Simulation of H_2O/LiBr Triple Effect Absorption Systems with a Modified Reverse Flow

Young Kyong Jo, Jin-Kyeong Kim, Yong Tae Kang*†

Department of Mechanical Engineering, Kyung Hee University, Yong In, Gyeong-gi 449-701, Korea

**School of Mechanical and Industry System Engineering, Kyung Hee University, Youn In, Gyeong-Gi 449-701, Korea*

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ABSTRACT: In this study, a modified reverse flow type, one of the triple effect absorption cycles, is studied for performance improvement. The cycle simulation is carried out by using EES(Engineering Equation Solver) program for the working fluid of H_2O/LiBr solution. The split-ratios of solution flow rate, UA of each component, pumping mass flow rate of solution are considered as key parameters. The results show that the optimal SRH (split ratio of high side) and SRL (split ratio of low side) values are 0.596 and 0.521, respectively. Under these conditions, the COP is maximized to 2.1. The optimal pumping mass flow rate is selected as 3 kg/s and the corresponding UAEVA is 121 kW/K in the present system. The present simulation results are compared to the other literature results from Kaita's (2002) and Cho's (1998) triple effect absorption systems. The present system has a lower solution temperature and a higher COP than the Kaita's modified reverse flow, and it also gives a higher COP than the Cho's parallel flow by adjusting split ratios.

Nomenclature

A	: heat transfer area (m^2)
COP	: coefficient of performance
ε	: effectiveness
h	: enthalpy (kJ/kg)
$\dot{m}$	: mass flow rate (kg/sec)
P	: pressure (kPa)
Q	: heat transfer rate (kW)
SR	: split ratio
T	: temperature (℃)
ΔT_{lm}	: log mean temperature difference (℃)
U	: overall heat transfer coefficient (kW/m^2K)
x	: concentration(%)

Superscript

0	: base condition
ABS	: absorber
CON	: condenser
EVA	: evaporator
H	: high
HTG	: high temperature generator
HHX	: high temperature heat exchanger
in	: inlet
L	: low
LHX	: low temperature heat exchanger
LTG	: low temperature generator
M	: middle
MR	: mass flow rate
MHX	: middle temperature heat exchanger

† Corresponding author
Tel.:+82-31-201-2990 ; fax: +82-31-202-8106
E-mail address: ytkang@khu.ac.kr

MTG : middle temperature generator
out : outlet
pump : pump
s : strong solution
SHX : solution heat exchanger
SRH : split ratio of high side
SRL : split ratio of low side

1. Introduction

It is well known that the performance of absorption system is lower than that of compression system. So, many researchers have been studied to improve absorption system performance such as double effect, triple effect and GAX system.[1 7] Recently in Korea and Japan, there are a lot of studies of the triple effect absorption system. However, the ideal triple effect system has some problems, such as corrosion, too high temperature to operate. To solve these problems, the system should be operated under the temperature of 200 ℃. Because of this fact, many researches are focused on the flow patterns of working fluid in the solution loop of system.

In 1994, Yoon et al.[8] simulated and analyzed one of the triple effect cycles, series and parallel flow cycles. Especially, he divided the parallel flow of Type-A and Type-B. Solution concentration is given to Type-A and split ratios are given to Type-B. He concluded Type-B has the highest COP among the three cycles. In 1998, Cho et al.[9,10] studied of parallel and series flow cycles. He analyzed the relations of split ratio and solution temperature, cooling capacity and COP. In 2001, Grossman[11] analyzed the advanced absorption cycles including triple and four effect H_2O/LiBr absorption cycles using the ABSIM program. In 2002, Kaita[12] carried out the simulation of four types of triple effect cycles, that is, series flow type, reverse flow type, parallel flow type, and modified reverse flow type. He found that parallel flow type has the highest COP and maximum solution temperature among four types, while reverse flow type has the lowest COP and maximum solution temperature. He concluded that the modified reverse flow type is an optimal pattern due to the high COP and low maximum solution temperature. In 2002, Kim et al.[13] proposed a compressor assisted absorption cycle to decrease the maximum heat source temperature.

