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Article

Adsorption water vapor characteristics on modified silica gel for desalination application

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Abstract

Energy, freshwater, and the environment are interrelated factors that permeate all our activities on the earth. They have become the most important and popular topics in research fields nowadays. This paper studies improving the performance of the adsorption desalination system by improving a commercial silica gel as an adsorbent. Acid treatment has been used to activation for the silica gel. Then, a composite adsorbent is prepared chemically using silica gel as a host matrix and impregnated in $CaCl_2$ salt hydrate. Water vapor adsorption isotherm and kinetics are investigated for raw, treated, and composite silica gel. The Dubinin-Astakhov (D-A) and linear driving force models (LDF) have fitted experimental isotherm and kinetic results. The system is driven by renewable energy such as solar energy. The results illustrated that the silica gel/$CaCl_2$ achieved water uptake (0.95 kg_{H2O}/kg). It is also observed that the composite silica gel based-adsorption desalination cycle provides specific daily water production of 70 % higher than the raw silica gel-based adsorption desalination cycle.

Keywords

Silica gel, Adsorption, Isotherm, Kinetics, Desalination, Renewable energy

1. Introduction

The adsorption desalination system has been viewed as a potentially competitive desalination method**.** (Ng et al., 2008; Thu et al., 2013a), Adsorption desalination is an emerging thermally-driven method that has been proven to be energy efficient and environmentally friendly. (Ng et al., 2013), It works by extracting waste heat from the exhaust or renewable solar and geothermal energy. (Ng et al., 2009; Ng et al., 2011; Thu et al., 2014), Unlike conventional methods, the adsorption desalination cycle produces two useful effects: potable water and cooling effect with only a single heat source input. The adsorption desalination system depends on the adsorption theory and uses a working adsorption pair (adsorbent and adsorbate). The adsorption desalination system consists of three major components, namely (i) adsorption beds, (ii) evaporator, and (iii) condenser, as shown in Fig**.** 1.

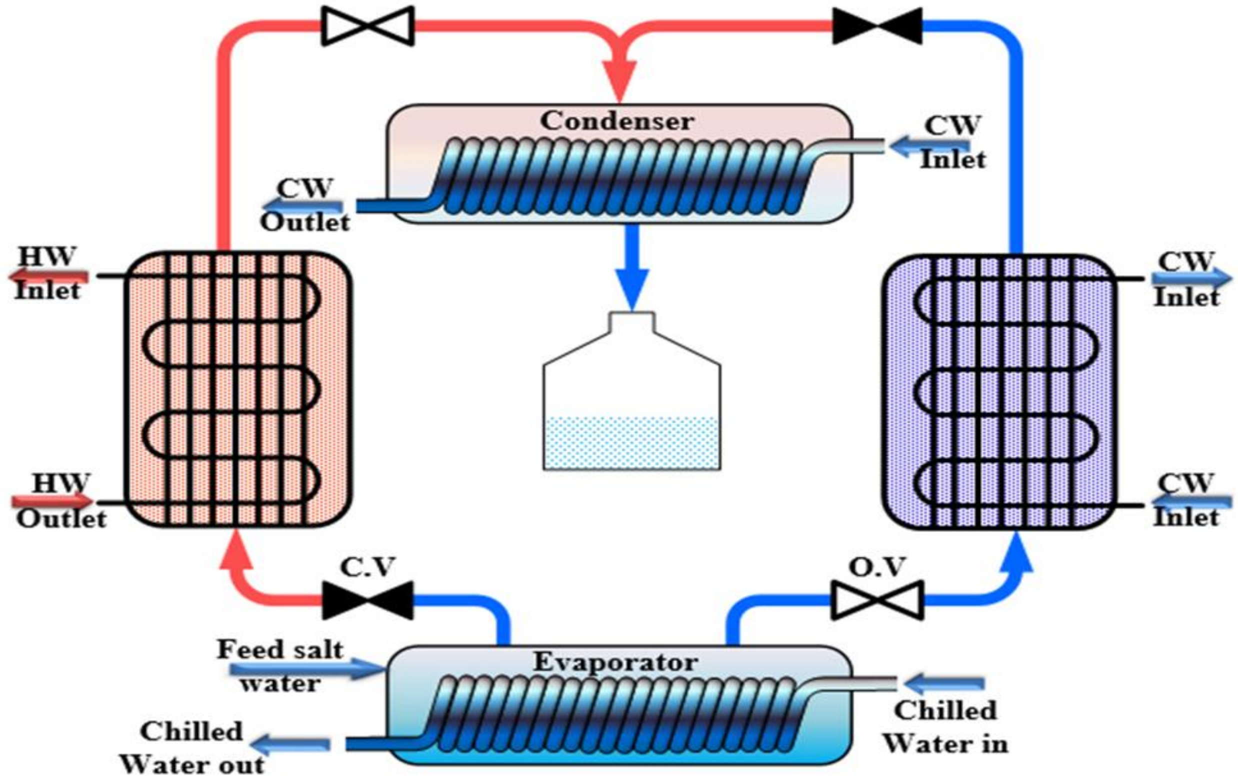


Figure 1. Adsorption desalination system.

