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Dynamic Simulation of the Impact of Silica Gel and Water Working Pairs on the Performance Characteristics of Adsorption Refrigeration Systems

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Abstract

Research on working pairs is essential for understanding the performance of adsorption refrigeration systems. This study aims to investigate the characteristics of two types of silica gels, RD and A, with respect to their capacity and rate of adsorption and desorption of water vapor. A modeling approach that integrates experimental results was used to simulate an adsorption refrigeration system, considering the properties of silica gels and boundary conditions. The simulations featured operating pressures of 2.5 kPa and a cooling temperature of 30°C for the adsorption process and operating pressures of 6.2 kPa with a heating temperature of 85°C for the desorption process. A Computational Fluid Dynamics (CFD) simulation method utilizing Toth Isotherm modeling was employed to determine the isothermal characteristics, while Linear Driving Force (LDF) modeling was used to assess the kinetic characteristics. The simulation results indicate that silica gel type RD has higher adsorption and desorption capacities than silica gel type A when interacting with water. After 100 seconds in the transient phase, type RD reached an adsorption capacity of 0.1741 kg/kg, while type A achieved only 0.1256 kg/kg. By the end of the process, type RD's adsorption capacity increased to 0.2127 kg/kg, whereas type A's capacity reached 0.1422 kg/kg. During the desorption process, type RD also exhibited higher desorption capacities at every stage. After 100 seconds, type RD recorded a desorption capacity of 0.0517 kg/kg, while type A reached only 0.0370 kg/kg. At saturation, the desorption value for type RD was 0.0474 kg/kg, in contrast to type A's value of 0.0334 kg/kg.

Keywords
Adsorption, Silica Gel, Uptake, CFD Simulation, 2D-axisymmetric

1. Introduction

Currently, there is an increasing global demand for residential cooling. Estimates indicate that electricity consumption for cooling will rise from 300 terawatt-hours (TWh) in 2000 to 4000 TWh by 2050 (Jakubcionis and Carlsson, 2017). Research by Sustainable Energy Development shows that buildings in the United States allocate approximately 33% of their electricity consumption to heating, ventilation, and air conditioning (HVAC) systems for cooling (Wang et al., 2014). These HVAC systems often rely on refrigerants such as chlorofluorocarbons (CFCs) (Hernandez and Fumo, 2020) and hydrochlorofluorocarbons (HCFCs) (マージア 2018). These synthetic substances have significant potential to contribute to global warming and deplete the ozone layer (Ugale and Pitale, 2015). Considering the ongoing energy crisis and the increasing energy consumption from HVAC systems, it is crucial to address the use of refrigerants that negatively impact the environment (You and Wang, 2023). To tackle the energy crisis effectively, we must adopt cooling systems that utilize renewable energy sources (Lund, 2007). One promising alternative is the Adsorption Refrigeration System (ARS), which can operate using low-grade heat sources (Wang et al., 2010). The technology serves as an alternative method to enhance energy efficiency in cooling systems (Henninger et al. 2017). The Adsorption Refrigeration System (ARS) employs green refrigerant technology (Satheeshkumar and Selwynraj 2023) by utilizing working pairs that capture low-grade thermal energy. One of its key advantages is that it has no ozone-depleting potential (ODP) and no global warming potential (GWP) (Satheeshkumar and Selwynraj 2023; Xu et al. 2021). ARS can serve as a substitute for traditional HVAC cooling systems (Mostafa et al. 2022) by utilizing adsorption and desorption processes (Sapienza et al. 2012). These phenomena occur due to Van der Waals forces between the molecules of the working pairs (adsorbate and adsorbent) on the surface of the adsorbent material (Elsheniti et al. 2018). The efficiency of the working pair in the ARS significantly affects the heat and mass transfer characteristics within the adsorber bed (Albaik et al. 2022). Working pairs play a crucial role in the adsorption refrigeration cycle and have various characteristics, including thermodynamic and chemical properties, physical properties, cost, and availability (Askalany et al. 2013). To improve the efficiency of adsorption refrigeration systems (ARS), it is essential to select the working pairs carefully based on the operating temperature and the cycle utilized. There are five main working pairs used in ARS systems: activated carbon with ammonia, activated carbon with methanol, activated carbon with ethanol, silica gel with water, and zeolite with water. Recently, research focusing on the combination of silica gel and water has increased, largely due to the advantage of utilizing relatively low-grade heat energy. The typical temperature range for adsorption cooling using silica gel and water is between 30°C and 80°C (Madhuri et al. 2023; Ng et al. 2001; Manila et al. 2020). Operating silica gel and water at temperatures above 120°C can lead to a decrease in the adsorption system's effectiveness (Ntsoane et al. 2019). Silica gel offers several advantages that make it a valuable material for various applications. These advantages include cost-effectiveness (Grande et al. 2020), availability as a naturally occurring substance (Sillanpaa and Bhatnagar 2015), the capability for regeneration at low temperatures, a high-water adsorption capacity (Najeh et al. 2016), and resistance to degradation (Xu et al. 2022). In particular, Adsorption Refrigeration Systems (ARS) make use of high-density silica gel. For clarity, we are considering two types of silica gel: Type A and RD. These types exhibit pore diameters ranging from 2.0 to 3.5 nm, pore volumes of 0.3 to 0.4 cm^3/g, and specific surface areas between 400 and 700 m^2/g (Elsheniti et al. 2018). Additionally, Ansys Fluent is capable of performing computational fluid dynamics (CFD) simulations to evaluate and compare the adsorption efficiencies of Type A and RD silica gels (Chua et al. 2002).