The objective of this study is to analyze the modified reverse flow cycle. Especially, the relations of cooling capacity and COP with respect to key parameters are analyzed when the maximum solution temperature of high temperature generator (HTG) is operated under the temperature of 200 ℃ for preventing corrosion problem. The split-ratios of solution flow loop, UA of each component, pumping mass flow rate of solution, and maximum solution temperatures are considered as the key parameters. In the present study, several results are compared to the other studies.

2. Description Of Four Types Of Triple Effect Absorption Cycles

Fig. 1 shows the schematic diagram of the parallel flow cycle. In this system, weak solution leaving the absorber outlet is distributed to high temperature generator (HTG), middle temperature generator (MTG), low temperature generator (LTG) at the same time. According to the Kaita's research, the parallel flow cycle has high COP and high maximum solution temperature. So, this system is evaluated having corrosion problem.

Fig. 2 shows the schematic diagram of the Series flow cycle. Whole weak solution leaving the absorber outlet flows to HTG, MTG and LTG in series. This system is evaluated having middle COP and middle solution temperature by Kaita's simulation results.

Fig. 3 shows the schematic diagram of the reverse flow cycle. In this system, whole weak

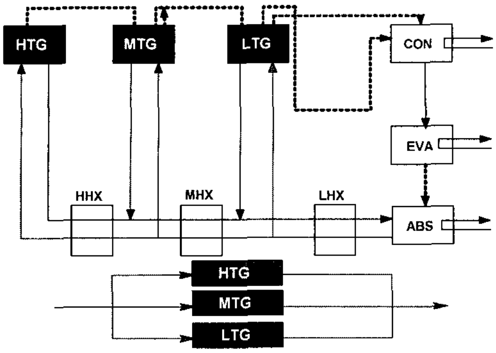

Fig. 1 The schematic diagram of parallel flow cycle.

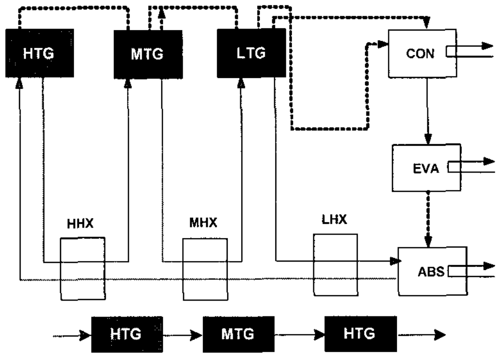

Fig. 2 The schematic diagram of series flow cycle.

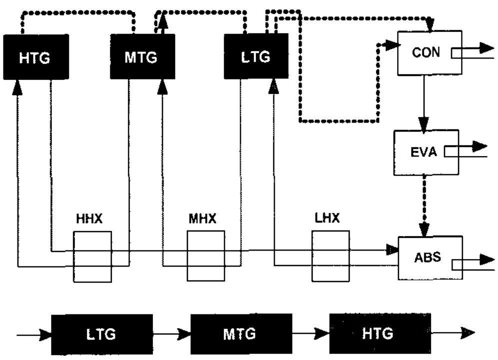

Fig. 3 The schematic diagram of reverse flow cycle.

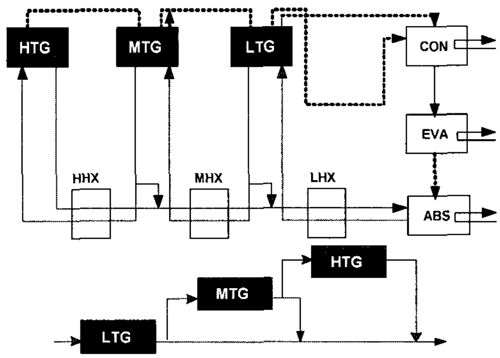

Fig. 4 The schematic diagram of modified reverse flow cycle.

solution leaving the absorberoutlet flows to LTG, MTGand HTG in orderly. Reverse flow cycle is evaluated havinglower maximum solution temperature and lower COP than the other cycles by Kaita's results.