Adsorption water vapor uptake is a major factor in adsorbents selection for adsorption applications. (Thu et al., 2013b), So, many researchers have studied the adsorption water vapor characteristics onto many adsorbents for use in adsorption applications. For example, Goldsworthy (2014) measured the water vapor adsorption isotherms for RD silica gel, AQSOA-Z01, AQSOA-Z02, AQSOA-Z05, and CECA zeolite 3A as adsorbent materials. The Maximum adsorption water vapor capacity were 0.315 kg/kg of silica gel, 0.22 kg/kg of Z01, 0.33 kg/kg of Z02, 0.235 kg/kg of Z05 and 0.235 kg/kg of CECA, Ng et al. (2001) investigated the adsorption water characteristics of three types of silica gel (A, 3A, and RD) for adsorption cooling application. The results showed that the maximum adsorption capacity was 0.4 kg/kg of silica gel. Chua et al. (2002) studied the adsorption characteristics of water vapor on two types of silica gel (A and RD). The maximum adsorption capacity for A and RD silica gel were 0.4 and 0.45 kg/kg, respectively. Xia et al. (2008) tested the adsorption equilibrium of water on silica gel for adsorption refrigerating application. The adsorption capacity was 0.3 kg/kg silica gel at 2.3 kPa and 25 °C. Alsaman et al. (2017) studied water vapor adsorption of a commercial silica gel for adsorption desalination–cooling application. The maximum adsorption capacity was 0.36 kg/kg of silica gel. The specific daily water production (SDWP) of about 4 m^3/ton of silica gel, with specific cooling power (SCP) 112 W/kg and coefficient of performance (COP) 0.45.

Researchers have studied the adsorption system's performance theoretically and experimentally at different operating parameters as; hot and cooling water temperature sources, cycle and switching time, etc. (Mitra et al., 2015; Alsaman et al., 2017; Rezk et al., 2019). Those studies illustrated that the SDWP was in the range of 1.5-7.2 m^3/ton of adsorbent, with SCP 45-170 W/kg and COP 0.2-0.5. The adsorption desalination system still needs to improve performance from the previous studies. Therefore, this paper examines enhancing the performance of adsorption systems by enhancing the ability of adsorbents to increase the adsorption capacities, which leads to an increase in the system's performance.

2. Results and Discussion

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

As shown in Fig. 2, the silica gel/$CaCl_2$ shows a higher adsorption capacity, reaching as high as 0.95 kg_{H2O}/kg of silica gel/$CaCl_2$ at 0.9 P/P_S. silica gel/HCl curve is increase until reaching 0.55 kg_{H2O}/kg at 0.9 P/P_S. Fig. 3(a–c) shows the water vapor adsorption isotherm onto raw silica gel, silica gel/HCl, and silica gel/$CaCl_2$ samples and their fittings with the D-A model at different adsorption temperatures. The fitted values for the D-A model are listed in Table 1.

