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The Role of h–BN on the Iodine Gas Sorption of Cu under High Humidity

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1. Introduction

The management of radioactive iodine gas I_2(g) is critical for environmental safety in nuclear engineering, particularly during the handling of spent fuel and radioisotopes. Currently, activated carbon (AC) [1] or silver-exchanged zeolites (AgZ) [2] are primarily used to capture I_2(g) during the chemical processing of iodine (I_2)-containing nuclear materials.

Recently, copper (Cu) has been identified as a promising alternative to Ag-based sorbents for I_2(g) capture due to its high affinity for I_2, cost-effectiveness, and non-toxicity. However, the impact of humidity has not yet been systematically studied, in addition to the effect of temperature on I_2(g) sorption.

In this study, we investigated the I_2(g) sorption properties of Cu particles supported by hexagonal boron nitride (h–BN) under dry and humid conditions at various temperatures. The role of h–BN in enhancing the I_2(g) sorption of Cu is discussed.

2. Experimental Procedures

Cu^0@h-BN composites were synthesized via a solvothermal reduction method, wherein Copper (II) nitrate trihydrate, h–BN powder, and ethylene glycol were thoroughly mixed and transferred in a Teflon-lined stainless-steel reaction autoclave and heated at 200°C for 24h. The synthesized composite was then vacuum-dried at 60°C for 12h.

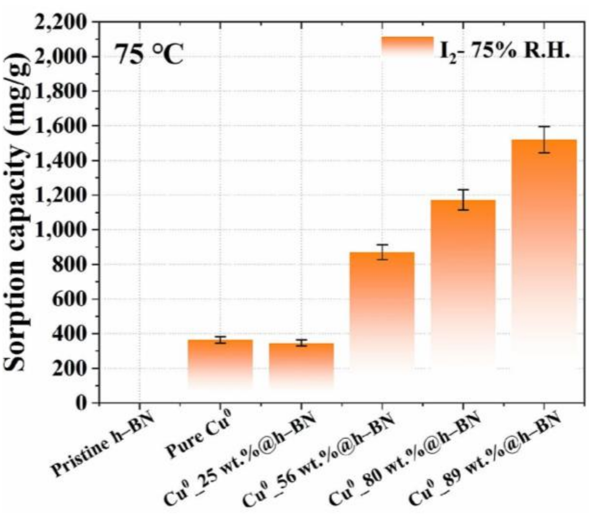
Non-radioactive solid I_2 crystals were used for the I_2(g) sorption test in a sealed desiccator, heated in an oven at temperatures ranging from 75°C to 250°C. Humidity was controlled using saturated salt solutions of NaCl and KNO_3 to maintain constant relative humidities of 75% and 85%, respectively. After 24h of exposure, the mass gain was measured once the samples cooled, and the results were compared with blank control tests carried out without I_2 exposure.

To characterize the Cu^0_x wt.%@h–BN composites, powder X-ray diffraction (PXRD), Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) in backscattered-electron (BSE) mode equipped with energy-dispersive X-ray spectroscopy (EDS), the Brunauer-Emmett-Teller (BET) method, thermo-gravimetric analysis–mass spectrometry (TG–MS), and X-ray photoelectron spectroscopy (XPS) were employed to assess their structural and thermal properties.

3. Results

Compared with pure Cu (Cu^0), Cu^0@h-BN composites exhibited reduced binding energies for the Cu 2p, B 1s, and N 1s peaks. These shifts indicate a redistribution of electron density through electron transfer at the interface of Cu and h–BN, creating additional active sites for interactions between Cu and I_2 molecules. The metal-support interaction (MSI) effect in Cu^0@h-BN composites thus plays a crucial role in enhancing both the performance and stability of the material for I_2(g) capture.

Experiments conducted at 75% and 85% relative humidity demonstrated that Cu^0@h–BN composites maintained strong I_2(g) sorption capabilities, whereas pure Cu^0 experienced a significant performance drop due to water-induced passivation. The presence of h–BN prevents excessive water sorption, thereby preserving the reactivity of Cu sites. The composite material reliably captures I_2 even at moderate temperatures below 100°C without rapid deactivation, underscoring the crucial role of h–BN in protecting Cu^0 against moisture. Furthermore, the h–BN substrate stabilizes Cu particles and promotes faster I_2(g) capture.



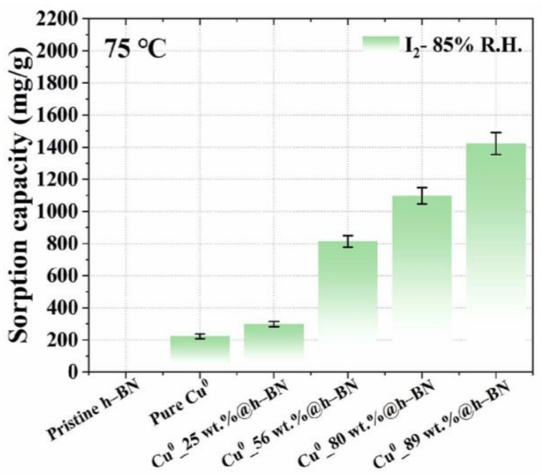


Fig. 1. The sorption performance of Cu^0@h-BN composites under humid conditions at 75% R.H. and 85%R.H.

3. Conclusions

This study demonstrates that the interactions between Cu and h–BN modify the electronic and chemical properties of the composite material. In particular, under humid conditions at moderate temperatures below 100°C, Cu^0@h-BN composites maintain stable I_2 sorption capabilities. The MSI effect within Cu^0@h-BN composites is proposed as a vital mechanism for improving the performance and stability of these materials in I_2(g) capture applications.

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