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Performance Comparison of Triple-Effect Parallel Flow and Series Flow Absorption Refrigeration Systems

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Abstract: Energy and exergy analysis of triple effect series and parallel flow absorption refrigeration systems with lithium bromide/water as working fluid pair is presented in this study. Thermodynamic properties, mass and heat flow rate and exergy destruction are evaluated in each component of the system. Furthermore, The Coefficient of Performance (COP) and exergetic efficiency (E) of the absorption systems under different operating conditions are estimated. The results show that the exergy destruction at the generator and absorber are more than that of the other components which was expected due to mixing in these components. The results also show that the COP of the system increase slightly with an increase of High Temperature Generator (HTG) and evaporator temperature. However, the exergetic efficiency of the system decreases as the HTG and evaporator temperature increase. The latter results apply for both the series and parallel flow systems. Another indication of the results is a relative preference of parallel-flow in comparison with series-flow. In addition it can be seen that the triple effect system has higher COP in comparison with double and single effect types.

Key words: Lithium bromide-water, exergy analysis, exergetic efficiency, coefficient of performance, irreversibility

INTRODUCTION

Recent developments in cooling systems show a growing interest in the application of absorption systems. Absorption refrigeration systems provide opportunities for energy saving because they can use heat energy to produce cooling, instead of electricity used by conventional vapour compression chillers. Furthermore, non-conventional sources of energy such as solar, waste heat and geothermal can be used as their primary energy input. In addition, absorption units use environmentally friendly working fluid pairs instead of CFCs and HCFCs, which deplete the ozone layer of the atmosphere (Chua *et al*., 2000). The first law analysis of double effect and triple effect lithium bromide-water absorption system has been done recently by some researchers (Xu *et al*., 1996; Arun *et al*., 2001; Kaita, 2002). Also Exergy analysis of single and double effect absorption refrigeration cycles with lithium bromide/water was carried out by some researchers (Talbi and Agnew, 2000; Arzu Sencan *et al*., 2005). However, there is a lack of data in the second law analysis of triple effect absorption refrigeration systems albeit of their higher COPs. In this study energy and exergy analysis is carried out for two types of Triple effect absorption refrigeration cycles, parallel and series flow, with lithium bromide/water as the working fluid pair. The study was performed for different operating conditions by means of the computer program.

MATERIALS AND METHODS

The series flow and parallel flow kinds of triple effect absorption refrigeration cycles shown schematically in Fig. 1 and 2 have been analyzed.

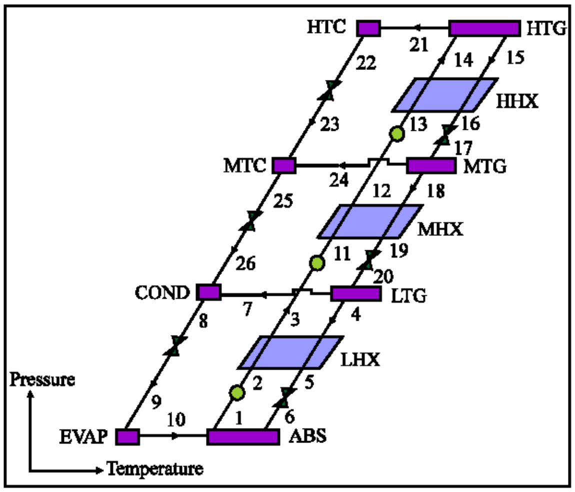

Fig. 1: Series flow cycle

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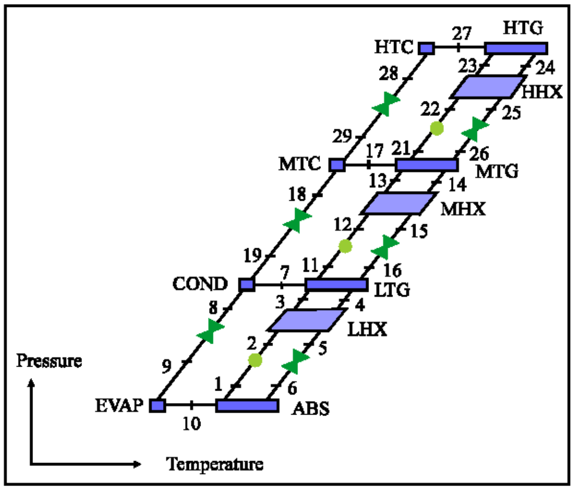