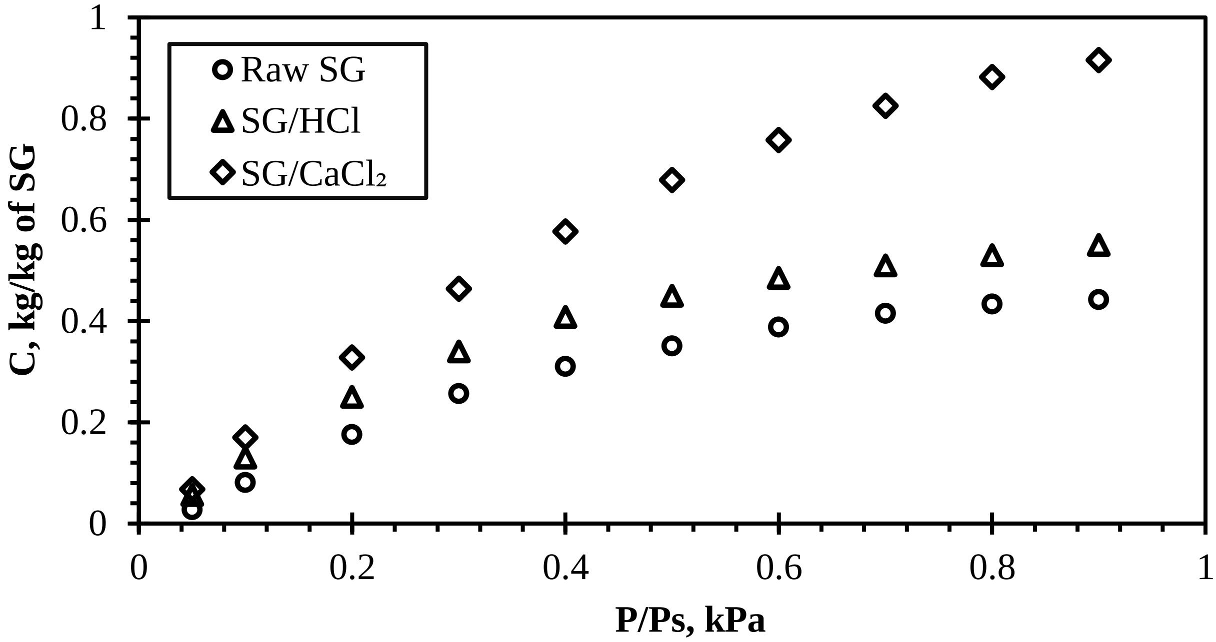
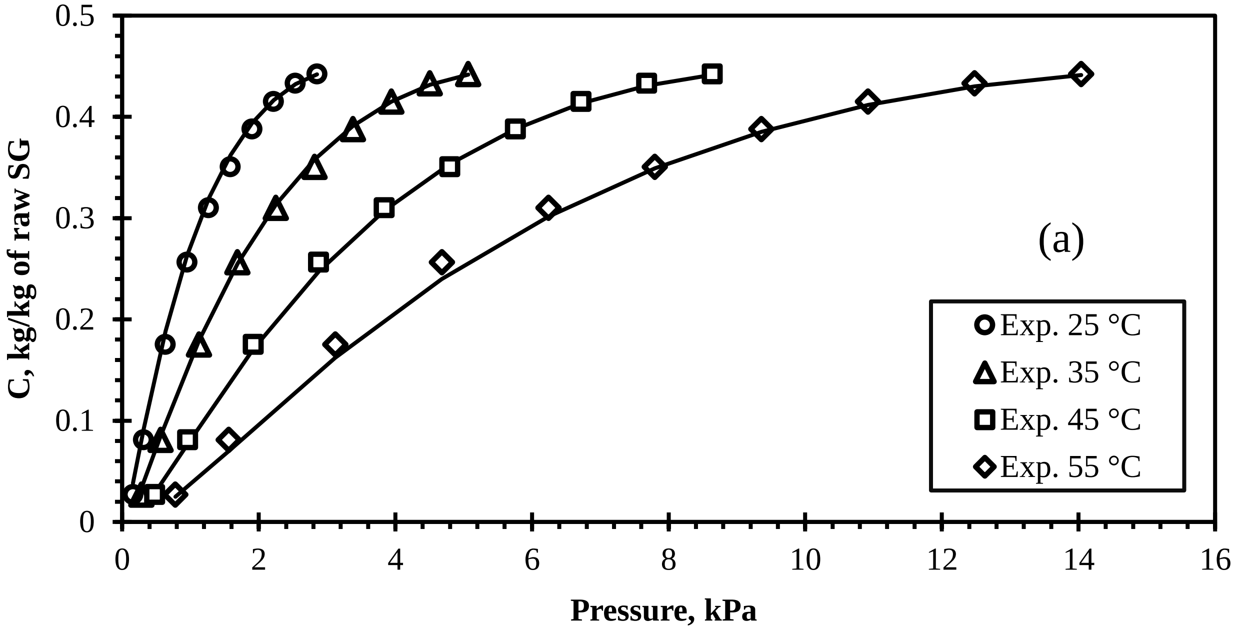
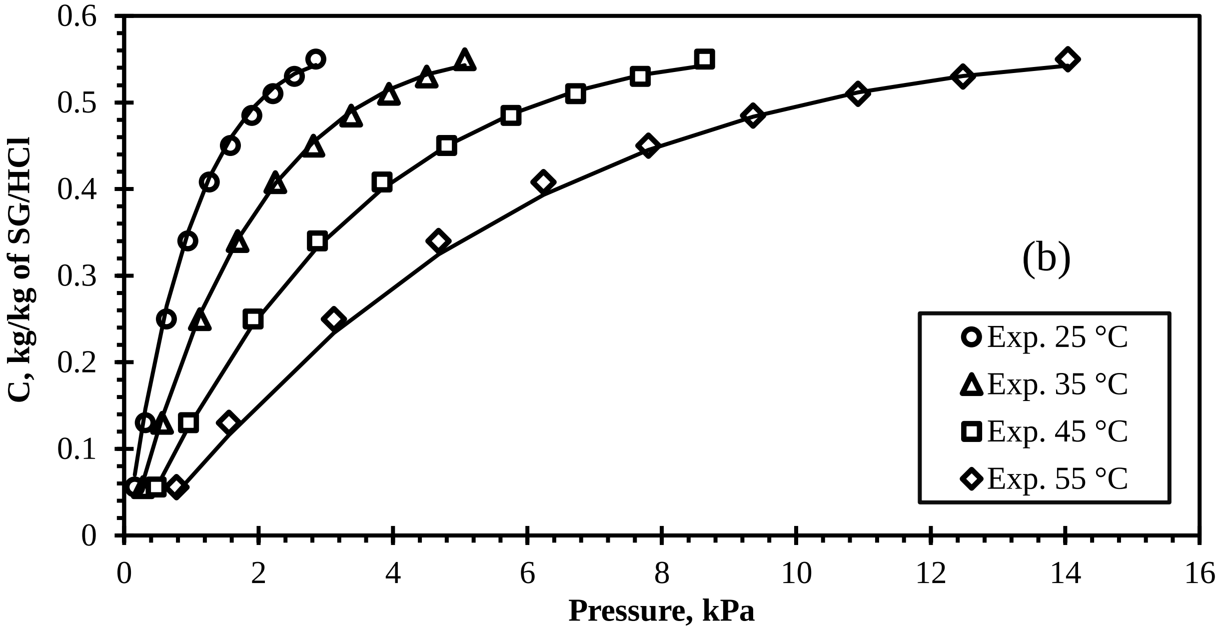


Figure 2. Water vapor adsorption isotherm onto raw silica gel, silica gel/HCl, and silica gel/$CaCl_2$ samples at 25 °C.





