure PH2). For T_{10} = 36 °C and T_{26} = 2 °C, T_{20} reaches almost 80 °C, and corresponding pressure PH2 is above 40 bar).

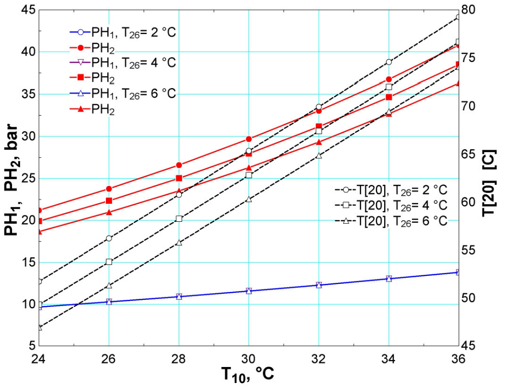

Fig. 1. *Influence of condensing temperature T_{10} on PH_1 and PH_2 for different evaporation temperatures T_{26}*

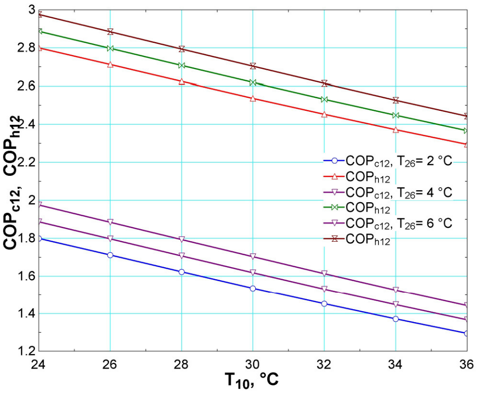

Fig. 2. *Influence of condensing temperature T_{10} on COP_c and COP_h for different evaporation temperatures T_{26}*

The increase of concentration difference between rich and poor solution for both lower (ΔX_1) and higher loop (ΔX_2) have a healthy influence on COPs for cooling and heating modes (see Fig. 3 and Fig. 4).

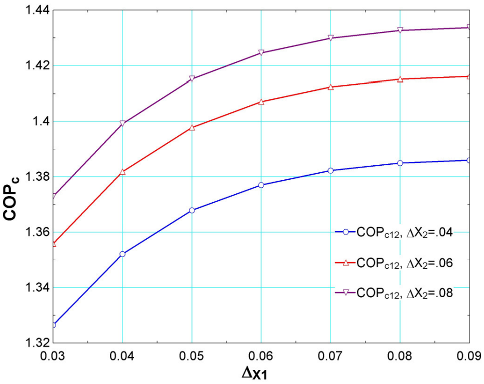

Fig. 3. *Influence of concentration difference between rich and poor solution for lower loop ΔX_1 on COP_c for different concentration difference for upper loop ΔX_2*

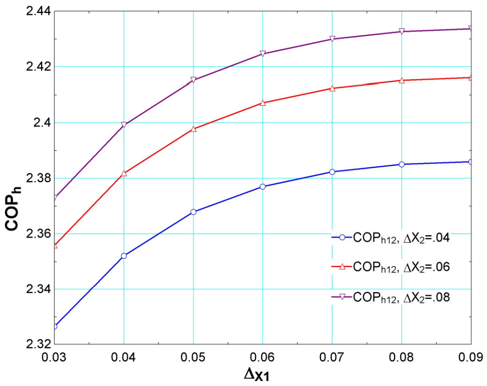

Fig. 4. *Influence of concentration difference between rich and poor solution for lower loop ΔX_1 on COP_h for different concentration difference for upper loop ΔX_2*

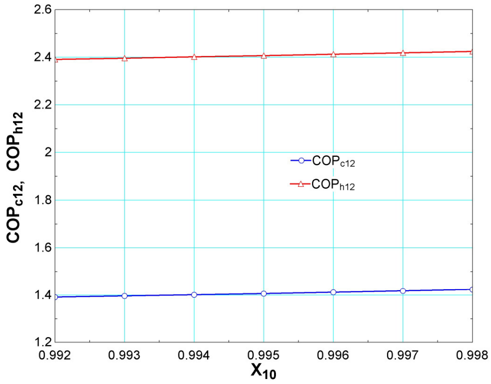

Fig. 5. *Influence of vapor concentration X_{10} on COP_c and COP_h*

Increase of vapor concentration X_{10} have a similar faint positive effect on COP (see).

5. Conclusions

The purpose of this study was to investigate the triple effect ammonia-water cycle. While the cycle itself was shown to be viable, further studies should address equipment and commercialization issues such as pumps, corrosion, and cost.

References

1. Herold, K.E., Radermacher, R., Klein, S.A.: *Absorption Chillers and Heat Pumps*. CRC Press, 1996.
2. Chiriac, F., Ţârlea, M. G., Gavriliuc R., Ilie, A., et al: *Maşini şi instalaţii frigorifice.* Bucureşti. AGIR, 2006, p. 136.
3. Shelton, Sam V., Jacob, D., Schaefer, L.A.: *Modeling and analysis of the air cooled ammonia-water triple effect cycle.* In: Advanced Energy Systems Division, 1999 Mechanical Engineering Congress and Exposition, Nashville, TN, Nov. 1999.
4. Porneală, S.: *Procese în instalaţii frigorifice şi pompe de căldură - Vol.2: Absorbţie, ejecţie, aer.* Galaţi,. Ed Zigotto, 2005.
5. Hwang Y.H. "KANGAROO CYCLE", 1995.