Fig. 2: Parallel flow cycle

In the series-flow cycle, Fig. 1, the weak solution from the absorber is sent directly to High Temperature Generator (HTG) and returned to the absorber through Middle Temperature Generator (MTG) and Low Temperature Generator (LTG). In the parallel flow cycle in Fig. 2, the weak solution is sent first to LTG and then to MTG and at the end to HTG. For thermodynamic analysis of the absorption system the principles of mass conservation, first and second laws of thermodynamics are applied to each component of the system. Each component can be treated as a control volume with inlet and outlet streams, heat transfer and work interactions. In the system, mass conservation includes the mass balance of total mass and each component of the solution.

$$\sum \dot{m}_i - \sum \dot{m}_o = 0 \tag{1}$$

$$\sum (\dot{m}x)_i - \sum (\dot{m}x)_o = 0 \tag{2}$$

where, $\dot{m}$ is the mass flow rate and x is mass concentration of LiBr in the solution and the subscripts i and o are inlet and outlet flow in the control volume. The first law of thermodynamics yields the energy balance of each component of the absorption system as follows:

$$\sum (\dot{m}h)_i - \sum (\dot{m}h)_o + \sum \dot{Q} + \sum \dot{W} = 0 \tag{3}$$

The exergy of a fluid stream can be defined as:

$$\psi = (h - h_0) - T_0(s - s_0) \tag{4}$$

where, ψ is the exergy of the fluid at temperature T and pressure P. h_0 and s_0 are the enthalpy and entropy of the fluid at environmental temperature and pressure. Irreversibility in each component is calculated by:

$$\dot{I}_{cv} = \sum_{in} \dot{m}\psi - \sum_{out} \dot{m}\psi + \sum \dot{Q}_i (1 - \frac{T_0}{T_i}) + \dot{W}_{act} \tag{5}$$

$\dot{I}_{cv}$ is irreversibility that occurred in the process. COP of the absorption system is defined as the ratio of control volume heat transfer in the evaporator to that of the generator.

$$COP = \frac{\dot{Q}_{Evap}}{\dot{Q}_{Gen}} \tag{6}$$

The exergetic efficiency, E, is defined as the ratio of the exergy gained at the evaporator to the exergy gained at the generator:

$$E = \frac{\Delta\psi_{evap}}{\Delta\psi_{gen}} \tag{7}$$

For simplification purposes, the work input to the solution pump and the frictional losses inside the system are neglected.

RESULTS AND DISCUSSION

The initial conditions introduced to the program include the ambient conditions, heat exchanger effectiveness and temperatures of HTG, evaporator and condenser and also absorber exit mass flow rate. With the given parameters, the program calculates all the thermodynamic properties at any point of the cycle. The results are presented in Table 1 and 2 for parallel and series flow, respectively.

Both tables were obtained with $T_{gen} = 200°C$, $T_e = 5°C$ and $T_c = 30°C$.

A parametric study was performed for the performance of both systems, varying the T_g and T_e. All these figures indicate and influence of above mentioned temperatures on first and second law efficiencies (Fig. 3-8). Figure 3 shows the variation of the COP of the parallel flow system. As, it can be shown from Fig. 3, in general the COP increases with an increase of T_g and/or T_e. However, this increase is highly pronounced at lower T_e and T_g. This can be explained by Fig. 4 and 5 that show the variation of HTG and Evaporator heat loud (Q_{htg} ,Q_e) with increasing T_g and T_e for parallel flow and take attention to the Eq. 6.