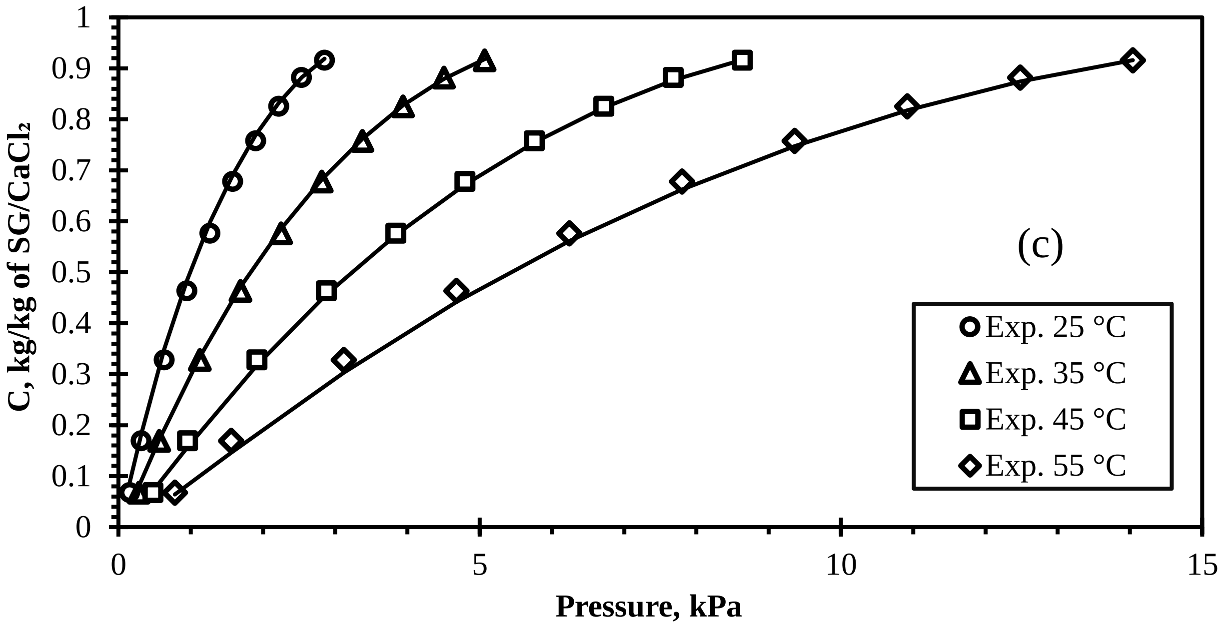


Figure 3. Water vapor adsorption isotherm onto: (a) raw silica gel; (b) silica gel/HCl; (c) silica gel/$CaCl_2$ samples and their fittings with D-A model at different adsorption temperatures.

Table 1. D-A fitted values for silica gel-water pairs.

Adsorbent	C_0 (kg/kg)	E (kJ/kg)	N (-)	Average Hst (kJ/kg)
Raw silica gel	0.45	4360	1.69	2890
Silica gel /HCl	0.55	4836	1.68	2957
Silica gel/$CaCl_2$	0.95	4021	1.39	2782

Figure 4 shows the experimental adsorption kinetics for the silica gel samples. The figure shows the similarity of the beginning of each of the raw silica gel, silica gel/HCl, and silica gel/$CaCl_2$ samples. Figure 5(a–c) shows the fitting of the experimental adsorption kinetics results for the different silica gel samples by the LDF model at different adsorption temperatures. The figure shows an excellent agreement between the LDF model and experimental results. The fitted values for the LDF model are listed in Table 2.

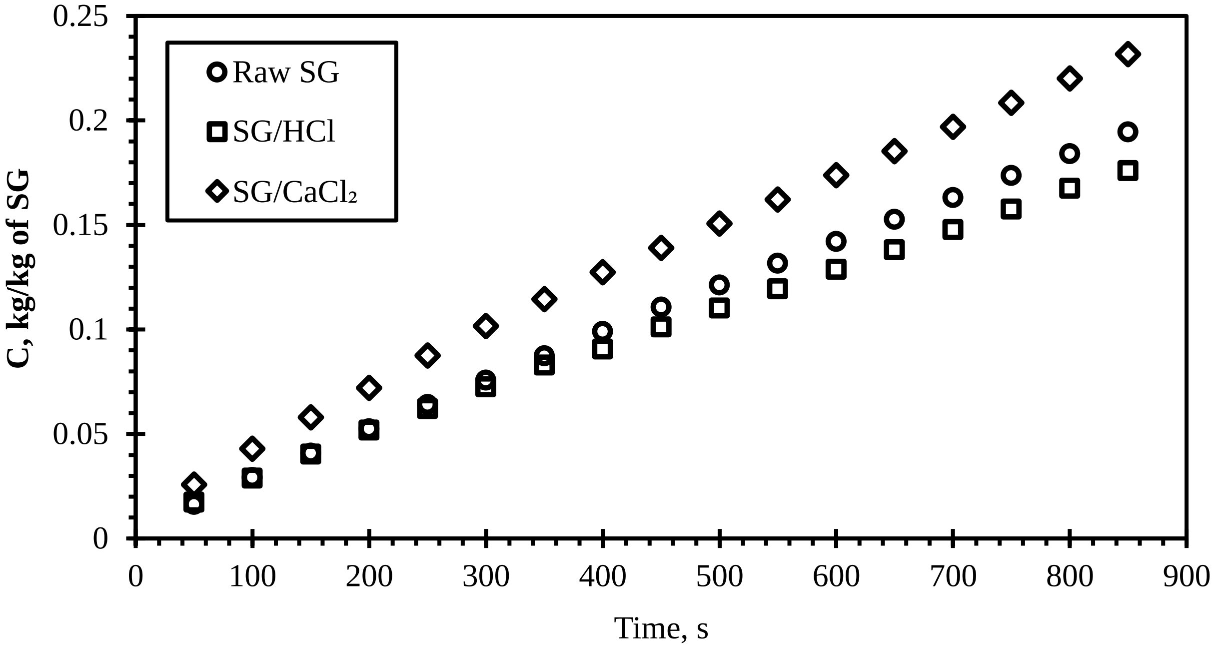
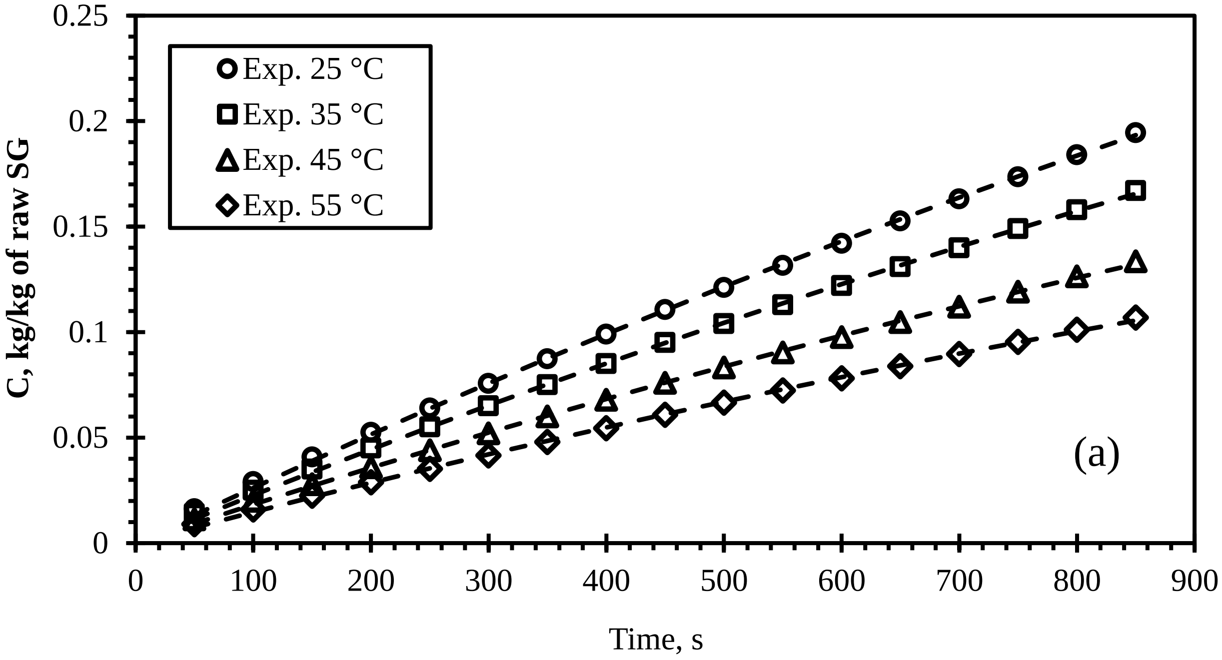


