Purification with

**ACTIVATED CARBON:**

Industrial
Commercial
Environmental

by

**JOHN W. HASSLER**

*Specialist in Activated Carbon
Research, Manufacture, Marketing since 1915*

Developed original process to manufacture activated carbon in America.

1974
CHEMICAL PUBLISHING CO., INC.
NEW YORK, N.Y.
PREFACE TO THE THIRD EDITION

Much of the text has been re-written to incorporate major changes that have developed during the past decade. The title has been altered to capture the attention of those entering fields in which the purification properties of activated carbon could be useful.

Activated carbon enters many diverse applications, and the human life span is too brief to gain first hand knowledge of all facets. Much information can be borrowed from the scientific literature, and some workers are in positions to open lines of communication with authorities in related fields. Through those avenues, much has been received to aid in the preparation of this text. Among the many individuals, who have contributed varied forms of aid, are the following:
F. M. Middleton and Jesse Cohen of Taft Laboratory
L. F. Gleysteen, J. R. Conlisk, R. W. Behrens of Atlas Chemical Industries
F. Schwartz of North American Carbon
P. Wiley, A. Y. Hyndshaw, B. Jensen, J. Lienhardt, J. Filickey,
S. Smith, J. Drudy, J.M. Wafer of Westvaco
H. Todd, Jr., of Connor Engineering Corp.
H. L. Barnebey of Barnebey-Cheney
J. C. Cooper, R. S. Joyce, P. Walker, F. M. Williams, D. G. Chalmers, E. J. Cunningham of Calgon Corp.
Don Clendenin of U.S. Steel
Charles M. Staffer of Witco Chemical Company
R. Hagberg of Sucrest Corp.
Y. Hara and T. Oda of Takeda Chemical Industries
Y. Eguchi of Hokkaido University
H. Yanai of Muoran Institute Technology
T. Mc Donald of ACS at Ohio State University
W. W. Hassler of Indiana University of Pennsylvania
J. C. Enneking of Union Carbide Corp.
S. B. Dhungat of Londa, India
Y. Kishimoto, Charcoal Consultant, Tokyo
W. C. Bokhoven, C. van der Meijden of N. V. Norit-Vereening Vekoop Centrale
A. Kleinmayer of Carbomafra, Brazil.
W. A. Welch, Lancaster, Pa
ABRIDGED PREFACE TO JAPANESE EDITION
OF ACTIVATED CARBON.

Although technical writing is a solitary and monetarily un-rewarding task, there are compensations, chief of which are the enriching personal contacts. During the writing of ACTIVATED CARBON, I had the priviledge of discussing many aspects with numerous authorities.

Following publication, I made many new friends as a result of a mutual interest in activated carbon. A memorable instance occurred in 1965 when I received a most friendly letter from Takashi Oda of Takeda Chemical Industries in which he expressed interest in preparing a Japanese translation of ACTIVATED CARBON. This I deemed a high honor and I transmitted the message to the Chemical Publishing Company of New York, N.Y. who are the copyright owners. An agreement was reached with the Kyoritsu Shuppan Company of Japan for the publication of a Japanese translation.

The translation has been made by Yoshitomo Eguchi. During a visit to the United States, he together with Yojiro Hara came to my home to discuss the many varied aspects of activated carbon. It was a delightful and memorable experience, and I will always treasure a fond memory of those two gentlemen who so truly represent the courteous and friendly people of Japan.
PREFACE TO SECOND EDITION

During the decade since the publication of the first edition of this text, entitled Active Carbon, new vistas have unfolded for the industrial user of activated carbon. There has been a growing awareness of the many diverse forms of carbon usefulness; new processing techniques have been developed; and granular decolorizing carbons are now available commercially.

Such forward steps have increased the spheres of activity in the industrial use of activated carbon. They often introduce problems as to the right path to follow, however, and in many ventures the potential user is denied the guidance that could be available. To explain, let us review the earlier history of adsorptive carbon in industry. We find that markets were first established in processes already using adsorbents, such as bone char and fuller's earth, for the purification of sugar, fats, glycerol, etc. Within those processes there are but few trade secrets, and the success of the operation depends mainly on efficient methods of manufacture and marketing. Consequently the users welcomed any and all aid they could obtain from suppliers of carbon. In general that attitude still holds in established applications and through such cooperation future growth can be assured in those markets.

Much growth, however, also can develop through participation in new products and in new processes. Unfortunately the opportunities for the supplier to contribute know-how in such ventures are frequently restricted because of the secrecy that so often surrounds the development. The reason for secrecy is understandable: Research and development costs are high, and these costs must be recouped in the relatively brief interval between the date a new product is placed on the market and the time for competition to catch up. Understandably, profit-minded industrialists, aware of ubiquitous competition, are unwilling to make
premature disclosures even to those that could provide assistance.

