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NOVEL COMPOSITE ADSORBENTS TO ENHANCE HEAT AND MASS TRANSFER IN ADSORPTION COOLING AND DESALINATION SYSTEMS

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1. ABSTRACT

Graphene nanoplatelets (GNPs) with high thermal diffusivity have demonstrated the ability to enhance the thermal characteristics of adsorbents, while ionic liquids (ILs) with hydrophilic properties have exhibited notable sorption and thermal attributes. This research endeavours to explore a novel composite adsorbent incorporating a combination of few-layered GNP and IL variants, specifically ethyl-methylimidazolium methane sulfonate (EMIMCH3SO3) and ethyl-methylimidazolium chloride (EMIMCl), along with the binder polyvinyl alcohol (PVA) to create composites denoted as GP-CL-30 and GP-CH3SO3-30, CP1 to CP9, each containing 30% IL content. These composites are to be compared against the benchmark adsorbent silica gel. The hypothesis is that by leveraging the superior thermal properties of GNP and the stability and solvation characteristics of ILs, the water production and cooling efficiency in adsorption-based cooling and desalination processes can be enhanced. Initial findings have shown a substantial enhancement in thermal diffusivity of the composites by 167%, which is 76 times higher than that of silica gel, along with increased water uptake of 0.9648 kg/kg compared to 0.3534 kg/kg for silica gel.

2. INTRODUCTION

An approach utilized to enhance the effectiveness of adsorption systems involves optimizing heat and mass transfer within the adsorbent bed by creating composites that incorporate thermal conductivity enhancers (TCEs) and binders [1, 2]. Binders play a crucial role in consolidating the composites, leading to improved packing density and thermal properties [2] While significant advancements have been made in enhancing the thermal properties of various consolidated composites comprising different additives and traditional adsorbents, limited research has been conducted on composites consolidated with ionic liquids (ILs), graphene nanoplatelets (GNPs), and binders. The objective of this study is to: (1) Develop composites consolidated with GP/IL and PVA binders; (2) Experimentally analyse the thermal and adsorption characteristics of the developed consolidated composites; (3) Investigate the influence of PVA binder concentrations of 2%, 5%, and 10%, as well as compression pressures of 1, 1.5, and 2 MPa, on the thermal and adsorption capacities of the composites.

3. METHODOLOGY

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The composite adsorbents were prepared utilizing the impregnation method, which entails creating a uniform blend by physically combining all constituent materials of the composites. Subsequently, the composites were compacted in a Mold to produce tablet or pellet forms. The adsorption characteristics were assessed employing a dynamic vapor sorption (DVS) analyser using the gravimetric technique, whereas thermal diffusivity was determined using the Laser Flash Analysis (LFA) method. To model the experimental adsorption isotherms, the Dubinin-Astakhov (D-A) model was employed. This model was selected due to its capacity to linearize adsorption data across various pressure levels, accurately correlating equilibrium pressure with the quantity of adsorbate absorbed by the composites throughout the micropore filling range. The utilization of the D-A model enabled the comprehensive description of the micropore structure, with the parameter n exponent offering insights into the nature of the isotherms.

4. RESULTS

The findings indicate that all composite materials exhibited superior thermal diffusivity relative to SG. Notably, the highest thermal diffusivity value of 4.652 mm2 observed in GP-Cl-30-CP7, manufactured under a synthesis condition of 2 MPa and 2% PVA content, can be attributed to the minimal void spaces resulting from compression, leading to decreased porosity and enhanced particle contact, thereby facilitating efficient heat conduction. This observation aligns with the conclusions drawn by Wu et al.[3] in their study of composite bricks made from silica gel and copper nano powder and PVA binder that compression close intraparticle space and improve contact area increasing the heat transfer Conversely, a lower binder concentration of 2% presents reduced resistance to heat transfer compared to higher concentrations, enabling a quicker propagation of heat throughout the composite material. The thermal examination outcomes for the composites can be found in Table 1.

Table 1: Thermal properties and composition of the developed composites

Composite name	Thermal diffusivity ($10^{-6}m^2/s$)	Composite name	Thermal diffusivity ($10^{-6}m^2/s$))	PVA concentration (%)	Compression Pressure (MPa0
GP-CL-30-CP1	3.679	GP- CH_3SO_3-30-CP 1	3.517	2	1
GP-CL-30-CP2	3.479	GP- CH_3SO_3-30-CP 2	3.052	5	1
GP-CL-30-CP3	2.734	GP- CH_3SO_3-30-CP 3	2.073	10	1
GP-CL-30-CP4	3.694	GP- CH_3SO_3-30-CP 4	3.582	2	1.5
GP-CL-30-CP5	3.54	GP- CH_3SO_3-30-CP 5	3.475	5	1.5
GP-CL-30-CP6	3.362	GP- CH_3SO_3-30-CP 6	2.482	10	1.5
GP-CL-30-CP7	4.652	GP- CH_3SO_3-30- CP 7	4.431	2	2
GP-CL-30-CP8	3.922	GP- CH_3SO_3-30- CP 8	3.895	5	2
GP-CL-30-CP9	3.779	GP- CH_3SO_3-30 -CP 9	3.619	10	2
Silica gel	0.365	Silica gel [4]	0.312	-	-