Figure 4. Water vapor adsorption kinetics onto raw silica gel, silica gel/HCl, and silica gel/$CaCl_2$ samples at P/P_s=0.9 and adsorption temperature=25 °C.



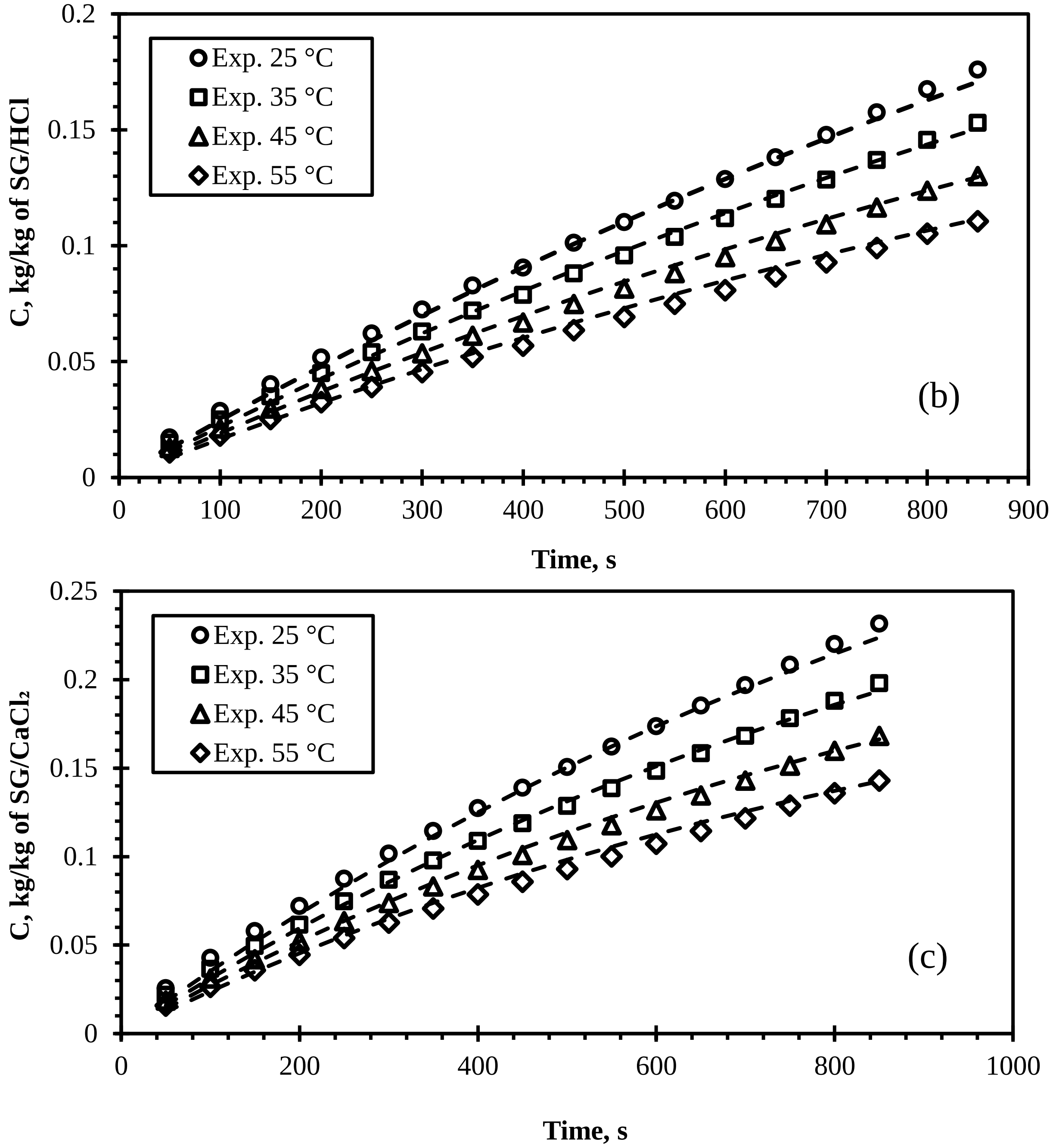
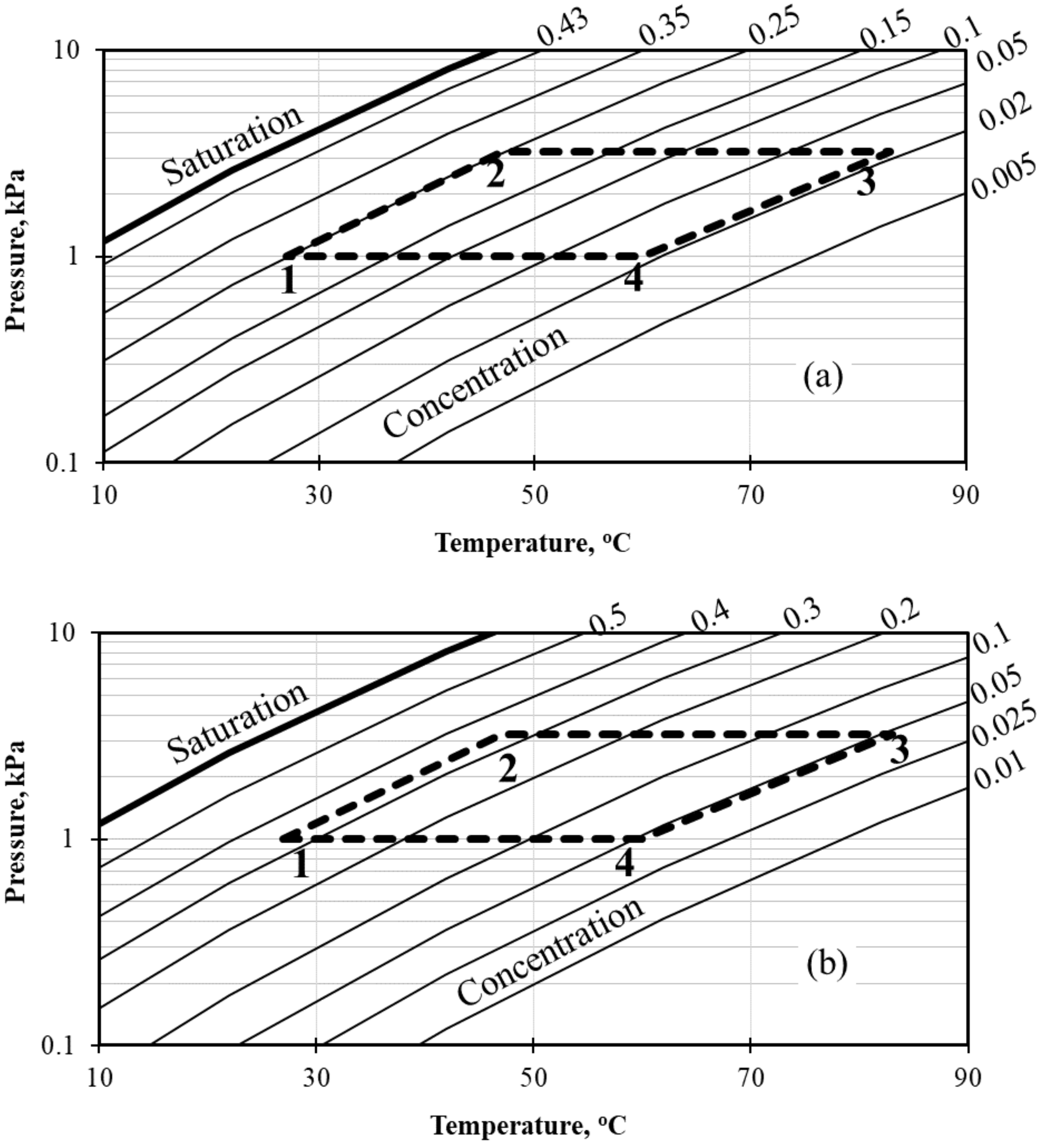


Figure 5. Water vapor adsorption kinetics onto: (a) raw silica gel; (b) silica gel/HCl; (c) silica gel/$CaCl_2$ samples and their fittings with LDF model at P/P_s=0.9 and different adsorption temperatures.

Table 2. LDF fitted values of silica gel-water pairs.

Adsorbent	E_a **(kg/kg)**	D_{so} **(m^2/s)**	**F (-)**
Raw silica gel	4337.83	1.31211E-21	45
Silica gel/HCl	4025.31	6.20821E-22	58
Silica gel/$CaCl_2$	5378.41	4.39860E-21	45

Figure 6(a–c) shows a P-T-C diagram (pressure, temperature, and water vapor capacity) for the adsorption desalination cycle of the investigated materials. The thermodynamic P-T-C cycle includes desorption (2-3) and adsorption (4-1) processes, and two switching time processes as pre-heating (1-2) and pre-cooling (3-4). The figure expressed that the silica gel/$CaCl_2$-based adsorption desalination cycle has an adsorption load (the difference between adsorption and desorption concentration) 70% higher than the raw silica gel-based adsorption desalination cycle.



