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Comparative Study of Isotherms of Activated Carbons Produced from Mango Kernels and Commercial Activated Carbons (ISO 9001:2000)

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Abstract

Waste handling and management has been a major challenge especially in the developing nations. Mango waste, with an estimated yield of 150,000 to 400,000 tons of wastes worldwide from mango processing, may cause environmental hazards. Exploring the suitability of and subsequent use of waste to replace commercial adsorbents in the area of adsorption refrigeration will address some of the waste management issues. Experimental studies of the isotherms of mango kernel activated carbons (MKAC) and that of commercial activated carbons (CAC- ISO 9001:2000) known to have suitable adsorption properties for both liquid and gas phase adsorption were carried out and compared to explore the potential of MKAC as a possible substitute. An experimental test rig was used to determine the isotherms of both MKAC- methanol and CAC- methanol refrigerant pairs. Desorption and adsorption isotherm for MKAC and CAC were determined and were observed to have same shape of curve (concave downwards). The shape of the isotherms observed from both pairs suggested the type I isotherms which are known to be highly microporous and as such suitable for gas phase adsorption. The isotherms show maximum desorption and adsorption capacities at pressure ranges of 2.5- 3.0 bar and 0.230- 0.240 bar respectively for MKAC and 2.7- 3.0 bar and 0.227 - 0.229 bar respectively for CAC. It was concluded that MKAC could be good substitute for commercially manufactured activated carbons for the design of gas phase adsorption cooling systems.

Keywords: Activated carbons, Desorption; Adsorption, Isotherms, Mango kernels.

1. Introduction

The isotherms are useful in the estimating the size of the adsorption system during design. The most common and useful method of presenting adsorption equilibrium data is the adsorption isotherm, a plot of the adsorbent capacity versus the partial pressure of the adsorbate at a constant temperature (Richards, 2000) Attempts have been made to develop generalized equations to predict adsorption equilibrium from physical data. This is difficult because adsorption isotherms take many shapes depending on the forces involved. Isotherms can be concave upward, concave downward, or "S" shaped. To date, most of the theories agree with data only for specific adsorbate-adsorbent systems and are valid over limited concentration ranges (Richards, 2000).

In designing adsorption systems, the isotherm is by far the most commonly used relationship for maximizing the adsorption capacity of the adsorption system. The shape of adsorption isotherm can provide qualitative information on the adsorption process and the extent of the surface area available to the adsorbate (Brunauer *et al. 1938*). It is difficult to experimentally measure the thermal properties of an adsorption process; therefore, the heats of adsorption of pure gases are usually derived from adsorption isotherms (Marchon *et al. 1998*]. It is well known that the adsorption cooling potential of adsorbent is determined by both maximum adsorption capacity and the rate of adsorption and desorption, among other parameters (El- Sharkawy *et al.*2006*)*.

The performance of adsorbents used in adsorption applications is governed by surface properties, such as surface area, micro-pores and macro-pores, size of granules in powders, crystals or in pellets. A large specific surface area is preferable for providing large adsorption capacity, but the creation of a large internal surface area in a limited volume inevitably gives rise to large numbers of small sized pores between adsorption surfaces. The pore size distribution of micropores which determines the accessibility of adsorbate molecules to the internal adsorption surface is important for characterizing adsorptivity of adsorbents. Materials such as zeolite and carbon molecular sieves can be engineered specifically for precise pore size distributions and hence 'tuned' for a particular separation (Sumathy *et al.* 2003). The main drawback of solid–vapor adsorption cooling/heat pump systems is their poor performance in terms of cooling capacity and COP. Adsorption characteristic of the adsorbent/refrigerant pair is one of the most essential parameters that affect the system performance. It is thus indispensable to realize and understand the adsorption features of the employed pairs in terms of adsorption isotherms, adsorption kinetics and heat of adsorption (El- Sharkawy *et al.* 2006).

It is imperative to explore the isotherm characteristics of activated carbon made from mango kennel waste in order to establish their suitability as potential replacement for commercial activated carbons as this will, to a large extent, solve problems of environmental pollution that is fast becoming an issue during the harvesting period of this agricultural waste (Wang *et al.* 1997).

The present study therefore deals with the experimental investigation of adsorption isotherms of a commercial activated carbon, known to be a good adsorbent for liquid and vapour phase adsorption applications, (ISO 9001:2000)/ methanol and mango kennel activated carbon/ methanol pairs for possible substitution of mango kennel activated carbons in adsorption cooling system application. The observed adsorption isotherms data obtained from the two pairs are compared to verify if mango kennel activated carbons falls into the desired shape of isotherms known to have micropores that are suitable for methanol up-take for cooling applications.