Figure 1 shows the water uptake for the developed composites and SG. The results showed that the water uptake for all the composites was higher compared to silica gel with the GP-Cl-30-CP1 developed with at 2% PVA and 1 MPa, achieving the highest water uptake of 0.9648 kg/ compared 0.3534 kg/kg for SG. The higher water uptake in composites is attributed to the presence of hydrophilic IL in the composite having high water solvation. It is worth mentioning that the lowest concentration of PVA (2%) and lowest pressure of 1MPa contributed to the high-water uptake as they did not alter the structure and properties of the composites compared to effect of high PVA concentration and compression pressure on the composite's adsorption capacity.

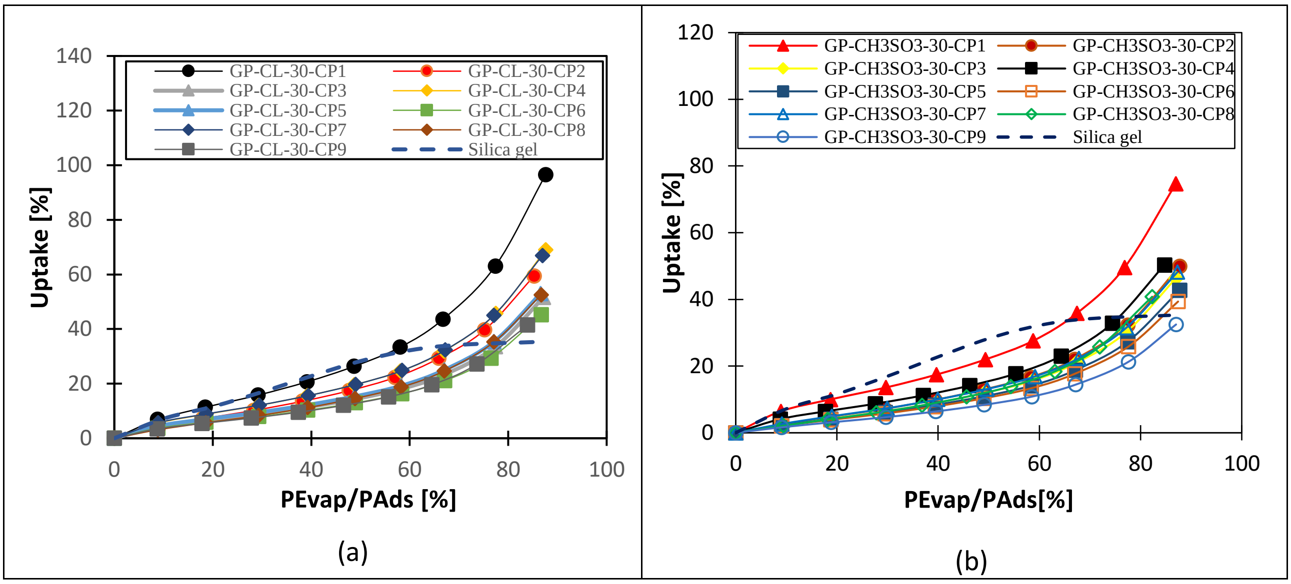

Figure 1: Equilibrium adsorption uptake for (a) GP-CL-30 and (b) GP- CH_3SO_3-30 CP1to CP9

Conclusions

The outstanding thermal diffusivity of GNP significantly improved the thermal response of the developed composite materials. In comparison to SG, all GP/IL composites exhibited notably high thermal diffusivity values. Particularly, the composite denoted as GP-CL-30-CP7, characterized by the lowest PVA concentration of 2% and the highest compression pressure of 2MPa, demonstrated the highest thermal diffusivity value of 4.65mm2/s, representing a 12.7-fold increase over SG. The presence of ILs had a considerable impact on the water absorption capacity of the composite materials, leading to higher water uptake levels compared to SG across all formulations. Specifically, the composite GP-CL-30-CP1, prepared at a compression pressure of 1 MPa and with a PVA concentration of 2%, exhibited the highest water uptake of 0.9648 kg, showcasing a 274% enhancement in water absorption relative to SG.

References

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