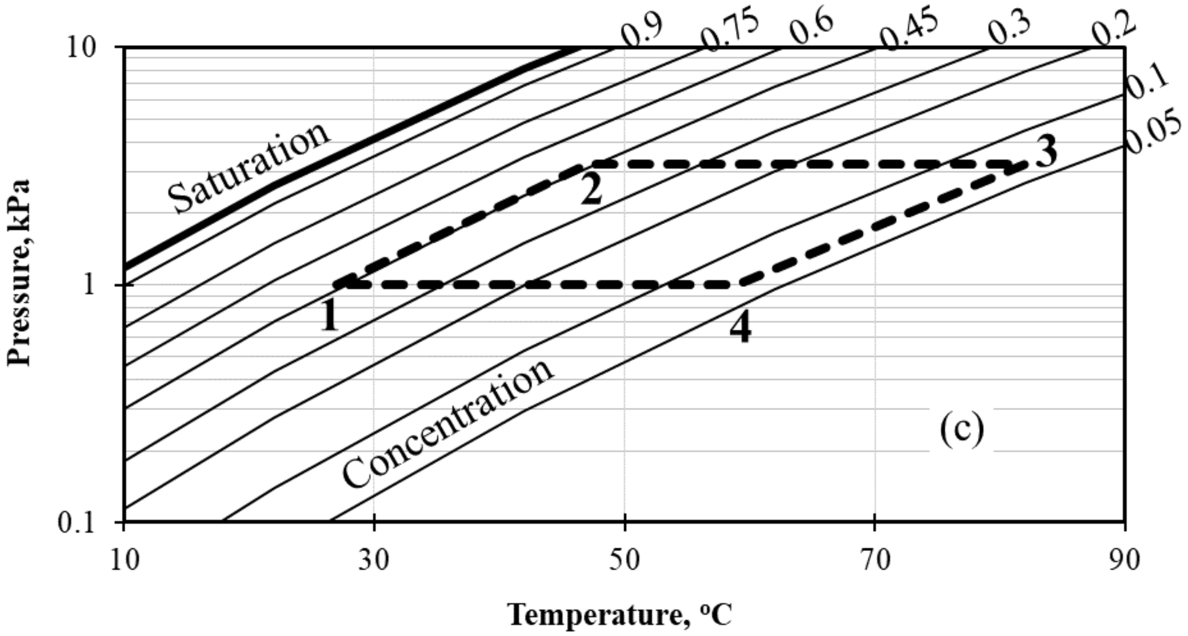


Figure 6. P-T-C diagram for adsorption desalination cycle: (a) raw silica gel; (b) silica gel/HCl; (c) silica gel/$CaCl_2$.

3. Materials and Methods

3.1. Pretreatment and preparation

The silica gel is treated with HCl for the highest surface area and adsorption capacity. The silica gel is placed in 60 ml of 2 mol HCl for 24 hours, stirring at room temperature. The mixture was filtered, washed with distilled water, and dried at 150 °C for 12 hours. The treated dried silica gel is impregnated with 30 wt.% $CaCl_2$ in distilled water. The mixture is filtered and dried at 150 °C for 12 hours to produce silica gel/$CaCl_2$ composite.

3.2. Water adsorption characteristics

The adsorption isotherms and kinetics of water vapor onto raw silica gel, silica gel/HCl, and silica gel/$CaCl_2$ are investigated using a water vapor adsorption analyzer (Lab. of Mech. Eng. Dep., Tabbin Institute for Metallurgical Studies, Cairo, Egypt). A 0.5 g of dried adsorbent is placed on the water vapor adsorption analyzer and heated at 100 °C for about 5 hours, with evacuation by the nitrogen.

For isotherm, the relative pressure (P/P_s) steps are set in range (0.05-0.9). The P/P_s, temperature, and weight are recorded every second. The adsorption isotherm step is ended when stable the sample weight during 15 min and moving to the next step. The D-A model is used to fit the experimental isotherm results given by Eq. 1. (Gordeeva et al., 1998)

$$C=C_o\exp\left\{-\left(\frac{\bar{R}T}{E}\ln\left(\frac{P_s}{P}\right)\right)^n\right\} \tag{1}$$

The isosteric heat of adsorption can be given by Eq. 2 below (Aristov et al., 1996);

$$H_{st}=h_{fg}+E\left[\ln\left(\frac{C_o}{C}\right)^{\frac{1}{n}}\right]+\frac{ET\alpha}{n}\left[\ln\left(\frac{C_o}{C}\right)\right]^{\frac{1-n}{n}} \tag{2}$$

For adsorption kinetics, the P/P_s value is set at 0.9. The adsorption water vapor uptake is measured with time (0-850 s). This procedure is repeated for different adsorption temperatures

(25-55 °C). The LDF model is used to fit the experimental results, given by Eq. 3 (Gordeeva et al. 1999; Mrowiec-Białon et al., 1999)

$$\frac{\partial C}{\partial t}=\frac{F_o D_s}{{R_P}^2}(C_{\circ}\text{-}C) \tag{3}$$

where,

$$D_s=D_{so}\exp\left(-\frac{E_a}{RT}\right) \tag{4}$$

4. Conclusions

The adsorption isotherms and kinetics of the composite silica gel-water pair have been investigated. The maximum adsorption capacity is about 0.95 kg/kg of composite. The experimental data have been fitted with D-A and LDF models. The average SDWP for the silica gel/CaCl2-based adsorption desalination cycle is 70 % higher than the raw silica gel-based adsorption desalination cycle. The adsorption desalination system can be powered by a low-grade heat source as solar energy, which can be operated efficiently in Egypt weather. From these conclusions, it can be recommended that it is better to increase the performance of the adsorption system for future work, which can be achieved by increasing the overall heat transfer coefficient. Future work should also investigate new adsorbent and composite materials.

References

Alsaman, A. S., Askalany, A. A., Harby, K., & Ahmed. M. S. (2017). Performance evaluation of a solar-driven adsorption desalination-cooling system. *Energy 128,* 196–207.

Aristov, Y. I., Tokarev, M. M., Restuccia, G., & Cacciola, G. (1996). Selective water sorbents for multiple applications, 2. $CaCl_2$ confined in micropores of silica gel: sorption properties. *React. Kinet. Catal. L.59,* 335-342.