1.1 Objectives

This study aims to thoroughly investigate the impact of using silica gel and water as working pairs on the adsorption characteristics within an adsorption refrigeration system that features a finned tube adsorber. The focus will be on key aspects such as adsorption uptake and kinetics, while also evaluating how these working pairs affect the temperature distribution across the fins in the system.

2. Literature Review

A refrigeration system is a process that transfers heat from a region with a lower temperature to one with a relatively higher temperature (Kayode, 2015). These systems are commonly used in both industrial and household settings for purposes such as food preservation, air conditioning, medical cooling containers, and cooling electronic components that generate heat during operation (Ibrahim and Mehmet, 2010). Most refrigeration systems currently in use are conventional types. However, they account for approximately 30% of global energy consumption (Rodriguez and Belman, 2014). This significant energy usage highlights the need for refrigeration systems that utilize renewable energy sources to help address the ongoing energy crisis (Lund, 2007).

Several researchers have conducted studies on adsorption refrigeration systems (ARS) using various methods and parameters. ARS is an environmentally friendly cooling technology that can be powered by low-grade thermal energy (Wang and Vineyard, 2011). In a research review by Zhang et al. (2020), it was explained that the choice of working pairs (adsorbent-adsorbate) is crucial for improving the coefficient of performance (COP) of the system. The review also highlighted the broad prospects and potential applications of ARS, although its COP remains lower than that of conventional refrigeration systems. According to Choi and Mills (1990), ARS faces challenges related to mass and heat transfer rates, which significantly affect the cycle time.

Various studies and innovations to enhance ARS performance continue to develop. In the review article by Ugale & Pitale (2015), it was explained that the selection of working pairs depends on the availability of heat source temperature and its application. Additionally, cycle time and adsorption rate are factors influencing the performance of adsorption systems. Saha et al. (2003), through experimental methods, demonstrated that the use of silica gel as a working pair can effectively be applied with hot water ranging from 40°C to 95°C as the heat source for the regeneration process. In the study by Xu et al. (2021), cooling was achieved with cooling water at 25.5°C. Askalany et al. (2013) stated that silica gel material has pore sizes of 2.3 nm (type A) and 0.7 nm (type B), with a specific surface area ranging from 100 to 1,000 m²/g. In the experiments by Pan et al. (2019), using silica gel and water as working pairs with hot water at 85.1°C resulted in outlet cooling water temperature, cooling capacity, heat rejection power, and COP of 39.9°C, 3.98 kW, 9.21 kW, and 0.632, respectively. In a comparison between silica gel and activated carbon as adsorbents, Sah et al. (2015) concluded that silica gel as an adsorbent provides a higher COP compared to activated carbon. Using computational fluid dynamics (CFD) simulation in Ansys Fluent, Jibri et al. (2017) investigated the performance of an adsorption cooling system using activated carbon and ethanol as working pairs. The results showed that the adsorbent temperature from the simulation aligned with experimental data over longer flow times. Additionally, there was a pressure drop with increasing adsorbent thickness due to viscous and inertial losses. In selecting the heat exchanger type for adsorber bed modification, Sharafian and Bahrami (2014) revealed that the finned tube heat exchanger has the best performance for adsorption refrigeration systems. Furthermore, Yaïci and Entchev (2019) conducted a CFD simulation of an adsorption cooling system with finned tube geometry and silica gel-water as working pairs. The results indicated that smaller silica gel particle diameters increase adsorption capacity. This finding aligns with the study by Jibri et al. (2017), which conducted simulations with a finned tube geometry, though it was limited to activated carbon and ethanol as working pairs. Based on these studies, similar research was conducted by varying two types of silica gel in an adsorber bed with finned tube geometry.