As can be seen from Fig. 4 and 5 the rate of increase in Q_e is faster than Q_{htg} with increasing T_g and T_e.

Figure 6 shows the variation of the second law efficiency of the parallel flow type with T_g and T_e. As, it

Table 1: State point data for triple-effect parallel flow cycle

Point	m (kg sec^{-1})	T (°C)	h (kJ kg^{-1})	x (%LiBr)	s (kJ kg^{-1} K)
1	1.000	30.0	66.4	52.93	0.2031
2	1.000	30.0	66.4	52.93	0.2031
3	1.000	47.3	103.1	52.93	0.3185
4	0.869	74.5	186.4	60.94	0.4213
5	0.869	52.2	144.2	60.94	0.2972
6	0.869	45.8	144.2	60.94	0.2599
7	0.036	58.1	2608.4		8.6190
8	0.131	30.0	125.7		0.4365
9	0.131	5.0	125.7		0.4525
10	0.131	5.0	2509.7		9.0240
11	0.723	58.1	126.0	52.93	0.3878
12	0.723	58.1	126.0	52.93	0.3879
13	0.723	87.0	187.4	52.93	0.5646
14	0.628	132.4	296.7	60.94	0.7161
15	0.628	95.3	226.0	60.94	0.5316
16	0.628	76.3	226.0	60.94	0.4311
17	0.037	113.9	2709.6		7.801
18	0.095	79.5	332.7		1.069
19	0.095	30.0	332.7		1.119
21	0.437	113.9	244.9	52.93	0.7189
22	0.437	114.0	245.1	52.93	0.7194
23	0.437	147.2	316.3	52.93	0.898
24	0.380	200.0	425.7	60.94	1.021
25	0.380	157.0	343.6	60.94	0.831
26	0.380	82.1	343.6	60.94	0.4624
27	0.058	178.9	2819.5		7.162
28	0.058	137.4	578.0		1.712
29	0.058	79.4	578.0		1.765

Table 2: State point data for triple-effect series flow cycle

Point	m (kg sec^{-1})	T (°C)	h (kJ kg^{-1})	x (%LiBr)	s (kJ kg^{-1} K)
1	1.000	30.00	66.35	52.93	0.2031
2	1.000	30.00	66.36	52.93	0.2031
3	1.000	48.06	104.60	52.93	0.3232
4	0.8351	80.00	208.80	63.38	0.4342
5	0.8351	55.00	163.00	63.38	0.3011
6	0.8351	50.59	163.00	63.38	0.2767
7	0.0289	58.12	2608.00		8.6190
8	0.1649	30.00	125.70		0.4365
9	0.1649	5.00	125.70		0.4525
10	0.1649	5.00	2510.00		9.0260
12	1.000	120.10	258.20	52.93	0.7534
14	1.000	187.20	402.40	52.93	1.0980
15	0.912	200.00	424.40	58.04	1.0680
16	0.912	160.10	266.30	58.04	0.8852
17	0.912	131.50	266.30	58.04	0.7465
18	0.8641	139.70	311.60	61.26	0.7472
19	0.8641	93.89	133.80	61.26	0.5218
20	0.8641	75.16	133.80	61.26	0.4229
21	0.088	187.20	2832.00		7.097
22	0.088	144.70	609.50		1.788
23	0.088	84.98	609.50		1.842
24	0.0479	139.70	2720.00		6.901
25	0.1359	85.00	355.90		1.134
26	0.1359	30.00	355.90		1.196

shows, the exergetic efficiency (E) of the system decreases with increasing T_g and T_e. This can be explained by the fact that an increase of T_g causes an increase of exergy entering the generator and also an increase of T_e causes a decrease of exergy entering the evaporator. According to Eq. 7 these changes of input exergies both result in the exergy efficiency to decrease.