Chua, H. T., Ng, K. C., Chakraborty, A., Oo, N. M., & Othman, M. A. (2002). Adsorption characteristics of silica gel + water systems. *J. Chem. Eng. Data. 47,* 1177-1181.

Goldsworthy, M. J. (2014). Measurements of water vapour sorption isotherms for RD silica gel, AQSOA-Z01, AQSOA-Z02, AQSOA-Z05 and CECA zeolite 3A. *Microporous Mesoporous Mater. 196,* 59-67.

Gordeeva, L. G., Mrowiec-Bialon, J., Jarzebskib, A. B., Lachowski, A. L., Malinowski, J. J., & Aristov, Y. L. (1999). Selective water sorbents for multiple applications, 8. Sorption properties of $CaCl_2$-SiO_2 sol-gel composites. *React. Kinet. Catal. L. 66,* 113-120.

Gordeeva, L. G., Restuccia, G., Cacciola, G., & Aristov, Y. I. (1998). Selective water sorbents for multiple applications, 5. LiBr confined in mesopores of silica gel: sorption properties. *React. Kinet. Catal. L. 63,* 81-88.

Mitra, S., Kumar, P., Srinivasan, K., & Dutta, P. (2015). Performance evaluation of a two stage silica gel-water adsorption based cooling cum desalination system. *Int. J. Refrig. 58,* 186-198.

Mrowiec-Białon, J., Lachowski, A. I., Jarze, A. B.¸ Gordeeva, L. G., & Aristov, Y. I. (1999). SiO_2–LiBr Nanocomposite Sol–Gel Adsorbents of Water Vapor: Preparation and Properties. *J. Colloid Interface Sci. 218,* 500–503.

Ng, K. C., Chua, H. T., Chung, C. Y., Loke, C. H., Kashiwagi, T., Akisawa, A., & Saha, B. B. (2001). Experimental investigation of silica gel-water adsorption isotherm characteristics. *Appl. Therm. Eng. 21,* 1631-1642.

Ng, K. C., Thu, K., Chakraborty, A., Saha, B., & Chun, W. (2009). Solar-assisted dual effect adsorption cycle for the production of cooling effect and potable water. *Int. J. Low Carbon Technol. 4,* 61-67.

Ng, K. C., Thu, K., Kim, Y. (2011). Solar-assisted adsorption cycle for the production of cooling effect and potable water, 2nd European Conference on Polygeneration – 30th March-1st April, 2011– Tarragona, Spain,2011.

Ng, K. C., Thu, K., Kim, Y., Chakraborty, A., & Amy, G. (2013). Adsorption desalination: An emerging low-cost thermal desalination method, *Desalination 308,* 161–179.

Ng, K.C., Saha, B. B., Chakraborty, A., & Koyama, S. (2008).Adsorption desalination quenches global thirst. *Heat Transfer. Eng. 29,*845–848.

Rezk, H., Alsaman, A. S., Al-Dhaifallahd, M., Askalany, A. A., Abdelkareem, M. A., & Nassef, A. M. (2019). Identifying optimal operating conditions of solar-driven silica gel based adsorption desalination cooling system via modern optimization. *Sol. Energy 181,* 475–489.

Thu, K., Chakraborty, A., Saha, B. B., & Ng, K. C. (2013). Thermo-physical properties of silica gel for adsorption desalination cycle. *Appl. Therm. Eng. 50,* 1596–1602.

Thu, K., Kim, Y., Amy, G., Chun, W. G., & Ng, K. C. (2013). A hybrid multi-effect distillation and adsorption cycle, *Appl. Energy 104,* 810–821.

Thu, K., Kim, Y., Amy, G., Chun, W. G., & Ng, K. C. (2014). A synergetic hybridization of adsorption cycle with the multi-effect distillation (MED). *Appl. Therm. Eng. 62,* 245–255.

Xia, Z. Z., Chen, C. J., Kiplagat, J. K., Wang, R. Z., & Hu, J. Q. (2008). Adsorption equilibrium of water on silica gel. *J. Chem. Eng. Data 53,* 2462-2465.

الملخص العربي

خصائص الامتزاز لبخار الماء على السيليكاجيل المعدل لتطبيق تحلية المياه

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الطاقة والمياه العذبة والبيئة عوامل مترابطة تتخلل جميع أنشطتنا على الأرض. لقد أصبحوا أهم الموضوعات وأكثرها شعبية في مجالات البحث في الوقت الحاضر. يدرس هذا البحث تحسين أداء نظام تحلية بالامتزاز من خلال تحسين السيليكاجيل التجاري كمادة مازة. تم استخدام المعالجة الحمضية لتنشيط السيليكاجيل. بعد ذلك ، تم تحضير مادة مازة مركبة كيميائيًا باستخدام السيليكاجيل وتشريبها في محلول كلوريد الكالسيوم. تم فحص كمية ومعدل الامتزاز لبخار الماء لكل من السيليكاجيل الخام والمعالج والمركب. تم ملائمة البيانات المعملية لـ isotherms والـ kinetics مع معادلات Dubinin-Astakhov وLDF. يدار نظام التحلية بالامتزاز بالطاقة المتجددة مثل الطاقة الشمسية. أوضحت النتائج أن السيليكاجيل/كلوريد الكالسيوم حقق قدرة امتزاز للماء تصل الي 0.95 كجم/كجم. ويلاحظ أيضًا أن نظام تحلية المياه بالامتزاز باستخدام السيليكاجيل/كلوريد الكالسيوم توفر إنتاجًا يوميًا من المياه بنسبة 70 ٪ أعلى من نظام تحلية المياه بالامتزاز باستخدام السيليكاجيل الخام.