Activated Carbon and The Artificial Kidney I

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Activated Carbon

Activated carbon (charcoal) has been utilized in industry for many years to decolorize and purify gases and organic liquids. There are a variety of grades of activated carbon used for many specialty applications, including municipal water purification, sugar refining, winemaking, radioactive gas adsorption, air purification, and various catalyst support systems. The purification process is one of adsorption (physical attachment by secondary bonding) of solute or gas molecules directly to the surface of the carbon. The extremely high adsorption capacity of activated carbon is a result of its large surface area. In some cases, this area can be as much as 1000-1400 m^2/gram. The high surface area is created by the presence of an extensive porosity in the carbon substructure. Macropores (greater than 1000 A in diameter) originate at the surface of the activated carbon particle and penetrate into the bulk carbon. Micropores (10 A to 1000 A in diameter) branch off from the macropores in the interior of the carbon; it is in these micropores where most of the solute adsorption occurs.

The adsorptive properties of a specific grade of activated carbon are due to its total surface area (which is dependent on the micropore size distribution), the pore structure, and the chemical nature of the carbon surface. The pore structure and total surface area depend upon the material used to produce the activated carbon and the methods of activation. Many organic materials (coal, peat, bone, petroleum, shells, wood, etc.) have been used at one time or another as a basis of activated carbon production. These materials are usually carbonized by high temperature treatment. The amorphous part of the carbon is then removed either chemically or with high temperature steam resulting in an extensive porous network of high surface area. The generation of this porous network is termed "activation" of the carbon.

If the major contribution to surface area and thus adsorption capacity is located in the micropores of molecular dimensions, then adsorption specificity depends on the molecular size of the solute molecules. For instance, a large solute molecule cannot penetrate into a micropore of too small diameter or of irregular shape. Thus these big molecules are "screened out" and prevented from adsorbing in the micropores. Even though the large molecules could adsorb in the large pores to which they could gain access, adsorption capacity would be small due to the small contribution to the total surface area provided by the macropores. Figure 1 illustrates the concept that for any molecule the effective surface area for adsorption exists only in the pores to which the molecule can gain access. Figure 2 is a photomicrograph of the surface of an activated carbon particle.

Figure 1

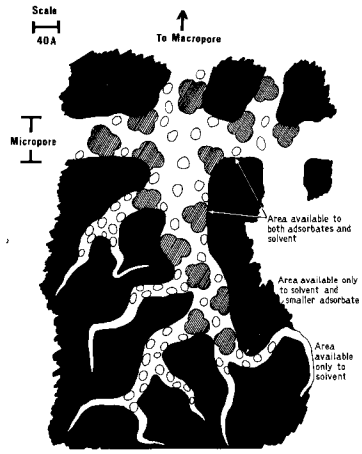

Figure 2

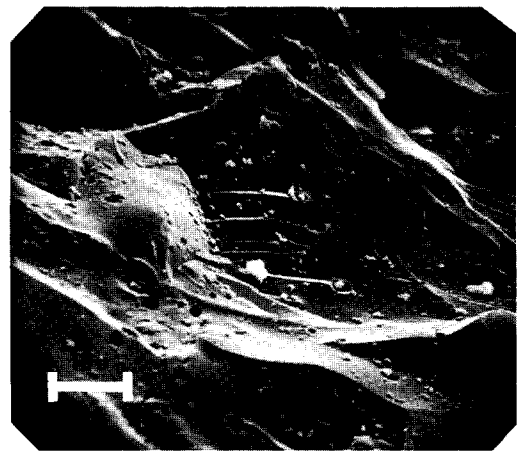

Figure 1. A schematic cross-sectional view of the pore structure in an activated carbon particle. Two kinds of solute molecules in a solvent (not shown) compete for adsorbent surface. The small micropores are inaccessible to the large solute molecules. The greater diffusional mobility and the smaller size of the second solute molecule allows it to reach the micropores and adsorb in large quantities. (Redrawn from Ref. 1, p. 7.)

Figure 2. A scanning electron micrograph showing the macroporous structure at the surface of a granular activated carbon particle. Some microparticles (center) probably generated in the activation process can be seen as well as several large surface fissures (upper left and lower right corners). Scale: 1 cm = 7 microns.

Hemoperfusion[2]

During the last nine years, hemoperfusion over activated carbon has been used both as an adjunct to conventional hemodialysis and as a treatment for severe, acute poisoning cases. Yatzidis (1964) did the pioneering work in applying charcoal hemoperfusion to patients with chronic renal failure.[3] His perfusion apparatus consisted of a siliconized glass cylinder containing approximately 200 grams of activated carbon. After assembly and sterilization, the column of charcoal was rinsed and primed with heparinized saline. During use, the patient's heparinized blood flowed from a cannulated artery, percolated up through the activated carbon, and out the top of the cartridge. The blood was then returned to the patient via a cannulated vein. At the end of the hemoperfusion, the blood remaining within the apparatus was slowly returned to the patient. The duration of these early clinical hemoperfusions ranged from 30 to 90 minutes and blood flow rates through the circuit varied from 150 ml/min to 300 ml/min. Yatzidis reported that at the beginning of a hemoperfusion over charcoal, plasma creatinine, uric acid, indican, phenolic compounds and guanidine bases were almost totally removed from the blood which flowed through the charcoal column. He also reported that clinical hemoperfusions removed negligible quantities of urea, magnesium, phosphates, sulfates, potassium, calcium, and water.

