Thermodynamic Analysis of the Effect of Generator Temperature on the Performance of a Single-Effect Absorption Refrigeration Cycle

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Abstract

A single-effect Vapour Absorption Refrigeration cycle with water-Lithium bromide solution as the working fluid pair has been modeled in the present study. For the proposed model, the first law and second law analyses are performed under steady state conditions. Thermodynamic properties at each state point of the cycle are calculated using related equations of state. For water, the IAPWS IF-97 standard is followed, whereas for the Lithium bromide solution, correlations from standard literature are adopted. The performance parameters considered are circulation ratio (CR), coefficient of performance (COP) and Carnot coefficient of performance (COPc). The variation of COP, COP_C and CR are studied at various generator temperature in the range of 80 °C to 95°C at different evaporator, condenser and absorber temperature levels. Non-dimensional entropy generation is found to be maximum in generator, comparable at absorber and evaporator, while being negligible for solution valve, refrigerant valve, solution pump and refrigerant heat exchanger. With increase in absorber, evaporator and condenser temperatures, non-dimensional entropy generation decreases almost linearly. However, with increase in generator temperature, entropy generation rate decreases nonlinearly. Heat transfer rates of absorber and generator are comparable, but entropy generation of generator is about 3.4 times higher. There exists a generator temperature at given condenser-evaporator temperature for which COP is maximum at a given cooling load.

Keywords: Vapour absorption, Refrigeration system, Thermodynamic analysis, Entropy generation

Introduction

A refrigerator, sometimes called chiller or cooler is a device which helps to attain and maintain a desired temperature in a confined space, lower than the surrounding. Thus heat needs to be carried away from this space, which is done by a fluid called refrigerant. Two basic thermodynamic cycles involving refrigerants for cooling are vapour compression cycle and vapour absorption cycle. Vapour compression cycles commonly use refrigerants that harm the environment, whereas absorption cycles involve environment-friendly working fluids. Another advantage of absorption refrigeration cycles is that that it utilizes waste heat (hot exhaust gases, solar energy, geothermal energy etc). Various combinations of working fluids have been tried and its performance assessment have been performed. In the recent few years, many trials are been carried to use absorption refrigeration cycle along with diesel engines[1], solar energy [2], cooling towers etc. Kaynakli and Kilic [3] have studied the effect of thermal load of evaporator, condenser, absorber and generator, COP, Carnot COP and efficiency ratio when the generator, evaporator, condenser and absorber temperatures are varied. Kilic and Kaynakli [4] has carried out first law and second law (based on entropy generation). They have studied entropy generation and non-dimensional generation of all components when the generator temperature is varied. Generator has maximum entropy and non-dimensional generation of all components. Therefore, it is the most important component to be considered as far as performance is considered. Therefore, in this paper entropy generation and non-dimensional generation of generator are studied at different evaporator, condenser and absorber temperatures when the generator temperature is varied. Also, the variation of COP, Carnot COP and CR are studied at different absorber, evaporator and condenser temperature when the generator temperature is varied.

System Description and Modeling

The schematic diagram of a single effect vapour absorption refrigeration cycle is shown in Figure-1. The system considered consists the following components: an absorber [A], an evaporator [E], a generator [G], two valves: refrigerant expansion valve [V1] and solution expansion valve [V2], a solution pump [P] and a solution heat exchanger [SHX]. There are two types of fluids that circulate within the vapour absorption refrigeration cycle: (i) Primary fluid: It refers to the pure refrigerant. (ii) Secondary fluid: This refers to the absorbent solution. In this cycle, it is water-lithium bromide solution. There are two types of absorbent that are present in the cycle-

strong absorbent solution and weak absorbent solution. Strong solution is the solution having relatively more refrigerant. So strong solution has lesser magnitude of mass fraction of Li-Br compared to the weak solution line. For the simulation of cycle, the following assumptions are considered.
(1) The system is analyzed under steady state.
(2) Pressure drops and heat loss from the flow lines are negligible.
(3) All expansion processes are isenthalpic.
(4) The pure refrigerant leaves the condenser as saturated liquid and the evaporator as saturated vapour.
(5) The solutions leaving the absorber and generator are saturated with respect to the absorber or generator temperature and pressure, respectively.
(6) All four basic heat exchangers (absorber, generator, condenser and evaporator) are modelled as constant temperature heat exchangers as one of the fluids involve phase change during heat transfer [5].
(7) The thermodynamic state of pure refrigerant leaving the generator is in superheated state.