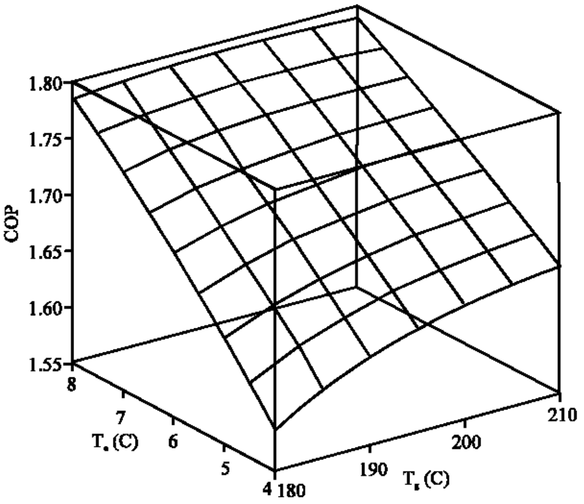

Fig. 3: Variation of the COP of the parallel flow type with the T_g and T_e

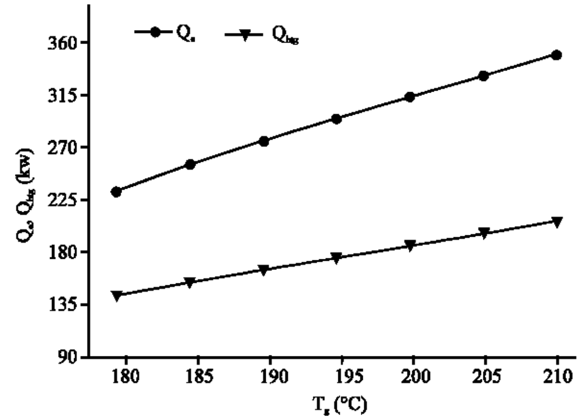

Fig. 4: Variation of Q_e and Q_{htg} with T_g for parallel flow type

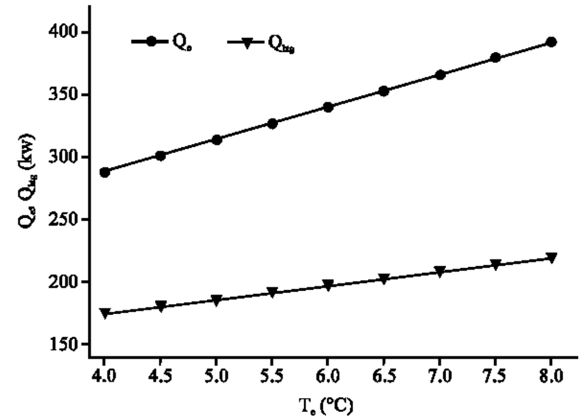

Fig. 5: Variation of Q_e and Q_{htg} with T_e for parallel flow type

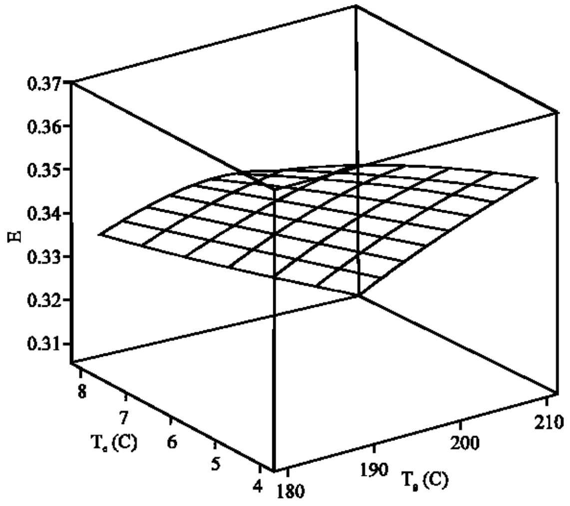

Fig. 6: Variation of the exergetic efficiency (E) of the parallel flow type with the T_g and T_e