3. Methods

3.1 CFD Model

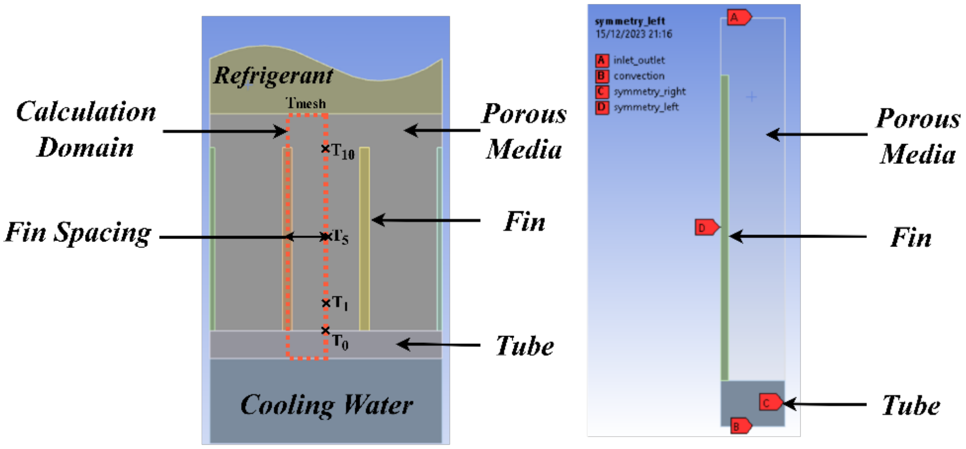


Figure 1. Simulation Domain

Figure 1 illustrates the application of a finned tube adsorber bed domain in the simulation, employing a 2D-axisymmetric model that replicates the approach described by Jribi et al. (2017). This study involved simulating the heat and mass transfer that transpires when water absorbs into silica gel. We performed the simulation using the Ansys Workbench 2022 R1 software. Fluent utilizes a mathematical framework that combines adsorption isotherm equations and adsorption kinetics equations with the conservation equations for mass, energy, and momentum.

3.2 Geometry

The silica gel is contained within a finned tube heat exchanger that is 700 mm in length, characterized by fins attached to its tubes. This heat exchanger is enveloped by mesh and a protective casing. The dimensions of the fins—including thickness, spacing, and height—along with the inner and outer diameters of the tube, are as follows: 0.53 mm (thickness), 3.7 mm (spacing), 10 mm (height), 26 mm (inner diameter), 29 mm (outer diameter), and 52.7 mm (additional relevant dimension). Cooling air circulates within the tube, while the heat exchanger is surrounded by ambient air, as demonstrated in Figure 1. Temperature measurements of the adsorbent are collected at designated points, referred to as T, located at heights of 0 mm, 1 mm, 5 mm, and 10 mm, which correspond to half the length of the adsorber. These T points will be utilized for subsequent comparisons with the findings of the study conducted by Jribi et al. (2017). The existence of a symmetry plane confines the computational domain to half of the area between two fins.

3.3 Meshing

The meshing process was conducted with an element size of 0.265 mm. The simulation domain was divided into 357 elements and 474 nodes, utilizing a soft behavior setting. The results obtained showed an orthogonal quality of 0.999583 and an orthogonal skew of 4.16891×10^{-4}. A quadrilateral dominant meshing approach was selected due to its superior accuracy and stability. The domain area was divided into solid and fluid regions, where the solid area included the fin and tube components, and the fluid area represented the refrigerant within the porous media.

4. Data Collection

4.1 Materials and porous zone properties

The materials used in the simulation include copper for the fin and tube components, air as the gas phase, and silica gel types A and RD as the solid materials in the porous zone. The properties of copper were sourced from the Fluent database. The characteristics of real gas air were obtained from the NIST Refprop database, which is embedded in Ansys Fluent. The properties of silica gel types A and RD were referenced from the research conducted by Chua et al. (2002), as presented in Table 1 below.

Table 1. Properties of Silica Gel

Properties	Symbol	Value Silica Gel A	Value Silica Gel RD	Unit
Pore size	-	0,8 - 5	0,8 – 7,5	*nm*
Porous volume	ν_μ	0,28	0,37	$cm^{-3}g^{-1}$
Particle bulk density	-	1.306	1.158	$kg\ m^{-3}$
Surface area	-	650	720	$m^2\ g^{-1}$
Average pore diameter	D_p	2,2	2,2	nm
Apparent density	ρ_a	730	700	$kg\ m^{-3}$
Skeletal density	ρ_s	2027	2027	$kg\ m^{-3}$
Spesific heat capacity	$C_{p,s}$	0,921	0,921	$kJ\ kg^{-1}\ K^{-1}$
Thermal conductivity	K_p	0,174	0,198	$W\ m^{-1}\ K^{-1}$
Porosity		0,645427	0,654403	-
Pre-exponential constant	K_0	$(4{,}65 \pm 0{,}9) \times 10^{-10}$	$(7{,}30 \pm 2) \times 10^{-10}$	$kg\ kg^{-1}\ kPa^{-1}$
Isosteric enthalpies of adsorption	Δ_{ads} H	$(2{,}71 \pm 0{,}1) \times 10^3$	$(2{,}693 \pm 0{,}1) \times 10^3$	$kJ\ kg^{-1}$
Toth constant	t	10	12	-
Monolayer capacity	q_m	0,4	0,45	$kg\ kg^{-1}$

The material's porosity values are derived from Equation (1) according to the research conducted by Jribi et al. (2017).

$$\gamma = 1 - \frac{\rho_a}{\rho_s} - \nu_\mu \rho_a \tag{1}$$

4.2 Correlation of adsorbent-adsorbate mass transfer

The rate at which water is adsorbed onto silica gel can be determined by analyzing experimental data using three different approaches: the linear driving force (LDF) method described in Equation (2), the Arrhenius equation presented in Equation (3), and Toth's isothermal adsorption model outlined in Equation (4).

$$\frac{dq}{dt} = k(q^* - q) \tag{2}$$

$$k \;= A\, exp\left(-\frac{E_a}{RT}\right) \tag{3}$$

$$q^* = \frac{K_0\, exp\left(\frac{\Delta_{ads}H}{RT}\right)P_1}{\left\{1+\left[\frac{K_0}{q_m}exp\left(\frac{\Delta_{ads}H}{RT}\right)P_1\right]^t\right\}^{\frac{1}{t}}} \tag{4}$$

Where k is the diffusion time constant, A is the pre-exponential factor, E_a is the activation energy of silica gel, R is the ideal gas constant, T is the equilibrium temperature of the adsorbate in the gas phase, P_1 is the equilibrium pressure of the adsorbate in the gas phase. The variables K_0, $\Delta_{ads}H$, q_m, and *t* are constant variables in the material properties, as indicated in Table 1.

