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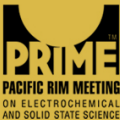
Exergy analysis on the low flow rate of solution in the atomization-based liquid desiccant system

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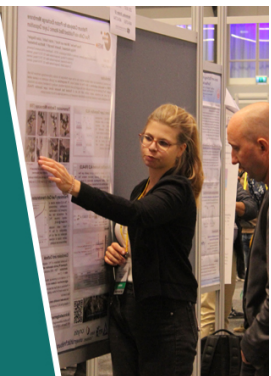


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Exergy analysis on the low flow rate of solution in the atomization-based liquid desiccant system

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Abstract. The purpose of this study is to analyse the proposed liquid desiccant absorber with low solution flow rate compared with the conventional packbed-type absorber. The total exergy destruction and exergy efficiency were estimated to assess the system performance. To determine the total exergy destruction and exergy efficiency, it was predicted that the specific thermal and chemical exergy in the inlet and outlet both air and solution side of the absorber. The results indicated that the average total thermal and chemical exergy destruction is 0.054 kW and 0.080 kW in the proposed system while it is 0.292 kW and 0.093 kW in the conventional absorber. The exergy efficiency is 0.573 and 0.114 on average in the proposed and conventional absorber, respectively.

1. Introduction

The liquid desiccant (LD) system has been considered as an effective dehumidification technology for independent temperature and humidity control [1–3]. The LD system required the cooling and heating concurrently and it was the significant energy consumption part in the system. Accordingly, the new LD systems with low solution flow rate have been investigated to reduce the solution cooling and heating energy [4–6]. Yang et al. [4,5] was proposed the ultrasonic atomization LD dehumidification system to achieve the low solution flow rate. However, the air temperature change is minimal compared to the change in humidity during the dehumidification process because of the low solution flow rate. Therefore, the more comprehensive performance evaluation of the LD system with low solution flow rate is still required. In this study, the LD absorber with solution atomization type using ultrasonic was proposed and it is compared with the conventional packbed-type absorber via detailed exergy analysis. The thermal and chemical exergy was estimated in inlet and outlet air and solution side of the absorber and the total exergy destruction and efficiency were also evaluated.

2. Simulation overview

2.1. System overview

A dehumidification and regeneration component, an air controller, and a solution controller made up the LD system. This system used an air fan in the air controller to force hot and humid outdoor air up into an absorber in the dehumidification section. The air was dehumidified by the mass transfer that occurs when the air and solution came into contact in the absorber. A vapor pressure difference between the air and the solution was what drives the majority of mass transfer, and the cooling coil in



the solution controller cooled the solution to widen this gap. Following the dehumidification procedure, a regenerator is used to maintain the concentration of the weak solution.

The heat and mass transfer area between the air and solution is very important factor for the air dehumidification and solution regenerator. Figure 1 shows a liquid desiccant absorber by the air and solution contact method. A conventional liquid desiccant absorber with packaging material was shown in Figure 1(a). The packing material is made up of numerous layers of cellulose media pads arranged in zigzag or other patterns to offer enough specific area. Because of this packaging material shape, the conventional absorber could achieve the desired heat and mass transfer area for sufficient dehumidification performance. As the results, the solution sprayed over this packaging material and the air was dehumidified by passing through wet media. The fundamental difference between the proposed and the conventional absorber, as shown in figure 1(b), was how to implement the contact area between the air and solution. The air and solution make contact through the packaging material in the conventional absorber, however, immediately make contact in the proposed absorber. The solution is sprayed as a very small droplet by an ultrasonic atomization into an absorber in order to obtain a sufficient contact area for a dehumidification performance similar to a packaging material.