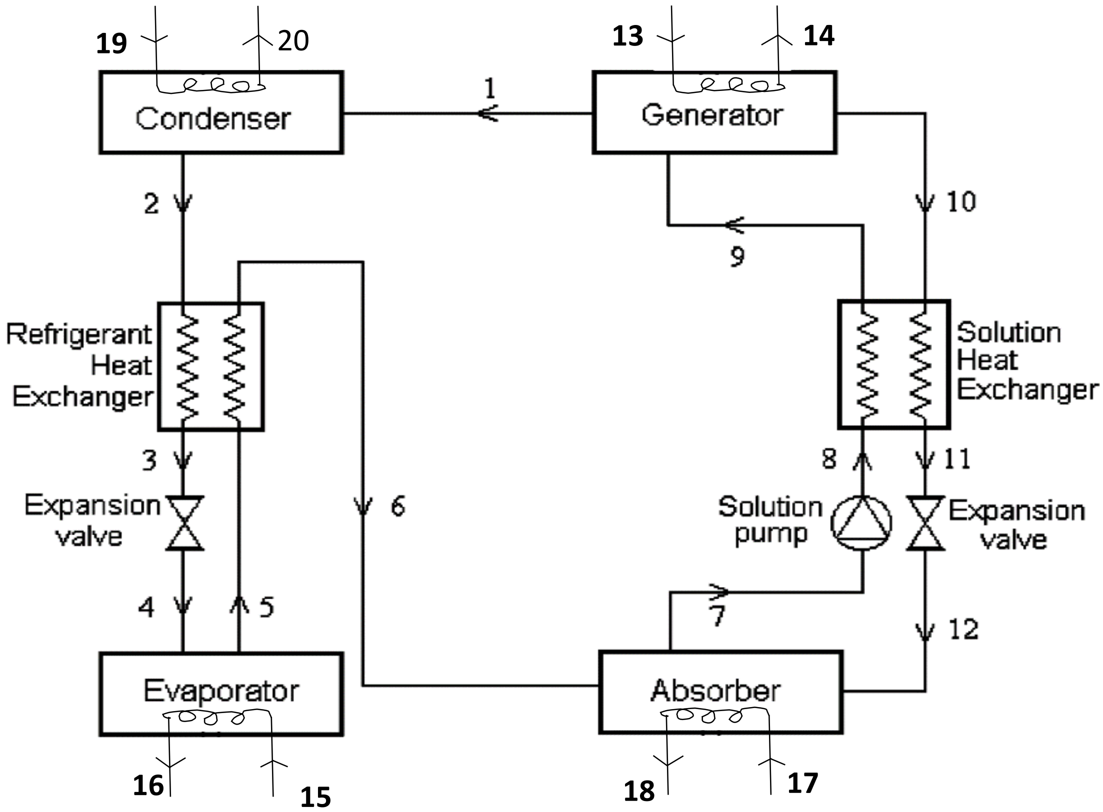

Fig-1: Block diagram of a vapour absorption refrigeration cycle

Thermodynamic Analysis

Based on the assumptions made, the steady state thermodynamic analysis of the considered system is carried out as follows:
(i) Each component of the cycle is considered as a control volume.
(ii)Then for each component, the following equations are applied:

- Overall Mass Balance………. $\sum(m)_{in} = \sum(m)_{out}$
- Material Balance equation for each individual material....... $\sum(xm)_{in} = \sum(xm)_{out}$

First Law Analysis: Energy balance equation [First law of thermodynamics for an open system neglecting kinetic and potential energies of fluid streams]………. $\sum(mh)_{in} + \sum(Q)_{net} = \sum(mh)_{out} + \sum(W)_{net}$