2. Materials and Methods

2.1 Materials/ Equipments

The materials used in the present research includes, 1 Horse power compressor, flow control valves, dial pressure meter, vacuum pressure meter, 6mm copper tube, RSS® analytical, 100% methanol, ISO 9001:2000, MKAC, experimental rig, dial thermometers and measuring cylinder, and electric heater.

2.2 Methods

The realisation of the foregoing objectives, an experimental rig was used which incorporates a combined adsorber/ generator, and a condenser/ evaporator integrating measuring devices for temperature and pressure. The system was to be capable of operating at high temperature and pressure. The experimental set up consist of two vessels, a vertical tube for conveying refrigerant vapour, pressure gauges, thermometer, control valves and an electric heater. One vessel acts as a combined adsorber/ generator while the other acts as an evaporator/ condenser for storing the condensed methanol. During generation, the liquid refrigerant (methanol) was released from the activated carbon in form of vapour and is conveyed to the condenser/ evaporator through the pipe.

The success of an adsorption/ desorption refrigeration cycle depends on the quality of the activated carbon used. The operation range of the dial thermometers were 0- 150°C and that of the pressure gauge was 0-25bar. These devices were selected within the designed operational conditions of the experiment with the test rig. The sensible heat of both the generator and the adsorbent was not to exceed 100°C, as excessive heating would result in the decomposition of the methanol to dimethylether (Li *et al.* 2004). Moreover the methanol was in contact with the metal used as the generator/ desorber since it was difficult to cast aluminium to the designed thickness and contend with the leakages on the generator/ desorber body, so unnecessary heating will result in the metal serving as a catalyst for the reaction to convert methanol to dimetylether (Richards 2000).

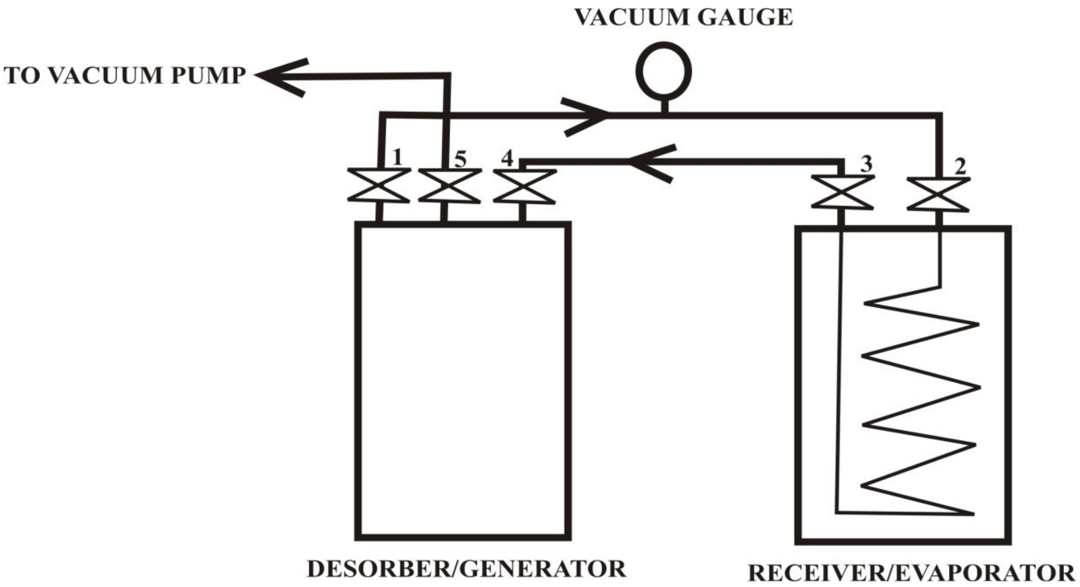

Fig. 1: Schematics of the experimental test rig

Plate 1: The generator assembly showing connection to the Compressor for pressurizing and evacuating the system

B

Plate 2: The copper cooling coils, (A) inserted in the receiver/ evaporator with a dial thermometer,(B).