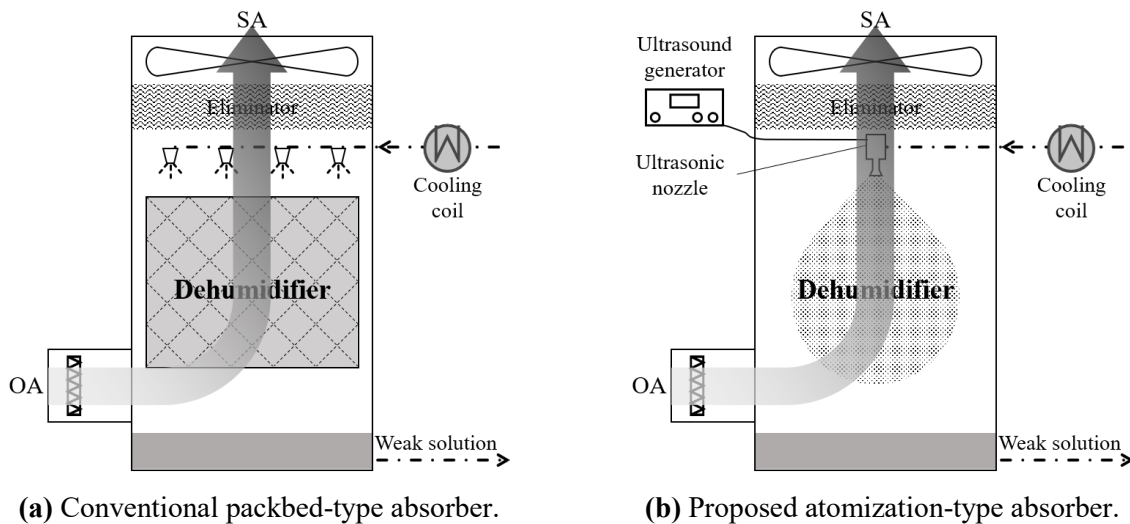


Figure 1. Schematic of a liquid desiccant absorber according to air and solution contact method.

2.2. Exergy analysis

The exergy destruction and efficiency were used as the index for evaluating thermodynamic properties of the proposed and conventional liquid desiccant absorber. It is hard to determine the exergy destruction and efficiency based on the entire component through direct computation. Therefore, the process of analysing becomes simpler by calculating the exergy of each state. A two-part exergy destruction formula is suggested for estimating the exergy destruction: one is thermal exergy by the heat transfer and the other is chemical exergy by the mass transfer between the air and solution [7].

The thermal exergy is described as the heat put out by the temperature difference [8]. Therefore, the specific thermal exergy of the air and solution can be expressed as:

$$ex_{th}(T) = cT_0 \left(\frac{T}{T_0} - 1 - \ln \left(\frac{T}{T_0} \right) \right) \quad (1)$$

with T_0 is temperature of the dead state, T is temperature of the current state, and c is the specific heat ($\text{kJ kg}^{-1} \text{K}^{-1}$)

The thermal exergy destruction of the air and solution can be written as:

$$E_{th,a} = m_a (ex_{th,a,i} - ex_{th,a,o}) \quad (2)$$

$$E_{th,s} = m_s (ex_{th,s,i} - ex_{th,s,o}) \quad (3)$$

with m_a and m_s are mass flow rate of air and solution. The subscripts a, s, i, and o mean the air, solution, inlet, and outlet, respectively.

Finally, the total thermal exergy destruction defined as:

$$E_{th} = E_{th,a} + E_{th,s} \quad (4)$$

The chemical exergy is expressed as the water vapor transfer during the dehumidification process [9]. Therefore, the specific chemical exergy of the air and solution can be written as:

$$ex_{ch}(\omega) = R_a T_0 \left((1 + 1.608\omega) \ln \left(\frac{1+1.608\omega_0}{1+1.608\omega} \right) + 1.608\omega \ln \left(\frac{\omega}{\omega_0} \right) \right) \quad (5)$$

with R_a is gas constants of air, ω and ω_0 are humidity ratio of the current and dead state.

Similar to the thermal exergy destruction, the chemical exergy destruction of the air and solution can be described as:

$$E_{ch,a} = m_a (ex_{ch,a,i} - ex_{ch,a,o}) \quad (6)$$

$$E_{ch,s} = m_s (ex_{ch,s,i} - ex_{ch,s,o}) \quad (7)$$

$$E_{ch} = E_{ch,a} + E_{ch,s} \quad (8)$$

Finally, the exergy efficiency of the liquid desiccant absorber can be calculated by the input exergy and exergy destruction [10–12]:

$$Ex_{eff} = 1 - \frac{E_{th} + E_{ch}}{m_a (ex_{th,a,i} + ex_{ch,a,i}) + m_s (ex_{th,s,i} + ex_{ch,s,i})} \quad (9)$$