4.3 The equation of mass conservation

The equation (5) is used to describe the conservation of mass in porous media.

$$\frac{\partial(\gamma\rho_g)}{\partial t} + \nabla\,.\left(\rho_g\vec{v}\right) = S_m \tag{5}$$

Where γ represents porosity, ρ_g denotes gas density, and S_m represents the amount of gas mass absorbed by the porous material, as described in the following Equation (6).

$$S_m = -(1-\gamma)\rho_p\frac{dq}{dt} \tag{6}$$

Where ρ_p represents the density of the adsorbent particles and $\frac{dq}{dt}$ represents the LDF equation as given in equation (2).

4.4 The equation of energy conservation

Considering the equilibrium between solid and fluid in a porous medium, the conservation of energy equation is formulated in the following Equation (7).

$$\frac{\partial}{\partial t}\left[\gamma\rho_g E_g + (1-\gamma)\rho_p E_s\right] + \nabla\left[\vec{v}\left(\rho_g E_g + p\right)\right] = \nabla.\left(k_{eff}\nabla T\right) - \nabla\,.\sum_j h_j\vec{J}_j + \nabla.\left(\bar{\bar{\tau}}.\vec{v}\right) + S_h \tag{7}$$

Where *E* represents the energy calculated by $E = h - \frac{p}{\rho} + \frac{v^2}{2}$, and *h* represents the enthalpy formulated as $\int_{T_{ref}}^{T} C_P\, dT$. Meanwhile, S_h is the heat source associated with the addition of heat to the porous zone through the process of adsorption, as defined in Equation (8) below.

$$S_h = -(1-\gamma)\rho_p Q_{st}\frac{dq}{dt}Q_{st}S_m \tag{8}$$

Q_{st} represents the heat of adsorption. Ansys Fluent utilizes User Defined Functions (UDFs) to implement both heat source (S_h) and mass source (S_m).

4.5 The equation of momentum conservation in porous medium

In the equation of momentum conservation, the momentum source (F) is calculated based on the losses of viscosity and inertia in a homogeneous porous medium. The value of F can be calculated using the following Equations (9) and (10).

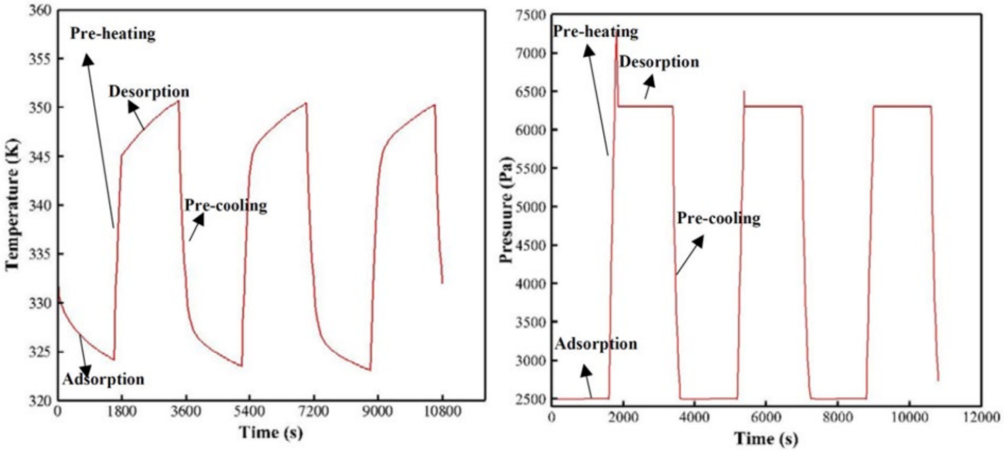
$$\frac{\partial}{\partial t}\left(\rho_g\vec{v}\right) + \nabla.\left(\rho_g\vec{v}\vec{v}\right) = -\nabla p + \nabla.\bar{\bar{\tau}} + \rho_g\vec{g} + \vec{F} \tag{9}$$

$$F_1 = -\frac{\mu}{\alpha}v_i - \frac{1}{2}\rho_g C|\vec{v}|v_i \tag{10}$$

The governing equations in sections 2.3 to 2.6 are utilized for conducting simulations in the Ansys Fluent program.

4.6 Boundary conditions

In order to establish suitable inlet/outlet boundary conditions for the working pairs that are used, researchers use graphs illustrating the correlation between temperature and time, as well as pressure and time, as depicted in Figure 2 below, in accordance with the investigation completed by Manila et al. (2020).



