Study on novel functional activated carbon and composites for adsorption heat pump systems

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題　　名 **Title**　Study on novel functional activated carbon and composites for adsorption heat pump systems
(吸着式ヒートポンプシステムのための新規機能性活性炭および複合材料の研究)

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論 文 内 容 の 要 旨

Thesis Summary

Conventional heat pump systems are responsible for the carbon footprints from the usage of considerable amount of electricity and chemical refrigerants having ODP and high GWP. Owing to the energy crisis and imposing of international regulations on the production and use of environmentally harmful refrigerants, research on adsorption heat pump (AHP) systems have been greatly intensified worldwide. Adsorption heat pump (AHP) systems being driven by industrial waste heat or solar heat offer as a promising alternative to tackle the energy crisis and environmental issues. However, their widespread adoption is hindered by advancements in the adsorbent material.

Among the various adsorbents studied so far, activated carbon (AC) has been proven potential adsorbents for AHP applications due to its high surface area and pore volume. It is also proven that adsorption uptake of ethanol and CO_2 onto AC increases with the increase of pore volume. However, the pore volume of AC found in open literature is not promising to increase the adsorption uptake at the preferred level for its commercial dissemination. Furthermore, thermal conductivity of AC is relatively poor because of its powder form and low packing density. As a result, AHP systems are bulky and low performance which hinders for spreading this novel technology.

From the above perspective, this thesis emphases towards the development of high performance ACs from relatively cheap and renewable precursors and consolidated AC composite adsorbents. The research strongly stresses on two factors, firstly, on the synthesis and characterization of the highly porous ACs from the two precursor biomasses (waste palm trunk and mangrove). Secondly, it includes the synthesis and characterization of composite adsorbents to enhance the thermal conductivity into the adsorbent material. Finally, this thesis presents the feasibility study of newly developed promising biomass-derived ACs and composites from the viewpoint of AHPs application using ethanol and CO_2 as the refrigerants. Apart from the synthesis, characterization, and adsorption characteristics of ethanol and CO_2 onto biomass-derived ACs and AC composites, the thesis provides the equilibrium thermodynamic analysis of adsorbents/ethanol and adsorbents/CO_2 pairs for adsorption cooling

applications.

Three types of adsorbents are synthesized; i) waste biomass-derived activated carbons (ACs), ii) AC composite adsorbents using expanded graphite (EG) and graphene nanoplatelets (GNPs), and iii) AC composite using polymerized ionic liquid (PIL) as a binder. Experimental investigation on the surface characteristics including surface area, pore volume, and pore size distribution of all synthesized adsorbents have been furnished. The thermal diffusivity and conductivity of all developed adsorbents are measured and promising are selected for the measurement of adsorption characteristics. Surface morphology of studied biomass-derived ACs is also presented. Finally, the porous properties and thermal conductivity data are compared with the hitherto commercial adsorbent Maxsorb III.

Ethanol and CO_2 adsorption characteristics of biomass-derived ACs and AC composites have been carried out using a gravimetric method at adsorption temperatures ranging from 20 to 70℃ and pressures ranges corresponding to the working conditions of adsorption cooling cycle. The experimental data are modeled for CO_2 and ethanol vapor adsorption isotherm and kinetics for the comparison. The adsorption models' parameters are optimized and accordingly their sensitivity is discussed. A comparative study between the synthesized AC based adsorbents and other ACs are also presented. It is found that the biomass-derived ACs are excellent potential adsorbent than that of any other ACs so far. A theoretical analysis of an equilibrium adsorption cooling cycle employing the biomass-derived ACs and composite adsorbents/refrigerant (ethanol and CO_2) pairs is presented using a time-independent model. The comparisons of specific cooling effect and coefficient of performances under various desorption and evaporation temperatures have been presented. The calculated SCE for ethanol and CO_2 is compared with Maxsorb III.

The pore volume of biomass-derived ACs surpasses all other ACs hitherto, which makes the benchmark. It possesses the highest pore volume is 2.87 $cm^3\ g^{-1}$ whereas Maxsorb III has only 1.70 $cm^3\ g^{-1}$. WPT-AC can adsorb up to 1.9 kg ethanol vapor per kg of adsorbent and shows 35% higher than net uptake of Maxsorb III/ethanol. Furthermore, WPT-AC (WC500)/CO_2 pair shows the adsorption uptake 2.6 $cm^3\ g^{-1}$ which is also 73% improvement compared to Maxsorb III/CO_2. It is the current benchmark. Expanded graphite (EG) contained AC composite possesses 11 times whilst GNPs contained AC composite shows 23.5 higher thermal conductivity than parent AC. Polymerized ionic liquid (PIL) binder based composite has 11% and 18% higher surface area and pore volume than that of any other conventional synthetic binders based composites. WPT-AC/ethanol adsorption cycle shows 36% higher SCE whilst M-AC/ethanol pair gives about 32% higher SCE compared to Maxsorb III/ethanol. In addition, biomass-derived ACs/CO_2 pair provides about 55 to 92% higher SCE compared to Maxsorb III/CO_2.