Second Law Analysis: Entropy generation……. $S_{gen} = \sum(S)_{out} - \sum(S)_{in}$

Simulation Code in MATLAB

The analysis is based on the following inputs: heat load ($\dot{Q}$_E), evaporator temperature (T_E), generator temperature (T_G), condenser temperature (T_C), absorber temperature (T_A), effectiveness of heat exchangers (ϵ_1, ϵ_2). ϵ_1 and ϵ_2 are the effectiveness of refrigerant and solution heat exchanger, respectively. For water, The International Association for the Properties of Water and Steam (IAPWS IF-97) [6] is used. For Lithium-Bromide solution, the relations proposed by Patek and Klomfar [7] are followed. MATLAB functions were developed with the help of these correlations. For the solution pump, pump efficiency (η_P) has been considered.

Validation of Simulation

In order to validate the proposed model, the simulation results are compared with the data available in the literature. COP and circulation ratio are calculated for T_E = 4°C, T_C = 35°C, T_A = 40°C, ϵ_1 = 70%, ϵ_2 = 70%, η_P = 95%. Present results matches closely with those reported by Kilic and Kaynakli [3] as shown in figure 2.

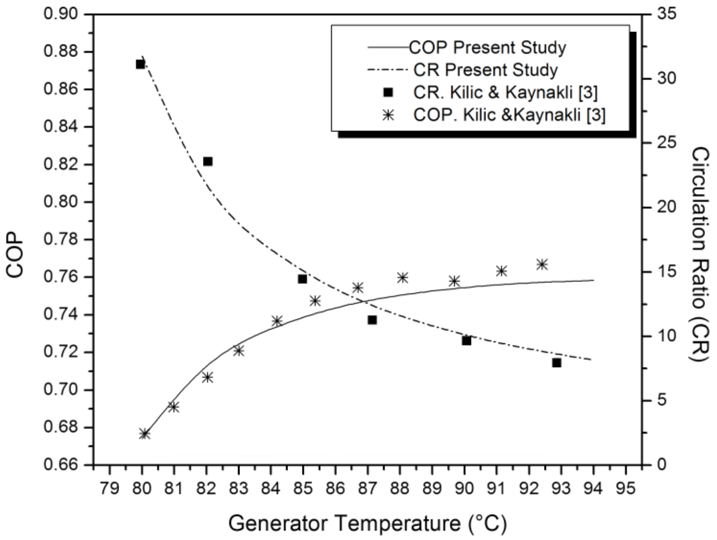

Fig-2: Comparison of COP and CR values with Kilic and Kaynakli
[T_E =4°C, T_C=35°C, T_A= 40°C, ϵ_1 = 70%, ϵ_2 = 70%, η_P =95%]

Results and Discussion

Figure 3 shows the heat transfer rates in all components of the cycle [T_C = 38°C, T_A = 40°C, T_G = 90°C, T_E = 4°C, Q_E = 10 kW, ϵ_1 = 50%, ϵ_2 = 50%, η_P = 90%]. It shows that heat transfer rates are comparable for condenser and evaporator, and for absorber & generator.

Figure 4 shows variation of COP, COP_C and circulation ratio (CR) at two different condenser temperatures (35°C and 37°C) when the generator temperature is varied in the range of 80°C to 95°C. It is observed that Carnot COP increases linearly with increase in generator temperature. Carnot COP is more for lower condenser temperature. Carnot COP increases linearly with increase in generator temperature. Actual COP is more for lower condenser temperature. With the increase of generator temperature, COP gradually increases and converges towards a common value. CR is higher for higher condenser temperature. It falls rapidly with the increase of generator temperature in the initial stages.

Figure 5 shows variation of COP, COP_C and CR at different evaporator temperatures (4°C, 6°C) when the generator temperature is varied in the range of 80°C to 95°C. Carnot COP increases linearly with increase in generator temperature. Higher Carnot COP is obtained for higher evaporator temperatures. With increase in evaporator temperature, COP is initially higher but with the increase of generator temperature COP rapidly increases and then converges towards a common value. Higher CR is obtained for lower evaporator temperature. CR rapidly falls with increase in generator temperature in the initial stages and then gradually falls as generator temperature further falls.

