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Automobile adsorption air-conditioning system using oil palm biomass-based activated carbon: A review

Mohammad Omar Abdullah[a,*], Ivy Ai Wei Tan[a], Leo Sing Lim[b]

[a] Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Malaysia
[b] Energy Research Group Laboratory, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Malaysia

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ABSTRACT

Refrigeration and air-conditioning technology are required to evolve in accordance to Montreal Protocol adopted in 1987 and Kyoto Protocol in 1997. This regulation concerns about the climate change in an attempt to phase-out chlorofluorocarbons (CFCs), followed by hydro-chlorofluorocarbons (HCFCs) and then moving to 1,1,1,2-tetrafluoroethane (HFC-134a) starting 2011. This trend leads to a strong demand of new systems for air-conditioning, especially in automobile. Adsorption cooling system, among other proposed cooling technologies, has a very good potential for automobile applications. Hence, there exists a need for a creative design and innovation to allow adsorption technology to be practical for air-conditioning in automobile in a near future. Oil palm shell-based activated carbon has been widely applied in various environmental pollution control technologies, mainly due to its high adsorption performance yet low cost. However, limited studies have been carried out on the characteristics and application of oil palm shell-based activated carbon in adsorption air-conditioning system. This paper is to present a comprehensive review on the past efforts in the field of adsorption air-conditioning systems for automobile. This work also aims to investigate the physicochemical properties of oil palm shell-based activated carbon and its feasibility for application in adsorption air-conditioning system. Some of the limitations are outlined and suggestions for future improvements are pointed out.

Contents

* Corresponding author. Tel.: +60 82 583280.
E-mail addresses: amomar@feng.unimas.my, amomar13@gmail.com (M.O. Abdullah).

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1. Introduction

In general, automobile air-conditioning systems are designed to provide comfort for the driver and the passengers during a journey. The conventional electrical-driven compression systems are widely used in almost all of the automobiles today. However, air-conditioning technology is required to evolve due to the new environmental regulations, notably Montreal Protocol in 1987, Kyoto Protocol in 1997 and European Commission Regulation 2037/2000. These regulations are concerning about the depletion of the ozone layer and also global warming, which decided to phase-out CFCs and followed by HCFCs and HFC-134a. As a result, this trend has led to a strong demand for a new air-conditioning technology. Among the existing air-cooling technologies, adsorption air-cooling system has good energy-saving potential. The advantages of this system are: it can be powered by using waste heat or solar, long lasting, low maintenance cost, used non-polluting refrigerants and friendly to environment [1]. Unfortunately, no working prototype has been practically run in present automobiles due to various restrictions, due to sizing and cooling capacity limitations. Adsorption refrigeration cycle powered by solar energy or waste heat exhausted from engines has been successfully used for ice making and cold production. For example, carbon–ammonia solar refrigerator for vaccine cooling [2], solar adsorption ice maker [3], silica gel–water adsorption refrigeration cycle driven by waste heat of near-ambient temperature [4], zeolite–water solar cold storage system [5] and a combined solar thermoelectric-adsorption cooling system using activated carbon–methanol working pair [6]. Based on the cited literatures, extensive research has been performed on adsorption refrigeration, but research on the possibility of applying this technology for automobile air-conditioning purposes is still rare. Therefore this review paper focuses on the adsorption system for automobile air-conditioning purpose.

Activated carbons have been tested with various adsorbates as the working pair in adsorption cooling system [7–10], however, most of the activated carbons studied were commercially available activated carbons which were synthesized from expensive and non-renewable materials. Activated carbon derived from oil palm shell has been widely used in various applications especially in environmental control technologies such as for the adsorption of methane [11], hexavalent chromium [12], copper ions [13], 4-chloroguaiacol [14], phenol [15] and treatment of landfill leachate [16]. Oil palm shell-based activated carbon has been proved to give high adsorption performance, however limited studies have been carried out on the application of this activated carbon in adsorption air-conditioning systems.

Besides, not many studies have been carried out on the physicochemical properties of activated carbon which are the most significant parameters affecting the adsorption performance and the cooling efficiency of an adsorption cooling system. Adsorption characteristics of activated carbon can be determined by the adsorption isotherms, kinetics and mechanism. It is of importance to precisely analyze the performance of an adsorption cooling system, based on an accurate determination of the adsorbent–adsorbate behaviour and on an exact understanding of the influence of operating conditions and the working pair characteristics on the performance, including the evaluation of the adsorption capacity and rate of adsorption of the activated carbon on the adsorbate [7].

2. Activated carbon

Activated carbon encompasses a broad range of amorphous carbon-based materials having high degrees of porosity and extensive surface areas. The properties of each finished activated carbon are influenced by the starting materials used and by the conditions of activation. The result is a myriad of activated carbons, each having a specific utility. The method most frequently used for preparation of activated carbon involves carbonization of the precursors at high temperature in an inert atmosphere followed by activation. There are mainly two different methods for activation, namely physical and chemical. Physical activation process comprises treatment of the char obtained from carbonization with some oxidizing gases, generally steam or carbon dioxide at high temperature. The porous structure is created due to the elimination of volatile matter during pyrolysis and the carbon on the char is removed during activation. The main function of gasification is to widen the pores, creating large mesoporosity. In chemical activation, a chemical agent is impregnated to the precursors prior to heat treatment in an inert atmosphere. The pores are developed by dehydration and oxidation reactions of the chemicals.

Activated carbons find wide applications as adsorbents, catalyst or catalyst supports. Activated carbon is one of the most important adsorbents from an industrial point of view. The main application of this adsorbent is for separation and purification of gaseous and liquid phase mixtures. In general, activated carbons can be divided into gas-adsorbing and liquid-phase carbons. The main distinction between gas-adsorbing and liquid-phase carbons lies in the pore size distribution. Basically, the structure of activated carbons containing pores are classified according to the International Union of Pure and Applied Chemistry [17] classification into three groups, micropores (pore size < 2 nm), mesopores (pore size 2–50 nm) and macropores (pore size > 50 nm). Gas-adsorbing carbons usually have the most pore volume in the micropore and macropore ranges, whereas liquid-phase carbons have significant pore volume in the mesopore or transitional pore range, permitting ready access of liquids to the micropore structure which results in rapid attainment of adsorption equilibrium for smaller adsorbates.

Activated carbons concern many industries as diverse as food processing, pharmaceuticals, chemical, petroleum, nuclear and automobile, because of their adsorptive properties due to high available surface area which is presented in their extensive internal pore structure. The high porosity of activated carbons is a function of both the precursor as well as the scheme of activation. Activated carbons are now frequently used in environmental processes for removing toxic gases and in wastewater as well as potable water treatments.