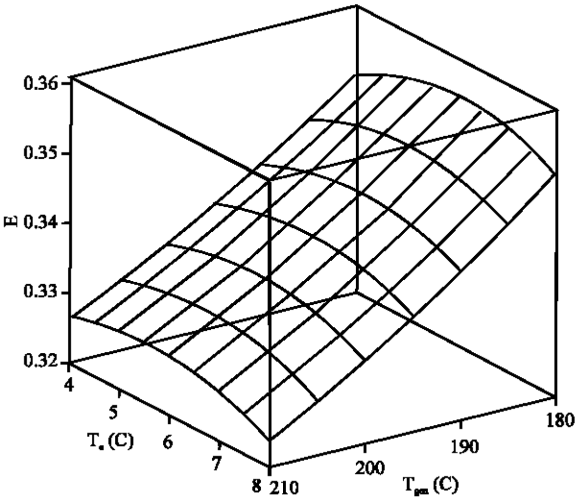

Fig. 8: Variation of the exergetic efficiency (E) of the series flow type with the T_g and T_e

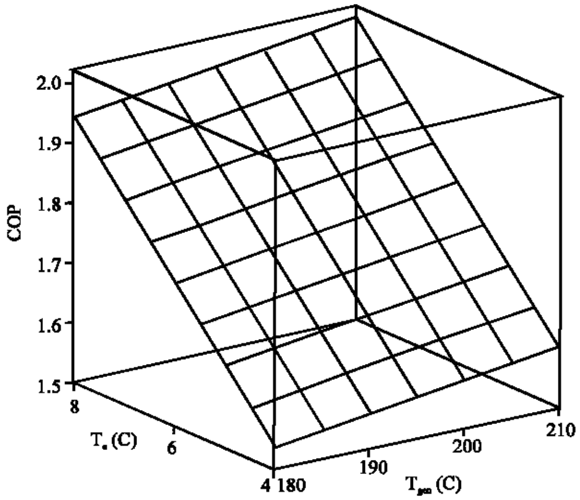

Fig. 7: Variation of the COP of the series flow type with the T_g and T_e

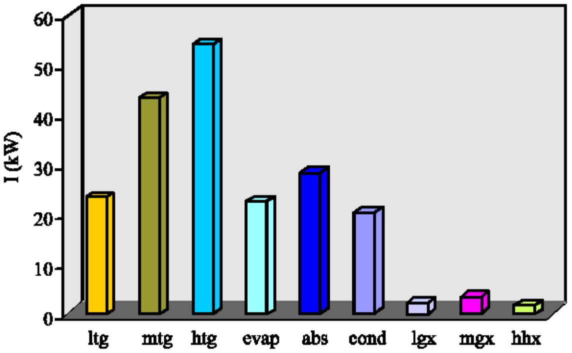

Fig. 9: Irreversibility at the various components of the parallel system

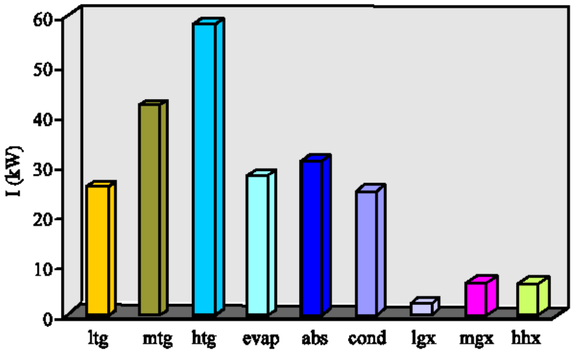

Fig. 10: Irreversibility at the various components of the series system

The results for series flow type (Fig. 7, 8) are similar to parallel flow type qualitatively. However, a relatively higher amount of COP and E is found for parallel system.

Irreversibilities in the absorber and generators are more than that of the other components of the system (Fig. 9, 10). This is due to the heat of mixing in the solution, which is not present in pure fluids.