Figure 6 shows variation of COP, COP_C and CR at different absorber temperatures (38°C, 40°C) when the generator temperature is varied in the range of 80°C to 95°C. With increase in generator temperature, Carnot COP increases linearly. COP_C is higher for lower absorber temperature. Initially COP increases rapidly and then the

COP rise gradually slows down. COP is higher for lower absorber temperature. CR is more for higher absorber temperature.

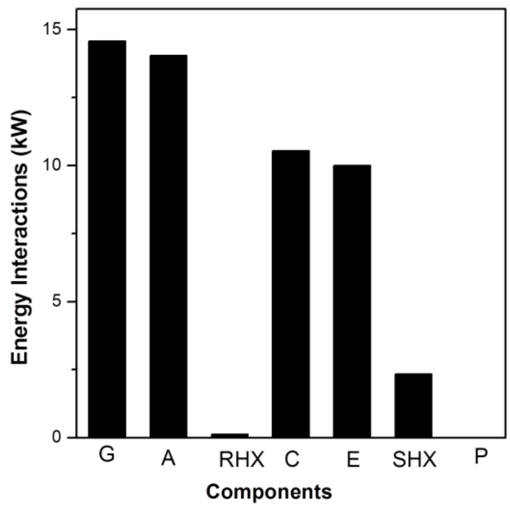

Fig-3: Energy interactions in all components

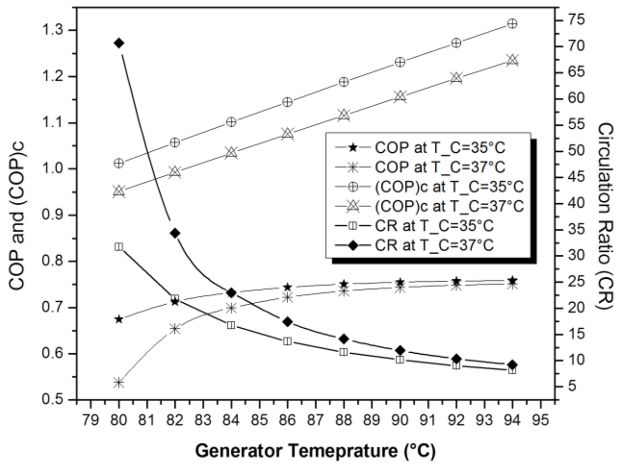

Fig-4: Variation of COP, COP_C and CR at different condenser temperatures when generator temperature is varied. [T_E = 4°C, T_A = 40°C, Q_E = 10 kW, ϵ_1 = 70%, ϵ_2 = 70%, η_P = 95%]

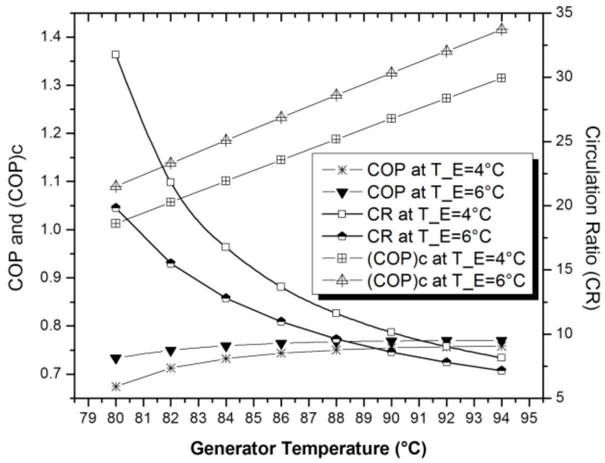

Fig-5: Variation of COP and COP_C at different evaporator temperatures when the generator temperature is varied [T_C=35°C, T_A=40°C, Q_E = 10 kW, ϵ_1 = 70%, ϵ_2 = 70%, η_P =95%]