Fig. 4 shows the schematic diagram of the modified reverse flow cycle. This system is similar as reverse flow cycle except for the solution split. Whole weak solution leaving the absorber outlet flows to LTG, MTGand HTG with bypass. According to the Kaita's results, this system has high COP and low maximum solution temperature. So, modified reverse flow has two advantages of preventing corrosion problem and having high performance. In the present study, this flow type is adopted and analyzed.

3. Description Of The Modified Reverse Flow Cycle Applied In This Study

Fig. 5 shows the schematic diagram of modified reverse flow cycle applied in this study. The system consists of three generators and heat exchangers, a condenser, an evaporator and absorber. There are two splitters in this system which located at the high pressure (between HTG and MTG) and low pressure (between MTG and LTG). Whole weak solution leaving the absorber is sent to LTG and distributed to absorber and MTG at the LTG outlet.The solution which is sent to MTG is divided absorber and HTG at the MTG outlet. Split ratio (SR)locating at low side is represented by SRL and that of high side is repre-

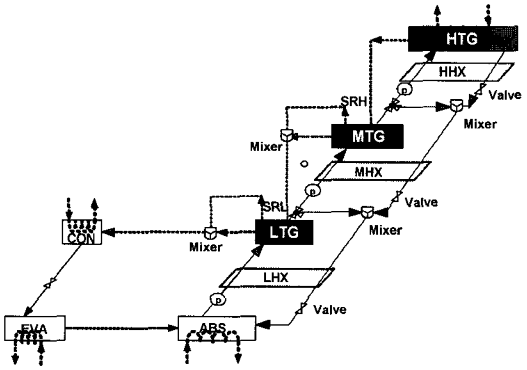

Fig. 5 The schenmatic diagram of modified reverse flow cycle in this study.

sented by SRH. SR is defined as;

$$SR = \frac{\dot{m}_{HTG,in}}{\dot{m}_{ABS,out}}$$

Where $\dot{m}_{HTG,in}$ is the solution mass flow rate of sending to HTG inlet and $\dot{m}_{ABS,out}$ is the solution mass flow rate of leaving absorber outlet. It means that if SR increases, the solution which goes to the generator increases, too. Refrigerant from the HTG is used as a heat source of the MTG and mixed with the refrigerant from MTG. After then, the mixed refrigerant goes to the LTG as a heat source and then it is combined again with the vapor from LTG. The combined refrigerant goes to the condenser, the evaporator, and the absorber.

4. Modeling Approach

EES (Engineering Equation Solver) program[14] is used to simulate and analyze the system and H_2O/LiBr solution is utilized as a working fluid. The system consists of four governing equations for each component. These equations and the definition of COP are summarized in Table 1. There are some assumptions in this study. First, all of the components are in the thermodynamic equilibrium states. Second it is neglected the pump power and heat loss. Third, all of the components are steady state. Fourth, whole refrigerant vapor of leaving the generator outlet is superheated state. The basis values are shown in Table 2. The split ratios are set to 0.5 initially, and effectiveness of solution heat exchangers (SHX) are set to 0.7. At the evaporator, inlet and outlet temperatures of chilled water are set to 12℃ and 7℃, respectively. Heat source temperature and high pressure are set as 230℃ and 297 kPa, respectively.