3. Simulation results

3.1. Thermal exergy comparison

To analyse the exergy trend according to outdoor air change, the thermal exergy in air and solution side of the inlet and outlet state was estimated during a week of typical summer season. Figure 2 and 3 show the specific thermal exergy in the air and solution side, respectively. In Figure 2 and 3, the black solid line means the inlet specific thermal exergy and the black dashed line means the outlet specific thermal exergy. The gray dotted line expresses the outlet air temperature. Because the proposed absorber operated by low-flow rate of the solution, the released heat from the air to solution was less. On the other hand, the heat could be extinguished well in the conventional absorber because of the same flow rates of the air and solution. Thus, the air temperature leaving the proposed absorber is higher than the conventional absorber. The outlet air temperature effects on the thermal exergy in outlet air state. Because the air dead state is solution inlet temperature, the conventional absorber shows a specific thermal exergy in outlet air state close to zero as indicated in Figure 2(b). Compared to the conventional absorber, the proposed absorber showed higher specific thermal exergy in outlet of the air side (Figure 2(a)). The average specific thermal exergy in outlet air was 2.148 kJ/kg and 0.083 kJ/kg in the proposed and conventional absorber, while it in inlet air was same as 3.194 kJ/kg.

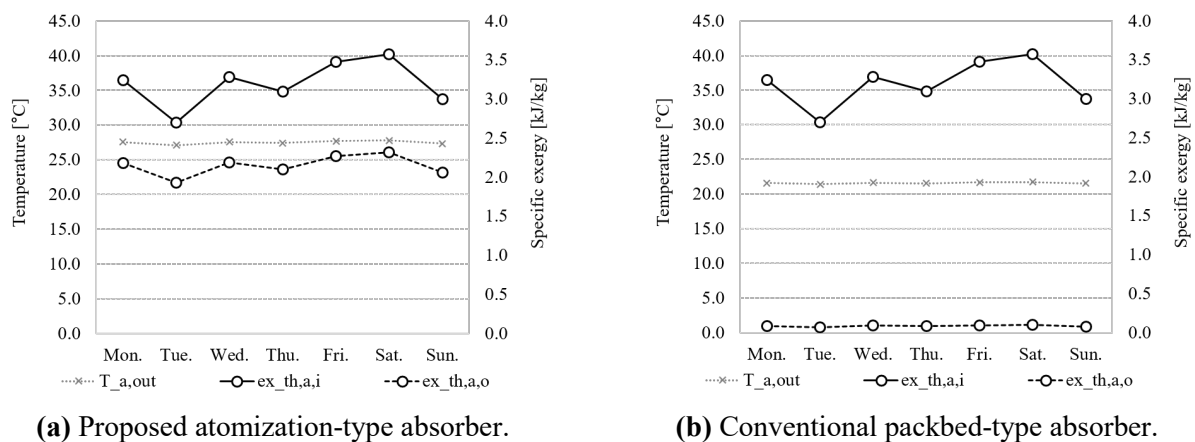


Figure 2. Specific thermal exergy in the air side.

In Figure 3, the solution temperature raised rapidly because of the low-flow rate of the solution in the proposed absorber than the conventional absorber. Therefore, the specific thermal exergy in the inlet and outlet states of the air was almost same as indicated in Figure 3(a). On the other hand, the solution temperature is lower, thus, the outlet specific thermal exergy of the solution was also lower in the conventional absorber as shown in Figure 3(b). Finally, the average outlet specific thermal exergy in outlet side was 2.824 kJ/kg and 0.208 kJ/kg in the proposed and conventional absorber, while it in inlet side was same as 2.932 kJ/kg.