(a) (b)

Figure 2. (a) temperatur adsorber bed, (b) pressure adsorber bed

Table 2 presents the values of the operating conditions that will be used in the Ansys Fluent simulation to complete the adsorption and desorption processes.

Table 2. Operating conditions

Parameter	Value
Evaporator Pressure (P_{evap})	2500 Pa
Initial bed temperature (T_{bed})	333 K
Water cooling temperature (T_{cold})	303 K
Water heating temperature (T_{hot})	358 K
Condenser temperature (T_{cond})	309 K
Condenser pressure (P_{cond})	6230 Pa

5. Results and Discussion

5.1 Validation

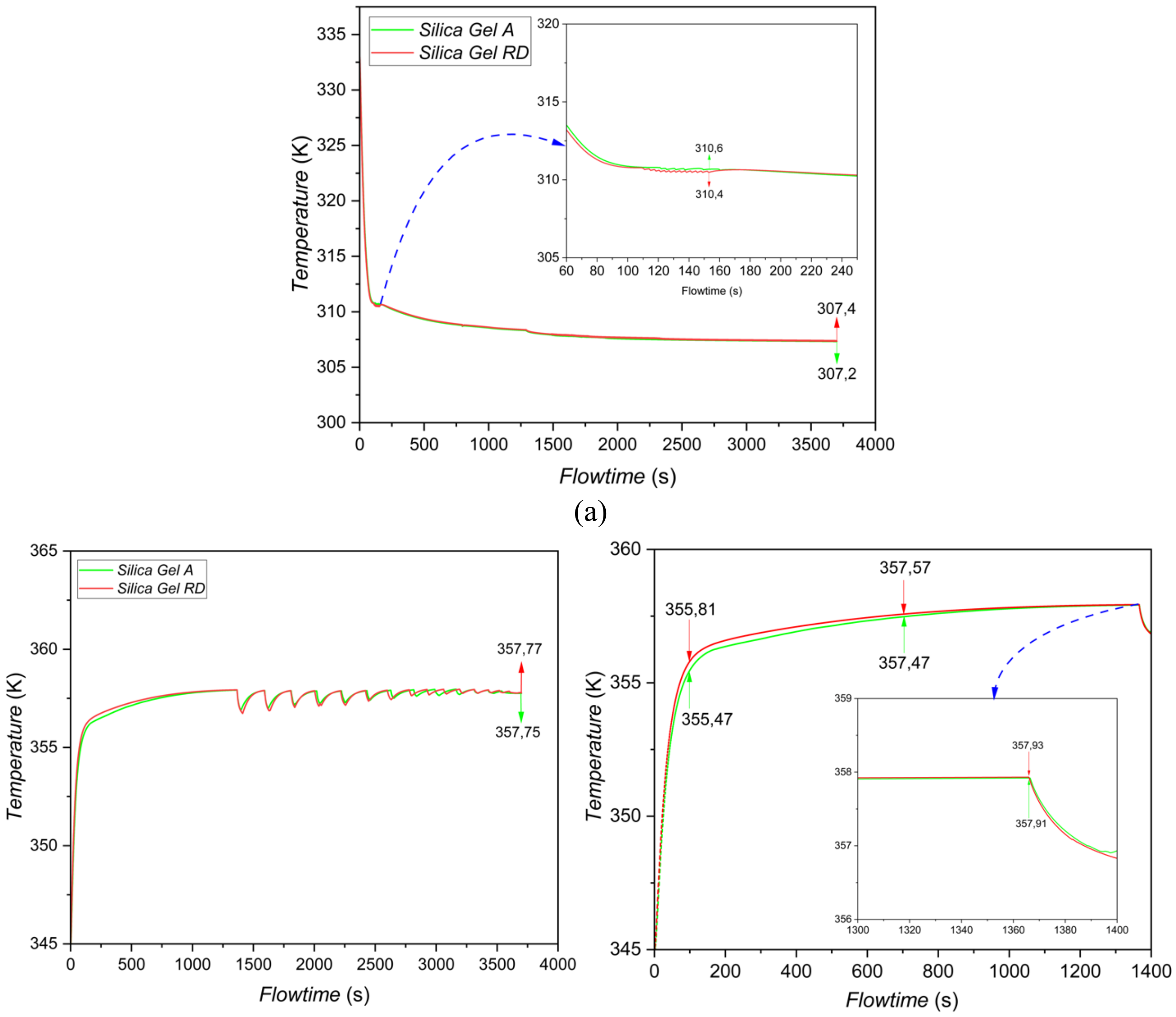
To compare validation data, temperature data needs to be collected from three points on the geometric model as shown in Figure 1. These points are referred to as T_0, T_1, and T_5. The validation results are displayed in Table 3.

Table 3. Validation results

Adsorben Thickness	Simulation Data Jribi *et al.* (2017).		Researcher Data Simulation		Eror (%)
	Time (s)	Temperature (Celcius)	Time (s)	Temperature (Celcius)	
0	84	48.8	84	49	0.413
1	80	52.2	80	52.53	0.632
5	76	54	76	54.27	0.518
Average					0.521

5.2 Temperature and pressure

The results of the simulation show that both working pairs achieve the same equilibrium temperature. Figure 3 below shows the graph of temperature as a function of time.