Table 1. Governing equations and COP

Mass Balance	$\sum_{in}\dot{m} = \sum_{out}\dot{m}$
H_2O/LiBr concentration balance	$\sum_{\in}(\dot{m}\times x) = \sum_{out}(\dot{m}\times x)$
Energy balance	$\sum_{\in}(\dot{m}\times h) = \sum_{out}(\dot{m}\times h) + Q$
Heat transfer equation	$Q = UA \times \Delta T_{lm}$
COP	$COP = Q_{EVA} / Q_{HTG}$

5. Results And Disccusion

Fig. 6 shows the effect of split ratios on COP and Q. The initial SR represented at Table 2. is written as SR_0. As SRH changes, SRL is fixed at 0.5 and as SRL changes, SRH is fixed at 0.5 in this figure. When SRH and SRL increase, more solution is sent to the HTG and much amount of solution exist at the HTG inside. So, less refrigerant is generated for given UA_{HTG} and the heat source temperature. This process has a negative effect on Q_{EVA} and COP. That is, split ratios are related to the vapor amount of HTG outlet and mass flow rate of refrigerant. At the evaporator, by increasing SRH and SRL, Q_{EVA} decreased when SRH/SRH_0 and SRL/SRL_0 are reached up to 1.15 (SRH, SRL = 0.575). In the lower values than 1.15, whole refrigerant is evaporated at the evaporator and over the higher

Table 2 Basic conditions

Concentration [%]	x_s	61
Effectiveness	ε_{HHX}	0.7
	ε_{MHX}	0.7
	ε_{LHX}	0.7
Mass flow rate [kg/s]	MR_{HTG}	15
	MR_{CON}	5
	MR_{ABS}	25
	MR_{PUMP}	2.5
Split ratio	SR_H	0.5
	SR_L	0.5
Pressure [kPa]	P_H	297
	P_M	60
	P_L	8.4
	P_{ABS}	0.98
Temperature [℃]	$T_{HTG,in}$	230
	$T_{CON,in}$	10
	$T_{EVA,in}$	12
	$T_{EVA,,out}$	7
	$T_{ABS,in}$	-10
UA [kW/K]	UA_{HTG}	4
	UA_{MTG}	10
	UA_{LTG}	5
	UA_{EVA}	110
	UA_{CON}	10
	UA_{ABS}	5

values of 1.15, the refrigerant of leaving evaporator outlet is superheated and Q_{EVA} decreases. Fig. 7 shows the effect of split ratios on COP. In this figure, SRH and SRL are-changed at the same time. The results shows that split ratios have an influential effect on COP. The COP has maximum value of 2.05 when SRH and SRL have each value of 0.6 and 0.5. Because the split ratios have an effect on mass flow rate of refrigerant, Q_{EVA} and COP are largely changed. In order to find the optimal conditions for maximizing COP, the optimization model is developed. The balance

(a) Parallel type

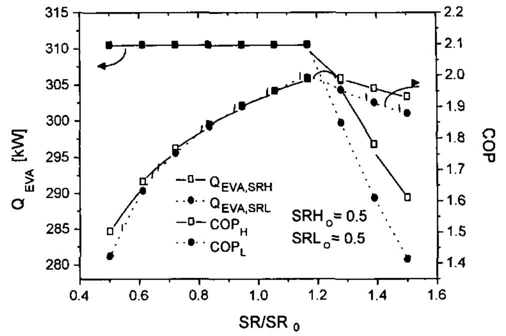

Fig. 6 Effect of split ratios on Q_{EVA} and COP.

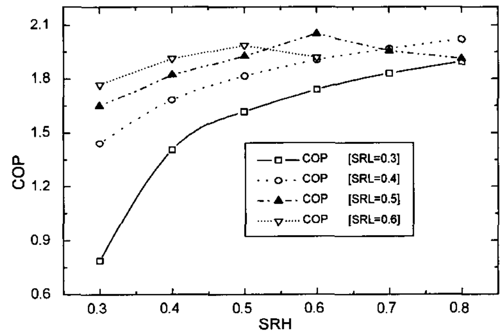

Fig. 7 Effect of split ratios on COP.

equations for each unit are set as constraints, and the maximized COP is the objective function. The optimization model is analyzed by the variable metric method. From the optimization analysis, the optimum split ratios are evaluated as SRH of 0.596 and SRL of 0.521. Under these conditions, the maximum COP is 2.1.