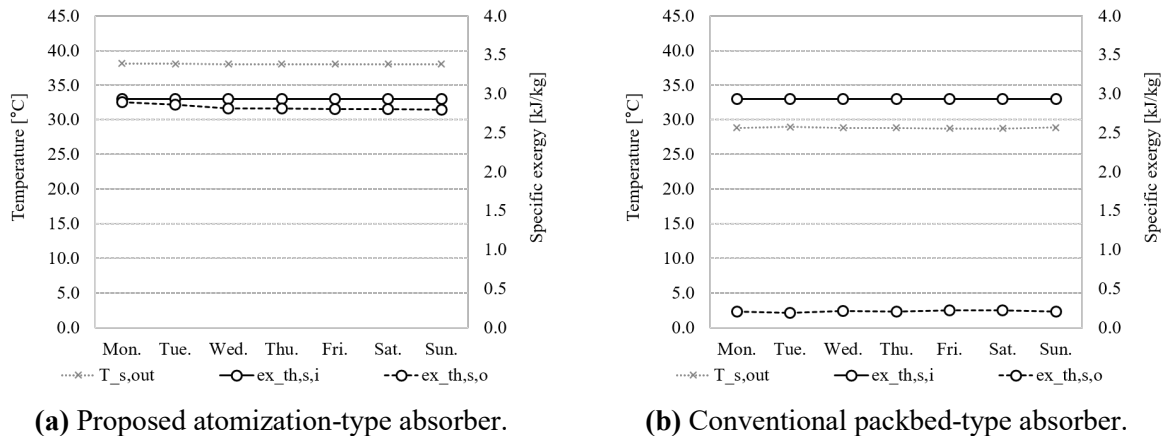


Figure 3. Specific thermal exergy in the solution side.

3.2. Chemical exergy comparison

The specific chemical exergy in air and solution side of the inlet and outlet state was also analysed. Figures 4 and 5 illustrate the specific chemical exergy in the air and solution side, respectively. In Figures 4 and 5, the black solid line means the inlet specific chemical exergy and the black dashed line means the outlet specific chemical exergy. The gray dotted line expresses the outlet air humidity ratio in Figure 4 and the outlet solution concentration in Figure 5. Two types of absorbers had similar dehumidification performance; the target humidity ratio of the outlet air is 0.010 kg/kg. The outlet air humidity ratio effects on the chemical exergy in outlet air state. As shown in Figure 4, the result indicated that the almost same specific chemical exergy in outlet of the air side such as 0.235 kJ/kg in the proposed absorber and 0.116 kJ/kg in the conventional absorber. The specific chemical exergy in inlet of the air was 1.425 kJ/kg on average.

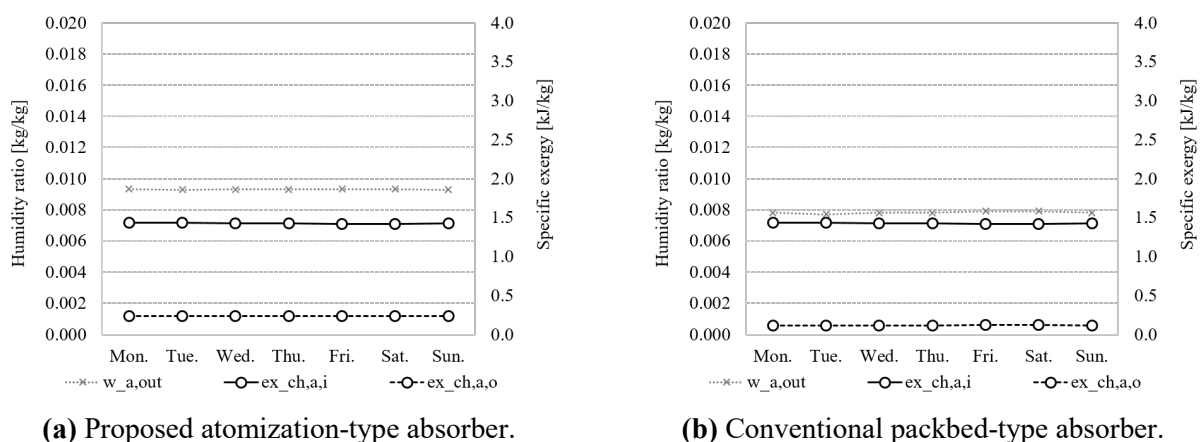


Figure 4. Specific chemical exergy in the air side.

In Figure 5, the solution was diluted significantly in the proposed absorber compared with the conventional absorber. The dehumidification rate is similar; however, the solution flow rate is lower

in the proposed absorber than the conventional absorber. Therefore, the average specific chemical exergy in the proposed absorber is 1.124 kJ/kg and 0.094 kJ/kg in inlet and outlet solution side, respectively, as indicated in Figure 5(a). On the other hand, in the conventional absorber, the average specific chemical exergy in outlet solution is 0.571 kJ/kg which is higher than the proposed absorber.