To achieve this objective, the developed test rig shown schematically in Fig. 1 and its assembled components in plates 2 and 3, and was first pressurized by pumping through the vacuum valve, 5 to detect leakages. After this procedure, the system was evacuated using a suction pump through the vacuum valve, 5 during which all other valves are opened (valves 1, 2, 3, and 4). After evacuating the system, valve 5 was closed for the rest of the experiment. In order to further analyse the characteristics of the MKAC, it was necessary to measure desorption and adsorption isotherm characteristics of MKAC- methanol pair and compare with the behaviour with commercial- methanol activated carbon (CAC - ISO 9001:2000) known to be a suitable adsorbent, measure the refrigeration effect (or the cooling effect) and the COP (Li *et al.* 2004*)*.

As seen in Fig. 1 as well as plates 1 and 2, the generator of mass 2300g which was immersed in 2000g of water was filled with 250g of methanol and 250g of activated carbon in the first instance to obtain the adsorbent capacity- ADC of 1g/g (masses of both MKAC and CAC were later varied to alter the adsorbent capacity). The water was heated using a hot plate with variable heat input control and the energy caused the temperature of the generator to rise which also caused the pressure of the refrigerant to rise. During the desorption process, the generator was heated and valves 1 and 2 were opened to allow for escape and subsequent condensation of the refrigerant vapour in the receiver/ condenser while the refrigerant vapour return line, valves

3 and 4 were closed. The increase in weight of the receiver was monitored. As heat was added, the increases in temperature of the generator as well as the generated weight of methanol were recorded at intervals of 15miutes. The desorbed refrigerant vapour then flow through the condenser pipe which was air cooled. Valves 1 and 2 which connect the condenser to the evaporator/ receiver containing cooling coils were then opened to accommodate the condensed vapour in the evaporator/ receiver, which was thermally insulated. The process continued until the temperature of the adsorbent reached the desorption temperature of about 100 ^{o}C. Valves 1 and 2, connecting the evaporator/ receiver to the condensing pipe were then shut and that of the methanol vapour return line, valves 3 and 4 were opened to allow the pressure of methanol in the evaporator/ receiver drop. When the temperature of the adsorbent in the generator as well as the pressure of the methanol in the evaporator dropped, the adsorbent re- adsorbed the refrigerant from the evaporator. During the return cycle, the weight loss of the refrigerant as it evaporates, temperatures at generator and evaporator/ receiver were measured after every 30 minutes. The cooling effect was obtained from refrigerant evaporation during the adsorption process as the temperature dropped in the insulated evaporator/ receiver. The MKAC and the CAC were subjected through this experimental procedure with the mass of the both activated carbons adjusted (200, 150, and 100g) to give initial adsorbent capacity (ADC) of 0.8, 0.6 and 0.4 g/g respectively

3. Results and Discussion

The experimental results are presented graphically in Figs. 2- 5 as presented below.