Fig. 8. shows the effect of overall heat coefficient (UA) on COP and Q. UA_{EVA} has a positive effect on COP and Q_{EVA}. UA_{HTG} has a positive effect on Q_{HTG} and negative effect on COP. When UA/UA_0 is reached up to 1.1 (UA_{EVA} = 121 kW/K), Q_{EVA} is stagnated the value of 338 kW because whole refrigerant is evaporated at the UA_{EVA} value of 121 kW/K and vapor quality is over 1.0. After the UA_{EVA} value of 121 kW/K, the refrigerant of leaving evaporator outlet is superheated and there is not any latent heat in this refrigerant. So,

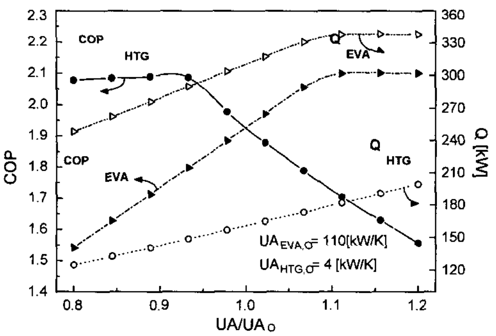

Fig. 8 Effect of UAs on COP and Q.

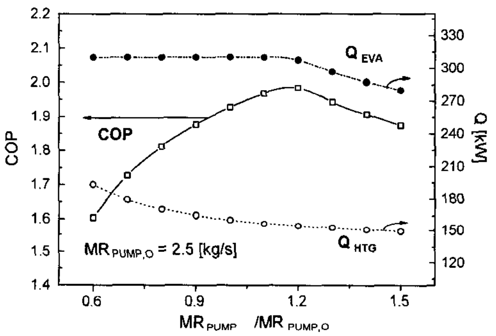

Fig. 9 Effect of pumping mass flow rate on COP and Q.

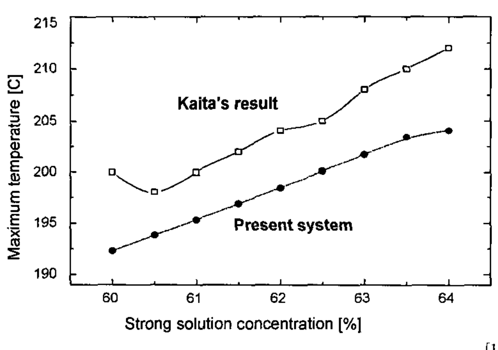

Fig. 10 Comparison with the Kaita's result [12] for maximum solution temperature in the modified reverse flow.

Q_{EVA} and COP are not changed over the value of UA_{EVA} of 121kW/K. In the system, the optimum value of UA_{EVA} of 121kW/K.

Fig. 9. shows the effect of pumping mass flow rate on COP and Q. The solution from the absorber is transported to LTG, MTG and HTG by the circulation pump. Mass flow rate at this pump is expressed as pumping mass flow rate and denoted as MR_{PUMP}. In Fig. 8, results show that the highest COP appears at the $MR_{PUMP}/MR_{PUMP,0}$ value of 1.2 ; MR_{PUMP} is 3.0 kg/sec. At this point, COP is 2.0 and Q_{HTG} and Q_{EVA} are 150kW and 300kW, respectively. As the value of $MR_{PUMP}/MR_{PUMP,0}$ increases, the inlet mass flow rate at HTG increases. From this result, it can be said that too much solution exist in the HTG, so the Q_{HTG} decreases. The value of $MR_{PUMP}/MR_{PUMP,0}$ increases over 1.2, the refrigerant passing through the evaporator is not wholly vaporized. Therefore, it is concluded that suitable mass flow rate of the present system is 3.0 kg/sec.