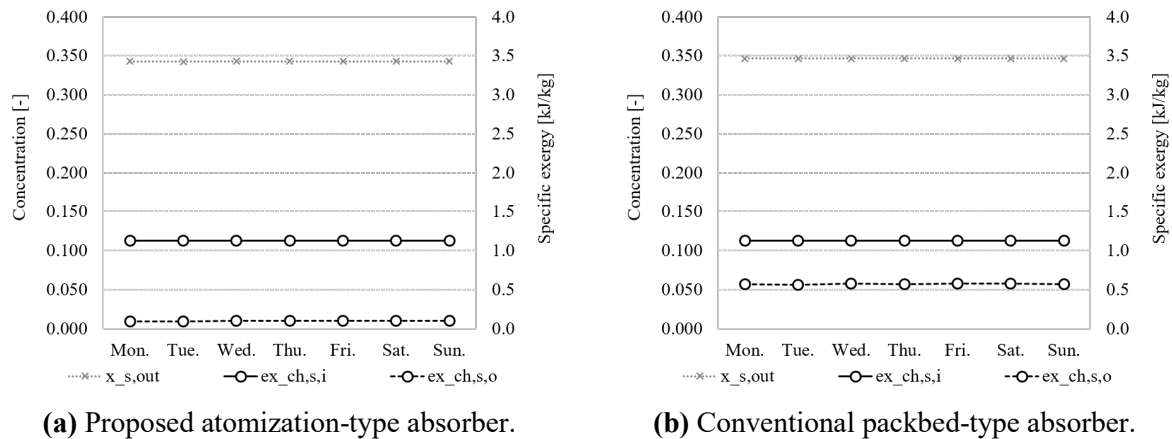


Figure 5. Specific chemical exergy in the solution side.

3.3. Exergy destruction and exergy efficiency

Figure 6 illustrates the exergy destruction and exergy efficiency of the proposed and conventional absorber. The black box shows the total thermal exergy destruction and the white box means the total chemical exergy destruction. The gray dashed line means the exergy efficiency. The variation of the inlet and outlet specific thermal exergy which is major factor of the thermal exergy destruction is bigger in the conventional absorber than the proposed absorber in both of the air and solution side. Although the air mass flow rate is same in both absorbers, the thermal exergy destruction is bigger in the conventional absorber because of the variation of the inlet and outlet specific thermal exergy. The average total thermal exergy destruction is 0.054 kW and 0.292 kW in the proposed and conventional absorber. In the chemical exergy, the air side specific chemical exergy is almost same, while the variation of the specific chemical exergy between the inlet and outlet solution is bigger in the proposed absorber than the conventional absorber. However, the conventional absorber was operated as more solution flow rate, the average total chemical exergy destruction is almost same as 0.080 kW and 0.093 kW in the proposed and conventional absorber. Finally, the average exergy efficiency in the proposed absorber is 0.573 while the conventional absorber had 0.114 average exergy efficiency.

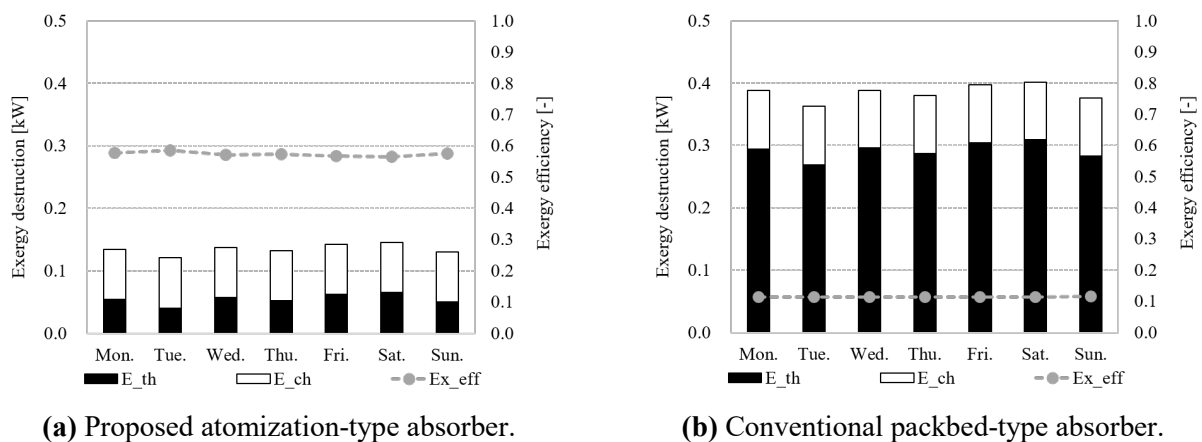


Figure 6. Total Exergy destruction and exergy efficiency.