Figure 11 shows the variation of the COP of triple effect parallel flow and series flow, double effect series flow and single effect systems with T_g when T_c = 30°C and T_e = 5°C. As it can be seen from this figure, for the triple effect systems there is a good agreement between present results and those reported in the literature. The results also show that the COP of triple effect systems is

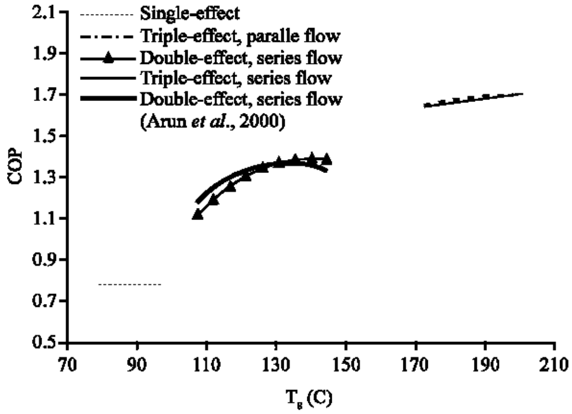

Fig. 11: Variation of COP with generator temperature (T_g) in single, double and triple effect absorption systems

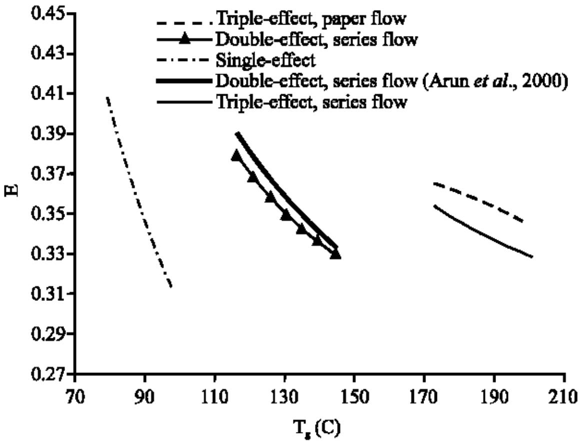

Fig. 12: Variation of exergetic efficiency (E) with generator temperature (T_g) in single, double and triple effect absorption systems

about 50% more than that of the double effect series flow that obtained from present results and other researchers (Arun *et al.*, 2000) work and is about 2.2 times more than that of the single effect systems. As it shows, exergetic efficiency (E) of triple effect parallel flow type is more than that of the series type (Fig. 12). Also in triple effect types the rate of decrease in E is lower in comparison with those of double and single effect systems.

CONCLUSION

For both triple effect series and parallel flow types there is an increase of COP and a decrease of E as HTG temperature (T_g) and/or evaporator temperature (T_e) increases.

Considering both the first law and second law efficiencies, there is a relative preference of triple effect parallel flow type in comparison with series type.

The COP of triple effect systems is about 50% more than that of the double effect systems and it is about 2.2 times that of the single effect systems.

For a given value of ΔT_g the variation of E for triple effect systems is less than that for double effect systems. This variation is the most for single effect systems.

Most of the irreversibilities occur in generators and absorber due to mixing losses in series and parallel flow types.

NOMENCLATURE

ABS = Absorber
COND = Condenser
E = Exergetic efficiency
EVAP = Evaporator
H = Enthalpy (kJ kg^{-1})
HHX = High-temperature heat exchanger
HTC = High-temperature condenser
HTG = High-temperature generator
LHX = Low-temperature heat exchanger
LTG = Low-temperature generator
MHX = Middle-temperature heat exchanger
MTC = Middle-temperature condenser
MTG = Middle-temperature generator
$\dot{m}$ = Mass flow rate (kg sec^{-1})
$\dot{Q}$ = Heat load (kW)
s = Entropy (kJ kg^{-1} K)
T = Temperature (K)
x = Mass fraction of lithium bromide (%)
COP = Coefficient of performance
$\dot{W}$ = Work (kW)
ψ = Exergy (kJ kg^{-1})
$\dot{I}$ = Irreversibility (kW)

Subscripts

c = Condenser
e, evap = Evaporator
g, gen = Generator
I = Inlet stream
o = Outlet stream

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