Fig. 10. shows the comparison of the Kaita's research of maximum solution temperature at the modified reverse flow. In 2002, Kaita reported the simulation results of four types of triple effect cycles. Among those cycles, in this study, the modified reverse flow is compared to the present system. The present system has lower maximum solution temperature than Kaita's results. To compare the same concentration with the lower maximum solution temperature, split ratios are set as 0.5 in this study. Kaita's split ratios are set as 0.75. Results show that the present system has lower maximum solution temperature than Kaita's one and the temperature difference is about 10 ℃.

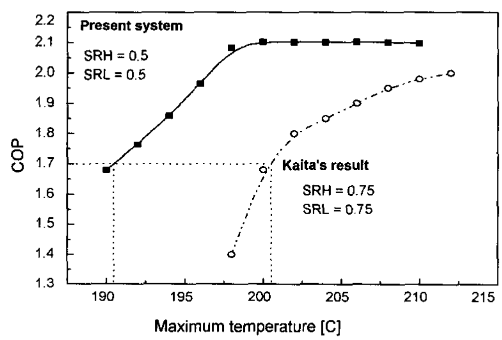

Fig. 11 Comparison with the Kaita's result[12] for COP in the modified reverse flow.

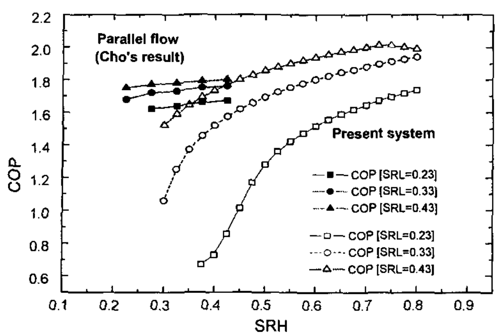

Fig. 12 Comparison with the Cho's result[9] for COP in the parallel flow.

Fig. 11 shows the comparison of the Kaita's result of COPat the modified reverse flow. To compare the same solution temperature with the higher COP, the split ratios are set as 0.5 in this study. However, Kaita's split ratios are set as 0.75. Results show that the present system has higher COP than the Kaita's modified reverse flow cycle. Especially, under the 200 ℃ maximum temperature, this system has higher COP than the Kaita's one.

Fig. 12 shows the comparison of the Cho's result of COP at the parallel flow. According to the Kaita's simulation results, the parallel flow cycle has the highest COP among the four flow types. However, this system has higher COP than Cho's parallel flow cycle by adjusting the split ratios. When this system has the same split ratios as Cho's system, COP is lower than Cho's parallel flow. However, as adjust split ratios, the present system has higher COP than Cho's system. So, it can be possible to have higher COP at the modified reverse flow by adjusting split ratios.

6. Conclusions

The cycle simulation of the modified reverse flow is studied. The split ratio, maximum solution temperature and pumping mass flow rate are considered as the key parameters. From the simulation results, the following conclusions are drawn.

1. The split ratio has an influential effect on the COP and cooling capacity. In this system, the optimum SRH and SRL are estimated as 0.596 and 0.521, respectively.
2. The optimum UA_{EVA} is estimated as 121 kW/K in this system. When UA_{EVA} is 121kW/K, whole refrigerant leaving the evaporator outlet evaporates with a vapor quality of 1.0.
3. The pumping mass flow rate has somewhat effect on the COP. In the present system, the optimum pumping mass flow rate is estimated as 3.0kg/sec.
4. Maximum temperature and COP are compared to the other simulation results from the literature. In comparisons of Kaita's modified reverse flow cycle, the present system has a higher COP and a lower maximum solution temperature. In comparisons of Cho's parallel flow cycle, the present modified reverse flow system gives a higher COP by adjusting split ratios.

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