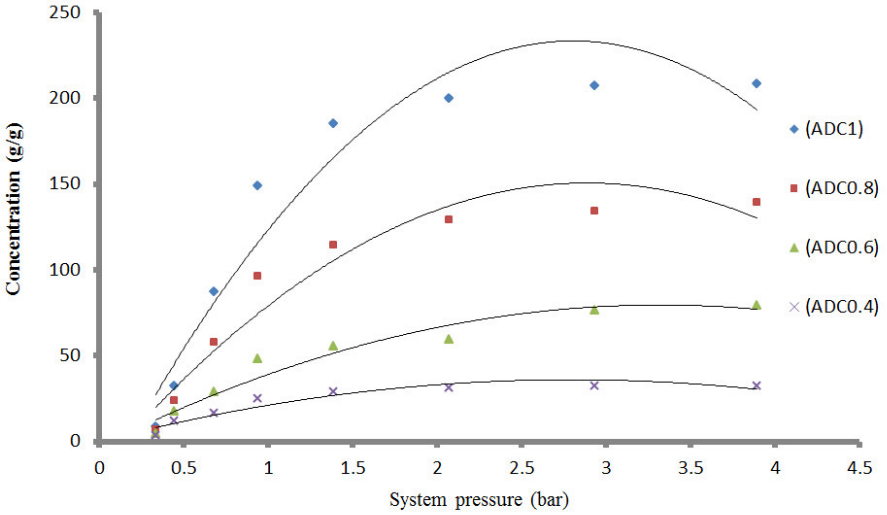

Fig. 2: Desorption Isotherms at 308.5K for MKAC

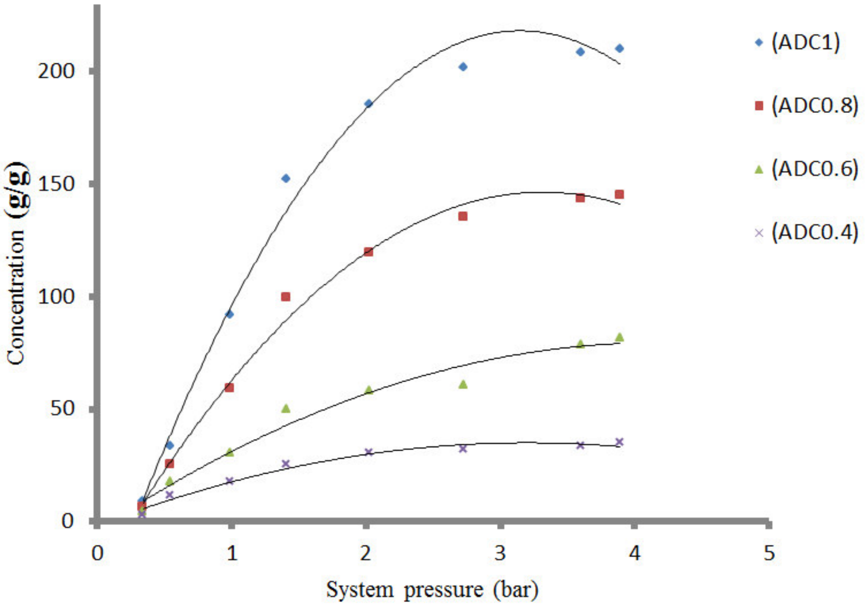

Fig. 3: Desorption Isotherms at 308.5K for CAC

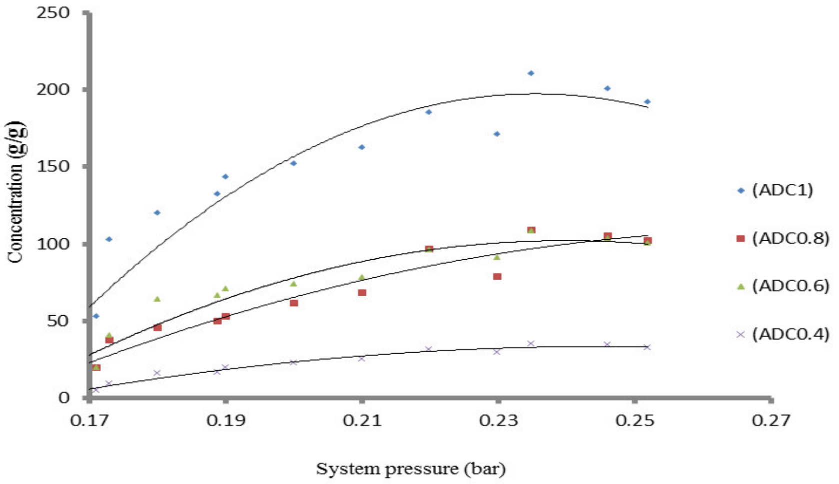

Fig. 4: Adsorption Isotherms at 301Kfor MKAC

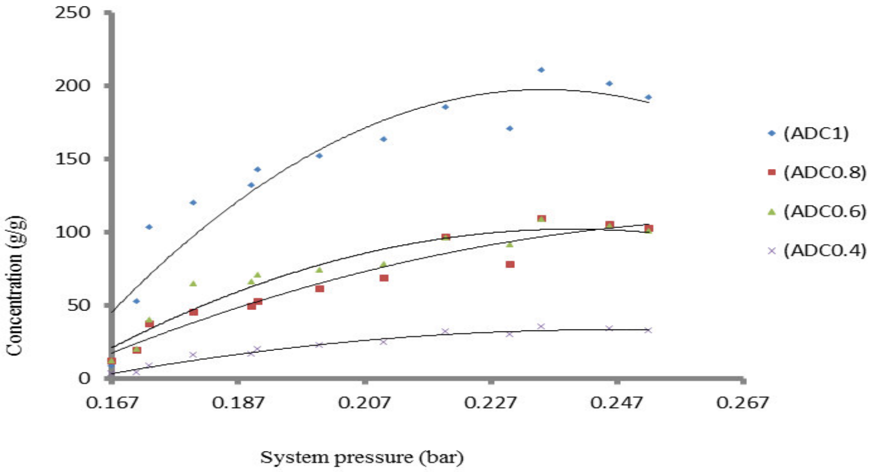

Fig. 5: Adsorption Isotherms at 301K for CAC

It has been correctly admitted that adsorption isotherms are a function of primary sites, shapes and pore size distribution (Cossarutto 2001). Desorption isotherms are presented in Figs. 2 and 3 while the adsorption are presented in Figs. 4 and 5. The Figs. show that desorption and adsorption capacity of MKAC-methanol and CAC- methanol increase with increasing pressures until maximum points are reached.