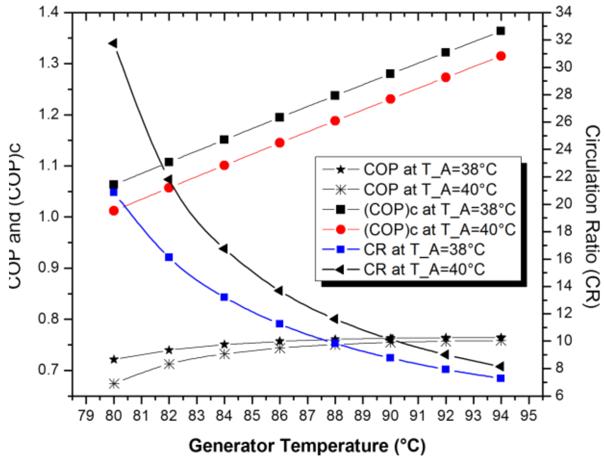

Fig-6: Variation of COP and COP_C at different absorber temperatures when generator temperature is varied [T_C=35°C, T_E=4°C, Q_E = 10 kW, ϵ_1 = 70%, ϵ_2 = 70%, η_P = 95%]

Figure 7 shows the non-dimensional entropy generation rates of all components of the absorption system. It is observed that non-dimensional entropy generation is maximum for absorber, comparable for absorber & generator, negligible for refrigerant & solution heat exchangers, valves and solution pump. Thus generator is the most important component with respect to non-dimensional entropy generation. Results tally with those stated by Kaynakli and Yamankaradeniz [4].

Figure 8 shows the variation of entropy generation and non-dimension entropy generation at different absorber temperatures (38°C, 40°C) for varying generator temperature in the range of 80°C to 95°C. Non-dimensional entropy generation decreases linearly with increase in generator temperature. Non-dimensional entropy generation is higher for lower absorber temperature. With increase in absorber temperature, entropy generation rate decreases non-linearly with increase in generator temperature.

Figure 9 shows the variation of entropy generation and non-dimension entropy generation at two different condenser temperatures (35°C, 37°C) for varying generator temperature in the range of 80°C to 95°C. Non-dimensional entropy generation decreases linearly with increase in generator temperature. With increase in condenser temperature, non-dimensional entropy generation decreases. Entropy generation rate decreases non-linearly with increase in generator temperature.

Figure 10 shows the variation of entropy generation and non-dimension entropy generation at different evaporator temperatures (4°C, 6°C) for varying generator temperature in the range of 80°C to 95°C. Non-dimensional entropy generation decreases linearly with increase in generator temperature. With increase in evaporator temperature, non-dimensional entropy generation increases. Entropy generation rate decreases non-linearly with increase in generator temperature. The nature of variation of entropy generation tallies with those stated by Kaynakli and Yamankaradeniz [4].

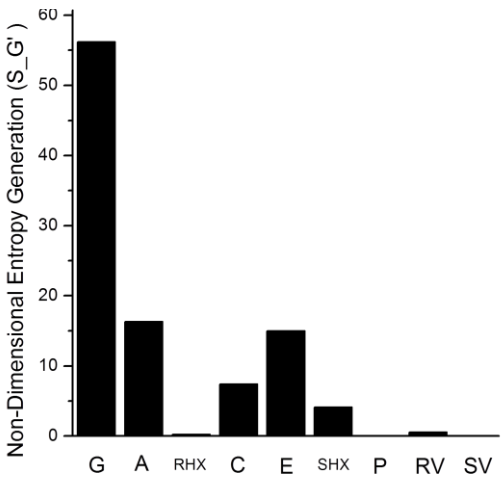

Fig-7: Non-dimensional absorber entropy generation [T_C = 38°C, T_A = 40°C, T_G = 90°C, T_E = 4°C, Q_E = 10 kW, ϵ_1 = 50%, ϵ_2 = 50%, η_P =90%].