From a comparison between charcoal hemoperfusion and hemodialysis utilizing a Kolff twin coil, Yatzidis concluded that a 60-minute perfusion of two or three charcoal columns was about as efficient as a conventional hemodialysis of four to

six hours duration. The disadvantages associated with hemoperfusion were limited to high heparin dosage levels, significant platelet drops, fluctuating white cell levels, drops in plasma fibrinogen, and the occurrence of several pyrogenic reactions. Plasma hemoglobin and hematocrit remained normal and in spite of the above limitations, the hemoperfusions usually resulted in an immediate improvement in the patient's general condition.

Dunea and Kolff[4] reported on preliminary clinical experience utilizing charcoal hemoperfusion to treat three uremic patients. Their perfusion apparatus and technique was similar to that reported previously by Yatzidis.[3] The clinical clearance data for creatinine and uric acid was promising. There were no significant changes in blood urea, serum phosphorus, serum electrolytes or white cell count. No pyrogenic reactions were observed. The carbon used had a low ash content and was washed in eight liters of physiological saline before perfusion. The only apparent disadvantages associated with the hemoperfusions were a significant decrease in platelets and blood loss in the column resulting from carbon packing and caking which made complete retransfusion difficult. Because of the low adsorptive capacity of carbon for urea, Dunea and Kolff concluded that charcoal hemoperfusion may be a useful adjunct to hemodialysis since it can do well what dialysis does poorly. For instance, it seems quite feasible to combine charcoal hemoperfusion and hemodialysis into a single artificial kidney system. Certain undesirable molecules would be removed by adsorption on the activated carbon while water, urea and electroyltes would be removed using a membrane hemodialyzer. The more efficient removal of middle and high molecular weight compounds may possibly cut down on dialysis times or even reduce the number of dialysis sessions required per week. This would not only lower the cost but it would also cut the time required each week for dialysis.

Another aspect of blood perfusion over activated charcoal is the ability of carbon to adsorb considerable amounts of barbiturates, salicylates, and glutethimide from plasma.[3] Yatzidis applied this finding to several patients with severe barbiturate poisoning.[5] He coated the carbon with cellulose acetate to reduce the blood damage which was so prevalent in the earlier clinical trials.[3] Several short-term hemoperfusions were effective in decreasing the plasma barbiturate levels and the general condition of the patients improved considerably. DeMyttenaere, et al.[6] evaluated the adsorption capacity of activated carbon for glutethimide (Doriden®) both in vitro and in vivo, utilizing dogs. They found charcoal hemoperfusion to be an effective method of removing glutethimide from blood and suggested that repeated hemoperfusions utilizing fresh carbon may be necessary for clinical poisoning treatments. DeMyttenaere reported that in vivo glutethimide clearances were superior to those previously reported for hemodialysis utilizing aqueous or lipid dialysate. A comparison of barbiturate removal by conventional hemodialysis, hemoperfusion over an anion exchange resin, and hemoperfusion over coated and uncoated activated carbon was conducted by Rosenbaum, et al. in 1968.[7] They found charcoal hemoperfusion to be superior over hemodialysis and anion exchange resin perfusion for the removal of barbiturate from blood. They also reported that hemoperfusion of charcoal caused a marked hypotension and reduction of platelets and white blood

cells. Histopathological tissue samples from dogs previously subjected to hemoperfusions showed charcoal emboli in the lungs and other viscera.

During the last three years, extensive research on hemoperfusion over activated carbon has been conducted by two groups. The first group under the direction of Dr. T. M. S. Chang in Montreal has applied charcoal hemoperfusion on a large scale to the maintenance of patients suffering from chronic renal failure. Chang initiated the concept of 'artificial cells' and the application of microencapsulation technology to medical problems.[8-10] In the last six years, Chang, et al. have utilized activated carbon coated with several polymeric materials for clinical hemoperfusions. Chang has demonstrated that 300 grams of activated carbon coated with albumin-coated colloidion membranes (ACAC) can remove creatinine and uric acid as effectively as a coil artificial kidney and more efficiently than a plate-type or capillary-type hemodialyzer.[11] Chang also reports that with proper carbon coating, washing, and sterilization prior to hemoperfusion no pyrogenic reactions occur and no carbon emboli will escape from the apparatus.[10,11,12] The presence of the albumin-coated colloidion membrane enhances the blood tolerability of the carbon resulting in only a small drop in blood platelets.[12]

Recently, Chang has reported the results of 55 hemoperfusions conducted on 11 patients utilizing albumin-colloidion coated activated carbon. The results support his earlier findings and he concludes that the ACAC artificial kidney system is safe and effective for the management of patients with chronic renal failure.[13]

Chang has also evaluated his albumin-colloidion coated activated carbon in terms of exogenous toxin adsorption. Nembutal and salicylate have been studied and removal from blood via hemoperfusions utilizing dogs seems to be efficient enough to revive the animals after administration of a fatal dose of the exogenous poison.[11] Quite recently, Chang reported that the ACAC artificial kidney has been used to treat a patient with acute glutethimide intoxication.[14] Two hemoperfusions resulted in a marked reduction of blood glutethimide, and the patient regained consciousness.

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