Attempts have previously been made to develop generalizes equations to predict adsorption equilibrium from physical data. This is difficult because adsorption isotherms take many shapes depending on the forces involved (Richards 2000). To date most of the theories agree with data only from specific adsorbent-adsorbate systems and are valid over a limited concentration range. Both desorption and adsorption isotherms from MKAC- methanol and CAC- methanol systems are concave in nature showing maximum capacity of the adsorbate concentration on the adsorbent at certain pressure ranges (that is maximum amount of vapour per weight of activated carbon that can be adsorbed. The peak of methanol concentration on the MKAC in Fig. 2 was between pressures of 2.5 to 3.0 bar. Beyond this pressure, the concentration of methanol on MKAC drops. This trend was observed at all the adsorbent capacities studied in the present work. The highest concentration of methanol on the MKAC was at adsorbent capacity of 1.0g/g while the lowest was at 0.4g/g adsorbent capacity. This indicates that the higher the amount of methanol available for desorption, the more it takes up the active site on the adsorbent. Similar concave- downward trend was observed for CAC- methanol pair. However, the maximum adsorbate concentration on the adsorbent sites was at 2.7- 3.0 bar. The maximum concentration of methanol on CAC at the observed pressure was less than that observed for MKAC. This could be due to the fact that MKAC have higher surface area than the CAC and hence more available sites for the adsorbate to occupy. During the adsorption phase as seen in Figs. 4 and 5 for MKAC and CAC respectively, the maximum concentration of methanol on MKAC and CAC were between 0.23 to 0.24 bar and 0.227 to 0.229 bar respectively. This adsorption pressure range is suitable for adsorption cooling operation and compares favourably with that reported by El- Sharkawy *et al.* (2006). The reported a pressure range 0.3 to 0.5bar as suitable cooling pressure range for both A-20/ethanol and A-15/ethanol pairs, also the adsorption isotherms from A-20/ethanol and A-15/ethanol pairs were concave in nature. In the present study, the concentration of methanol on the adsorption sites available for both activated carbons increase with increasing adsorbent capacity in an order of 1.0>0.8>0.6>0.4g/g. Similar shape of isotherms were observed for the adsorption isotherms (concave downward). The observed shape for activated carbon- methanol system was also reported by Richards (2000). This observation indicates that the produced MKAC has the capacity to adsorb high amounts of methanol and thus suitable as a possible substitute for CAC that are presently used. Cossarutto (2001) reported that whatever the amount of burn off in the activated carbon, the shape of the isotherms are unaffected. Desorption and adsorption equilibrium was established at pressures of 2.5 to 3.0bar and 2.7- 3.0bar for MKAC and CAC respectively. This represents the pressure at which the number of molecules arriving a surface of the adsorbent equals the number of molecules leaving. The adsorbent bed becomes saturated with Vapour and cannot remove and additional vapour. According to Brunauer *et al* (1940) the observed isotherms in the present study are of the Type I isotherm which indicates the predominance in the microporosity of the adsorbent structure which are indeed suitable for gas phase adsorption. The MKAC has greater adsorption rate and CAC. In adsorption from the gas phase, mainly microporous carbon is used whereas mesoporous carbon is applied in liquid phase processes (Benaddi *et al.* 2000). As seen in Figs. 2- 5, the equilibrium adsorption/ desorption capacity of MKAC- methanol is larger than CAC- methanol system.

4. Conclusion

Production of activated carbons from mango kernels for use as adsorbent for gas phase adsorption cooling is worthwhile. This is due to the fact that the observed isotherms are of the type I and accordingly such isotherms are suggestive of highly microporous adsorbent and can be used to design adsorbent- adsorbate cooling pair. Future research should focus on other agricultural waste abundantly found in developing nations to address the purpose of exploring their unique potential in replacing commercial adsorbents. Also studies have shown that mango kernel contains 7- 12% of oil rich in stearic (24- 57%) and oleic (34- 56%) (Gunstone, 2006; Schieber *et al.,* 2001). These qualities make it a potential source for good grade of low- fats oil for future studies. This will have positive impact on the socio-economic and environmental factors.

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