(a)

(b)

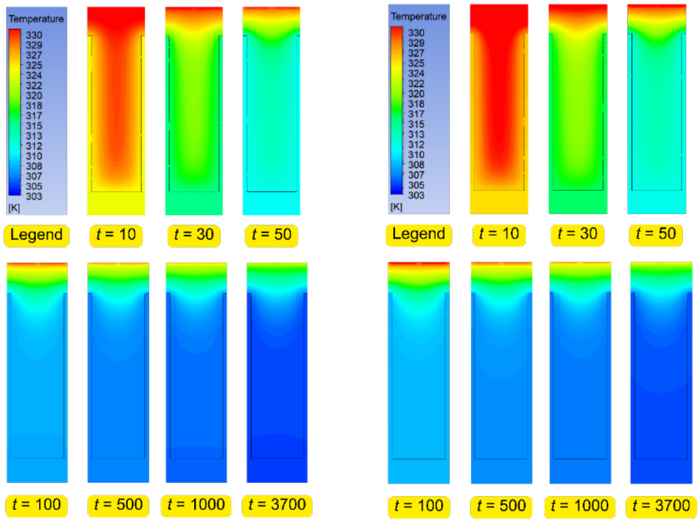
(c)

Figure 3. Temperature adsorbent, (a) at adsorption from 0 to 3700s, (b) at desorption from 0 s to 3700 s, (c) at desorption from 0 s to 1400 s

In the initial phase, there is a significant temperature change that is followed by a gradual stabilization towards the end. The significant temperature change is referred to as the transient phase, while the gradual stabilization of temperature is known as the saturation phase.

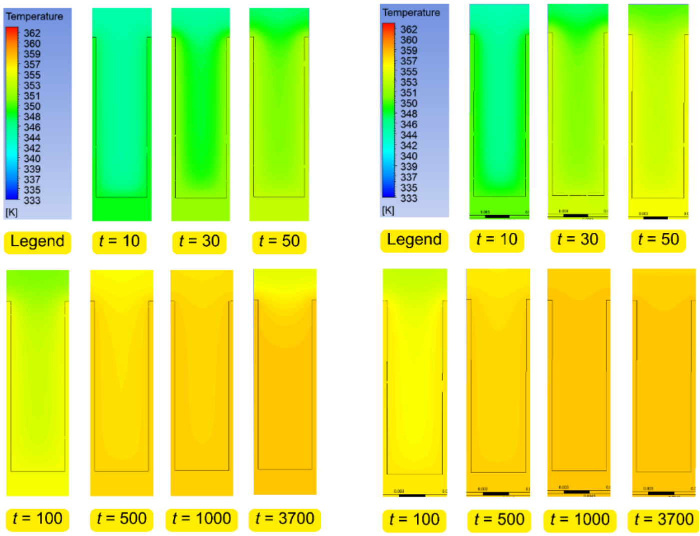
During the adsorption process in the transient phase, silica gel of type RD exhibits a lower temperature compared to type A. This transient phase lasts from 333 K to 310.6 K for type A and from 333 K to 310.4 K for type RD, with a duration of 157 seconds. The saturation phase begins at 158 seconds. During this phase, the temperature of silica gel type A is notably lower than that of type RD. At the end of the cycle, the temperature of silica gel type A is 307.2 K, whereas type RD has a temperature of 307.4 K.

During the desorption process, silica gel type RD demonstrates a higher temperature compared to type A in the transient phase (Figure 4). Over a 100-second interval, type A's temperature increases from 345 K to 355.4 K, while type RD's temperature rises from 345 K to 355.8 K. By the conclusion of the cycle, specifically at 3700 seconds, the temperatures of both silica gel types are nearly identical, measured at 357.77 K for type RD and 357.75 K for type A. Figure 5 provides a visual representation of the temperature distribution among the adsorbents.



(a) (b)

Figure 4. Adsorption temperature distribution in the domain for, (a) silica gel A, (b) silica gel RD



(a) (b)

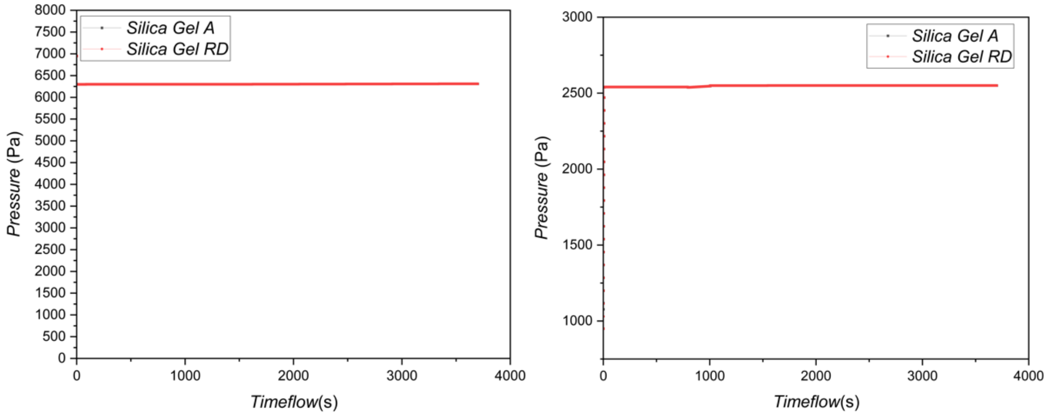
Figure 5. Desorption temperature distribution in the domain for, (a) silica gel A, (b) silica gel RD

