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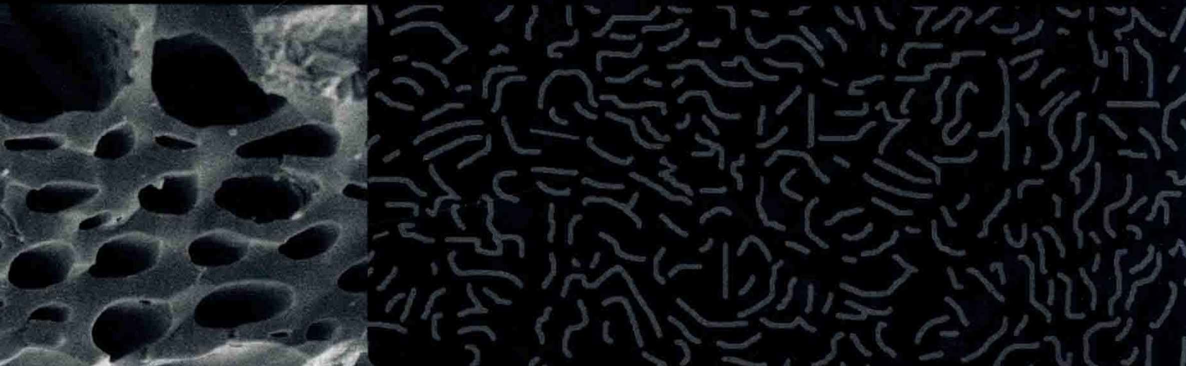
Activated Carbon



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ACTIVATED CARBON

This book is dedicated to our dear wives:
Audrey and Angela
for total support at all times

Preface

With its immense capacity for adsorption from gas and liquid phases, activated carbon is a unique material. It occupies a special place in terms of producing a clean environment involving water purification as well as separations and purification in the chemical and associated industries. In these roles, it exhibits a remarkable efficiency as the international production is a little more than half a million tonnes per year, with perhaps 2 million tonnes being in continuous use. This is equivalent to the allocation of 200 mg per person of the world population to be compared with the world use of fossil fuels of 2 tonnes per person of the world population.

Much is already written about activated carbon such that the Google search engine will offer over one million pages from the Internet. These pages are mostly descriptive and uncoordinated. Currently, there exists a need for a text which establishes a framework into which factual information can be located and explained. Further, carbon science has expanded rapidly in recent years with considerable relevance to an understanding of activated carbon. Again, these information are mostly uncoordinated and need to be assimilated into a comprehensive story. This assimilation is the purpose of this book.

An effective use of activated carbon requires a knowledge about the structure of its porosity, obtained from equilibrium data, namely the pore-size distributions of the microporosity in particular, of the pore-size distributions of the mesoporosity, of the composition of the carbon surfaces onto which adsorption occurs, and knowledge of the dynamics of adsorption to indicate its effectiveness in industrial use.

The authors experienced, during the course of writing, that two areas of major conflict exist within the scientific literature. Rather than simply describe these, attempts were made to resolve these two conflicts. First, the area of crystallography continuously presents the concept of the graphitic micro-crystallite as being the constituent of all carbons, the concept being carried over into the literature of Raman Spectroscopy. There is no evidence from adsorption studies that graphitic surfaces are part of activated carbons. In fact, the concept of the *crystallite* was flawed almost from the moment of its inception, several decades ago, and has blocked a realistic understanding of structure in both non-graphitizable and graphitizable carbons. The concept serves no purpose.

Second, despite what the advertisements may say, no instrument of adsorption exists (other than planometers) for the measurement of surface area. Such instruments measure adsorption capacity and a programmed microchip somewhere in the instrument converts from units of *grams adsorbed* to *meters squared per gram*, assuming that an atomic surface can be equated to a macro-surface, such as a mirror. This assumption has led to much non-productive debate. The characterization of activated carbon requires knowledge of pore volumes (e.g. $0.35\,cm^3\,g^{-1}$) but such numbers are less dramatic to the human ear than the sound of $1000\,m^2\,g^{-1}$. The concept of "surface area" is here to stay but its "image" should not be analyzed too deeply. This is the opinion of this book.