4. Conclusion

In this study, the liquid desiccant absorbers with ultrasonic atomization of the solution and packaging media were compared via detailed exergy analysis. The total exergy destruction and exergy efficiency were estimated to evaluate the system performance. The specific thermal and chemical exergy in inlet and outlet both air and solution side of the absorber was predicted to calculate the total exergy destruction and exergy efficiency. The primary outcomes of this study are as follows.

- The average total thermal and chemical exergy destruction is 0.054 kW and 0.080 kW in the proposed system whereas it is 0.292 kW and 0.093 kW in the conventional absorber. The chemical exergy destruction is almost same because of the similar dehumidification rate. However, the conventional absorber has higher thermal exergy destruction than the proposed absorber because of the heat transfer difference between the air and solution. The reason is that the proposed absorber has low solution flow rate compare with the conventional absorber.
- Finally, the exergy efficiency is 0.573 and 0.114 on average in the proposed and conventional absorber, respectively, because the proposed absorber has lower exergy destruction than the conventional absorber through the heat and mass transfer characteristic based on the low solution flow rate.

The main contribution of this study is that the system performance of the liquid desiccant absorber with low solution flow rate was demonstrated in detailed exergy analysis. Therefore, the requirement for a low flow-based liquid desiccant system was proved, however, the detailed sensitivity analysis of each operating parameters affecting exergy destruction were still remained. The pilot test also should be carried out in future.

Acknowledgments

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References

- [1] Winkler J, Munk J and Woods J 2018 Effect of occupant behavior and air-conditioner controls on humidity in typical and high-efficiency homes *Energy Build.* **165** 364–78
- [2] Chung T W and Luo C M 1999 Vapor pressures of the aqueous desiccants *J. Chem. Eng. Data* **44** 1024–7
- [3] Conde M R 2004 Properties of aqueous solutions of lithium and calcium chlorides: Formulations for use in air conditioning equipment design *Int. J. Therm. Sci.* **43** 367–82
- [4] Yang Z, Zhang K, Yang M and Lian Z 2014 Improvement of the ultrasonic atomization liquid desiccant dehumidification system *Energy Build.* **85** 145–54
- [5] Yang Z, Zhang K, Hwang Y and Lian Z 2016 Performance investigation on the ultrasonic atomization liquid desiccant regeneration system *Appl. Energy* **171** 12–25
- [6] Yao Y, Li W and Hu Y 2020 Modeling and performance investigation on the counter-flow ultrasonic atomization liquid desiccant regenerator *Appl. Therm. Eng.* **165** 114573
- [7] Dincer I and Rosen M A 2015 *Exergy analysis of heating, refrigerating and air conditioning _ methods and applications* (Amsterdam: Elsevier)
- [8] Chengqin R, Nianping L and Guangfa T 2002 Principles of exergy analysis in HVAC and evaluation of evaporative cooling schemes *Build. Environ.* **37** 1045–55
- [9] Liang C H, Li N F and Huang S M 2020 Entropy and exergy analysis of an internally-cooled membrane liquid desiccant dehumidifier *Energy* **192** 116681
- [10] Zhang Q, Liu X, Zhang T and Xie Y 2020 Performance optimization of a heat pump driven liquid desiccant dehumidification system using exergy analysis *Energy* **204** 117891
- [11] Zhang L, Liu X, Jiang J and Jiang Y 2014 Exergy calculation and analysis of a dehumidification system using liquid desiccant *Energy Build.* **69** 318–28
- [12] Naik B K and Muthukumar P 2019 Energy, entransy and exergy analyses of a liquid desiccant regenerator *Int. J. Refrig.* **105** 80–91