In both working pairs, silica gel type RD has the highest average temperature of 328.65 K, which is higher than that of silica gel type A, which is 328.39 K, observed at a flow time of 10 seconds. This indicates that silica gel type A cools slightly faster, by 0.0791%, at the beginning of the adsorption process. By the end of the process, at a flow time of 3700 seconds, silica gel type A reaches the lowest average temperature of 307.34 K, which is marginally lower than the temperature of silica gel type RD, recorded at 307.36 K. The temperature difference between the two types is only 0.0065%.

During the desorption process, silica gel type RD has the highest average temperature at 345.85 K, surpassing type A, which reaches an average temperature of 345.54 K after 10 seconds of flow time. This indicates that silica gel type RD has a 0.0897% higher rate of heat absorption during the transient phase of the desorption process. At 3700 seconds, silica gel type RD achieves its maximum average temperature of 357.79 K, slightly higher than type A, which reaches 357.77 K. The temperature difference between the two is only 0.0055%.

A heat transfer tube filled with cooling water at 303.15 K is located at the lower part of the modeling domain, as shown in Figure 1. During the desorption process, this tube contains water at a temperature of 358 K. The upper part of the domain is bounded by the adsorbate in the vapor phase, which acts as both the temperature inlet and the adiabatic pressure inlet. For the adsorption process, the initial temperature of the adsorbent is set to 333 K, while for desorption, it is set to 345 K. At time t = 0, the cooling water begins to cool the adsorber bed, initiating the adsorption process. Conversely, heated water warms the adsorber bed, starting the desorption process. Fins positioned between the right and left sides of the adsorber bed facilitate heat transfer from the adsorbent to the tube. This heat transfer creates temperature gradients that persist for up to 3700 seconds.

The pressure within the domain is approximately uniform, attributable to the consistent values observed in the pressure inlet profile. Figure 6, presented below, illustrates the average pressure of the adsorbent.



(a) (b)

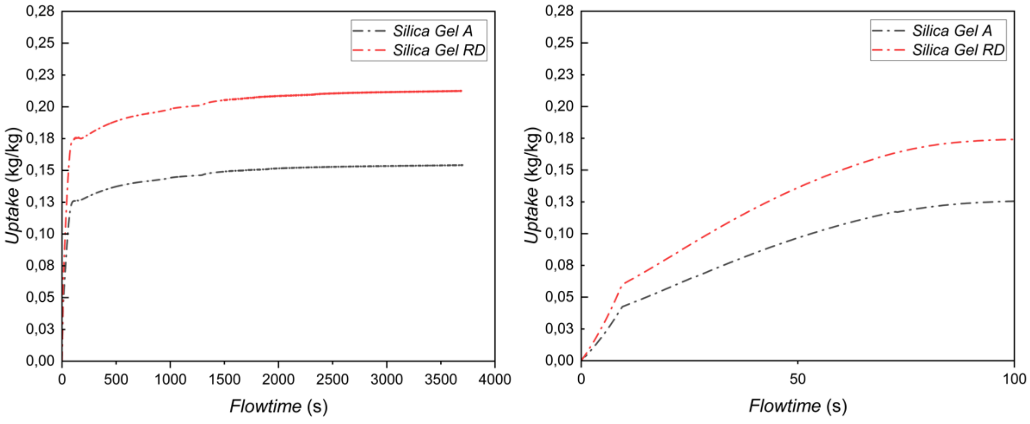
Figure 6. Pressure profile, (a) adsorption process, (b) desorption process

According to Figure 6, the pressure inlet boundary condition is consistent with the findings of Manila et al. (2020), as shown in Figure 2. As a result, the operating conditions during the simulation have been adjusted to align with the experimental research involving silica gel and water as working pairs.

During the adsorption process, heat is released from the adsorbent to the heat transfer fluid (HTF) within the tubes, leading to a decrease in the temperature of the adsorbent. In contrast, during the desorption process, the adsorbent absorbs heat from the HTF, causing the temperature to increase and the release of the adsorbate. Variations in the working pairs influence the rate of heat release, resulting in different temperature contours. However, switching between silica gel types A and RD as working pairs does not significantly affect the pressure changes within the simulation domain.