Central to activated carbon is the activation process which enhances the original porosity in a porous carbon. Activation uses carbon dioxide, steam, zinc chloride, phosphoric acid and hydroxides of alkali metals, each with its own activation chemistry. The story of what happens to a molecule of carbon dioxide after entering the porosity of carbon at 800 °C leading to the eventual emergence of less than two molecules of carbon monoxide is fascinating and talks about "atomic ballet".

This book, essentially, elaborates upon the origins of activated carbons, their structure and manufacture as well as their effectiveness for purification and separation.

This book points to the general direction of applications which is a subject area so immense that several volumes would be needed to summarize. However, searching the appropriate scientific journals, available electronically and with efficient computers, rapidly provides several thousands of applications.

Enjoy this book.

Harry Marsh
Francisco Rodríguez-Reinoso

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Contents

CHAPTER 1

Introduction to the Scope of the Text

1.1 Activated Carbon

Question: *What is activated carbon?*
Answer: Activated carbon is porosity (space) enclosed by carbon atoms.

Question: *What is the size and shape of this porosity?*
Answer: Porosity has the size of molecules and is probably slit-shaped.

Question: *What are activated carbons used for?*
Answer: They are used for purification of water and of air and separation of gas mixtures.

Question: *What is activation?*
Answer: Activation is selective gasification of carbon atoms (thermal activation). Activation involves the use of phosphoric acid (chemical activation).

Question: *What are activated carbons made from?*
Answer: From hard woods, coconut shell, fruit stones, coals and synthetic macromolecular systems.

Question: *Can any natural organic material (NOM) be used to make activated carbon?*
Answer: No. Although NOM carbonize to porous carbon, only few provide commercially attractive activated carbons.

Question: *Are all activated carbons very similar to each other?*
Answer: No. There are several hundred commercial activated carbons available, with different sizes of porosity with specific applications.

Question: *Can different activated carbons be made from one source?*
Answer: Yes. Figure 1.1 contains isotherms of seven activated carbons from olive stones showing significant differences in pore sizes and pore contents.

Question: *What are isotherms?*
Answer: Please read Chapter 4.

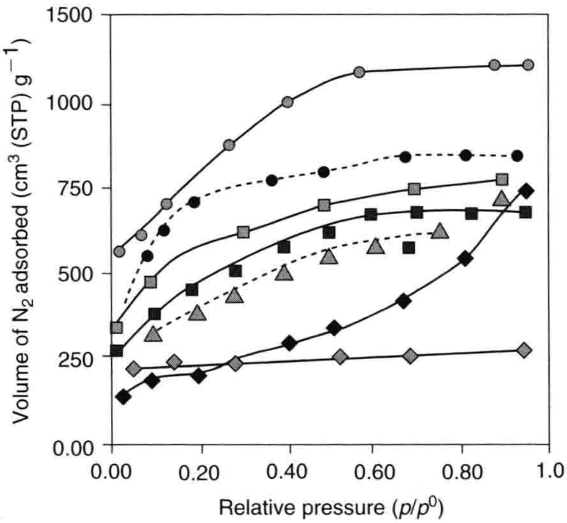

Figure 1.1. Adsorption isotherms of nitrogen at 77 K for seven activated carbons from a common precursor (olive stones), showing how the shape of the isotherm and extents of adsorption vary according to the method of preparation (adapted from Rodríquez-Reinoso F. The role of carbon materials in heterogeneous catalysis. *Carbon* 1998;36(3):159–175).

Question: *Is there a common structure in activated carbons?*
Answer: Yes, they are all assemblies of defective graphene layers.

Question: *Can activated carbons be described as amorphous materials?*
Answer: Emphatically, no.

Question: *Is shape and size of porosity all important for activated carbons?*
Answer: No. The chemistry of surfaces of porosity (functionality) has also to be considered.

1.1.1 Talking About Porosity

This text is a comprehensive overview of those issues within carbon science and technology which are considered to be essential to an understanding of the origins, preparation, characterization and applications of activated carbon. Carbon materials and activated carbons in particular are complex materials the study of which is not restricted to a single discipline but to several disciplines from geology to crystallography, to chemistry to theoretical physics, to manufacturing technology and environmental controls, and including aspects of economics and marketing. A good working knowledge of structural characterization (i.e. what is inside an activated carbon), of gasification kinetics (how to make an activated carbon) and of adsorption theory (a very effective way of understanding the porosity of carbons) is vital for those with interests and obligations toward industrial applications of activated carbon.