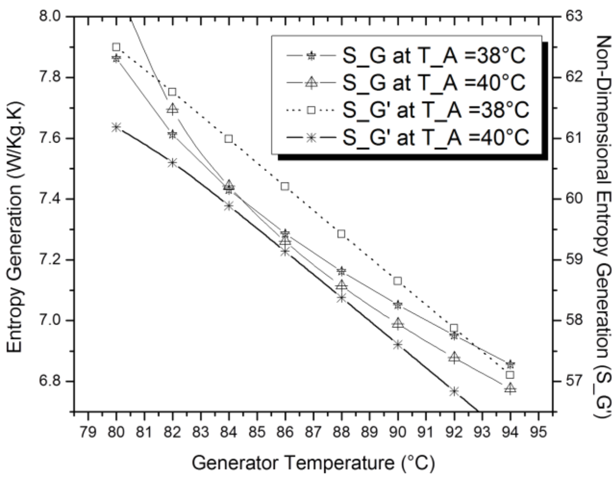

Fig-8: Entropy generation & non-dimensional entropy generation at different absorber temperatures for varying generator temperature [T_C = 35°C, T_E = 4°C, Q_E = 10kW, ϵ_1=70%, ϵ_2=70%, η_P =95%]

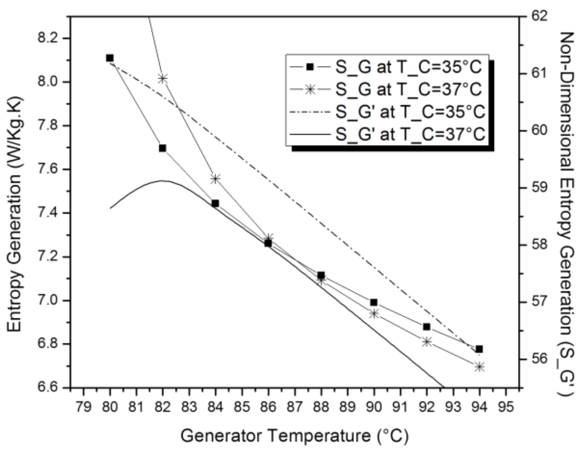

Fig-9: Entropy generation & non-dimensional entropy generation at different condenser temperatures for varying generator temperature [T_A = 40°C, T_E = 4°C, Q_E = 10kW, ϵ_1= 70%, ϵ_2=70%, η_P =95%].

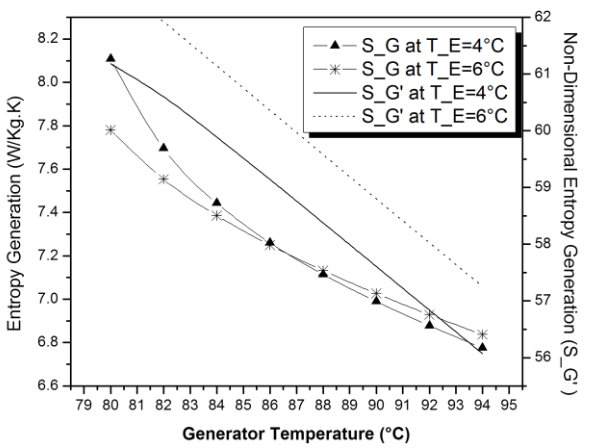

Fig-10: Entropy generation & non-dimensional entropy generation at different evaporator temperatures for varying generator temperature [T_C = 35°C, T_A = 40°C, Q_E = 10 kW, ϵ_1= 70%, ϵ_2 = 70%, η_P =95%].

Conclusion

From the studies carried out for variation of actual COP, it is found that there exists a certain generator temperature for each given condenser-evaporator temperature combination, for which COP is maximum at a given cooling load. If temperature of hot fluid falls below temperature of strong solution inlet temperature to generator, a hypothetical situation of negative COP arises. It happens because the generator instead of receiving heat starts to lose the same. Steady state study shows that heat loads of absorber and generator are comparable. But entropy generation shows that maximum entropy generation takes place in the generator. Non-dimensional entropy generation is maximum for generator, comparable for absorber & evaporator, negligible for solution valve, refrigerant valve, solution pump & refrigerant heat exchanger. Therefore, nature of variation of entropy of generation with generator temperature at different evaporator, absorber & generator temperatures is important. It is observed that with increase in absorber, evaporator & condenser temperature, non-dimensional entropy generation decreases almost linearly. With increase in generator temperature, entropy generation rate decreases nonlinearly.

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