5.3 Mass Transfer

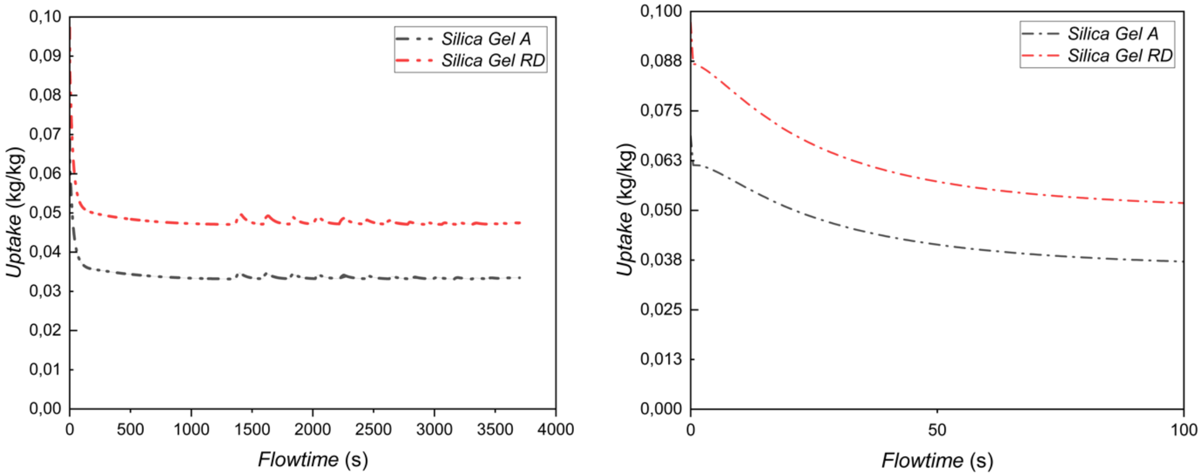
During the adsorption process, mass transfer takes place from the fluid to the porous material. In this study, silica gel is used to absorb water. Figure 7 below illustrates the capability of the adsorption process.



(a) (b)

Figure 7. Adsorption uptake at flowtime 0 to (a) 3700 s (b) 100 s

The adsorption capacity curve can be divided into two distinct segments: the transient phase and the saturated vapor phase. The transient phase occurs between 0 seconds and 100 seconds, while the interval from 100 seconds to 3700 seconds represents conditions that are close to saturation. During the transient phase, which is the initial rapid adsorption period, the mass transfer rate is high due to the significant difference in vapor pressure between the silica gel and the surrounding water vapor. In contrast, the saturation phase (or near-saturation phase) is characterized by a gradual approach to equilibrium, where the adsorption rate decreases as the silica gel nears its maximum capacity. For the working pair of silica gel type A with water, the adsorption capacity reaches 0.1256 kg/kg at the end of the transient phase (after 100 seconds) and increases to 0.1422 kg/kg by the end of the adsorption process. In the case of the working pair of silica gel type RD with water, the adsorption capacity reaches 0.1741 kg/kg at the end of the transient phase (after 100 seconds) and increases to 0.2127 kg/kg by the end of the desorption process.



(a) (b)

Figure 8. Desorption uptake at flowtime 0 to (a) 3700 s (b) 100 s

Figure 8 illustrate the desorption outcomes for silica gel type RD, which demonstrate superior values in comparison to type A. Initially, silica gel type A presents a desorption capacity of 0.0687 kg/kg, whereas type RD exhibits a capacity of 0.0972 kg/kg. At the conclusion of the transient phase, which occurs at 100 seconds, type A attains a desorption capacity of 0.0370 kg/kg, while type RD achieves 0.0517 kg/kg. By the end of the saturation phase, at 3700 seconds, type A reports a capacity of 0.0334 kg/kg, and type RD records a capacity of 0.0474 kg/kg.

6. Conclusion

The researchers emphasized the key characteristics of silica gel types A and RD as adsorbents during isothermal and kinetic adsorption and desorption operations conducted at cooling temperatures of 303.15 K and heating temperatures of 358 K. They found that the adsorption and desorption capacities of silica gel type RD with water are greater than those of silica gel type A. After 100 seconds, the adsorption capacity of type RD is 0.1741 kg/kg, while type A achieves only 0.1256 kg/kg. By the end of the process, the adsorption capacity of type RD increases to 0.2127 kg/kg, whereas type A only reaches 0.1422 kg/kg. Throughout the desorption process, type RD consistently exhibits a higher desorption capacity. At the end of the transient phase, after 100 seconds, the desorption capacity of type RD is 0.0517 kg/kg, compared to type A, which achieves only 0.0370 kg/kg. By the end of the saturation phase, type RD shows a desorption value of 0.0474 kg/kg, while type A has only 0.0334 kg/kg. Additionally, the optimal cycle time for using silica gel types A and RD with water is limited to just 2000 seconds.

In terms of temperature distribution, silica gel type A is more effective in cooling compared to type RD, although the difference is minimal. Variations in the working pairs between silica gel types A and RD do not significantly impact temperature and pressure changes. Additionally, the isothermal characteristics of the silica gel used greatly influence adsorption performance, as indicated by adsorption and desorption capabilities. When considering the properties of the adsorbent material, higher porous volume values are associated with improved adsorption capabilities. However, the results of this study cannot be fully generalized to different working conditions without specific adjustments. The characteristics of adsorption and desorption are significantly influenced by factors such as temperature, pressure, working pairs, and cycle time. Therefore, to apply these findings to other scenarios, further simulations or experimental validations are needed to ensure accuracy under different working conditions.

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