An unfortunate consequence of this situation is that in many ventures that could become more efficient through the use of activated carbon, it may not be used; or it may be used ineffectively because of lack of know-how. In such situations a suitable written text can be useful because it asks no questions and carries away no data. This potential has guided the preparation of this revision. No attempt is made to furnish a definitive treatise; instead, the text is an introduction to basic principles and practices that should be considered in the industrial use of activated carbon. To that end the organization of subject matter has been altered and additional material is included.

Much of the added material is drawn from experiences during nearly fifty years' work with activated carbon. In 1915, I started with the West Virginia Pulp and Paper Company in its endeavor to pioneer the development of decolorizing carbons in this country. That endeavor culminated in the manufacture of Filtchar, the first commercial decolorizing carbon produced in America. From then till 1958, I participated in the research, manufacture, and marketing of other activated carbons including Nuchar and Suchar. On reaching retirement, I engaged in free-lance consulting. I am now associated with Barnebey-Cheney, a producer of activated carbon. I am also associated with the AMERICAN SOCIETY FOR TESTING AND MATERIALS in a research study to develop standard testing methods and nomenclature for activated carbon.

The experience of a single individual or group cannot cover an adequate understanding of all aspects of this many-sided subject. Therefore to provide a more comprehensive know-how I have sought the cooperation of others. In this I have had the assistance of sales, service, and research groups who have read sections of the manuscript, and supplied many valued suggestions. For making much of this help available, I am especially indebted to the following:

I am also grateful to many who have contributed much in varied ways: Some supplied information needed for presenting specialized topics; some assisted in the preparation and editing of the manuscript; some drew attention to important items that otherwise would have been overlooked; still others corrected errors in the presentation. The information has been gathered for a number of years and limitations of space and memory preclude naming all who contributed. A limited list includes:


Permission to reprint tables and figures has been acknowledged with the respective items. Some tables and figures for which permission was requested and granted have not been used because of subsequent changes in the manuscript.

I have made extensive use of the Deitz Bibliography of Solid Adsorbents. As it is in the form of a collection of abstracts, this publication offers the reader a better view of the content of each article than does a bare reference to the original source. Similar use has been made of Chemical Abstracts.

A word of explanation is in order for the change in title. The designation Active Carbon, used in the earlier book, is favored in a number of scientific circles, whereas most industrial workers prefer the term Activated Carbon. Inasmuch as this text is focused primarily on industrial aspects, it seems fitting to call this work Activated Carbon.

The preface to the first edition is included to establish continuity, and also to give recognition to the many persons who assisted in the preparation of the original text.

Finally, I am happy to express my perennial gratitude to my wife, Clara—my partner in all undertakings.

JOHN W. HASSLER

June, 1963.
PREFACE TO FIRST EDITION

This text has been prepared for operators and research workers in industry. I have attempted to survey principles and practices involved in the use of active carbon with the belief that an insight into the underlying features may suggest possible improvements in existing applications and also stimulate a search for new procedures.

The subject matter is grouped into three principal parts. Since many readers will be interested in only certain aspects, each part has been prepared so that it can be read independently of the others. Following an outline of the history and methods of manufacture, the next ten chapters discuss fundamental factors involved in adsorption by active carbon.

Applications are described in Chapters 13–30. A general outline is given of a number of applications, together with the specific objectives that are sought in each case. An operator will often find more helpful information from a description of how things are done in other processes than by copying what is being done elsewhere in his own field. With this in mind, some rather impractical procedures are described because they present novel approaches which could be useful in other applications.

The last four chapters cover experimental methods that have been found helpful in developing industrial applications.

Part of the information in this text has been drawn from personal experiences during thirty-five years’ association with the manufacture and marketing of active carbon and this includes information received directly from other workers. To an even larger extent, the discussion is based on information in the literature. Some published data are obscure and other data are in dispute, so that it becomes the responsibility of the author to try and sift the facts. Consequently, the reader should be aware
of the fact that the text contains not only facts, but also beliefs and opinions. The inquiring reader may find statements that he will question. This is as it should be. Questions stimulate independent thinking and this is necessary to integrate new facts with older knowledge. New facts become useful when they enlarge our vision and provide a new approach to problems.

I wish to express appreciation to those authors and publishers who granted permission to reproduce data. I have been fortunate in having received suggestions, criticisms, and information from many workers who have specialized knowledge. A number of authors checked references to their work and others reviewed portions of the manuscript. Professors Elroy J. Miller, Harold J. Cassidy, and F. E. Bartell gave helpful suggestions for portions of the text dealing with fundamental aspects of adsorptive behavior. Dr. Homer Adkins reviewed the chapter on catalysis, and Dr. H. L. Riley the section on the structure of carbon. Dr. Arthur Grollman read the chapters dealing with biochemicals; solvent recovery was reviewed by Dr. A. B. Ray, and air purification by Mr. Hugh Porter. The chapters on the removal of toxic gases and that on laboratory methods of gas adsorption were reviewed by personnel of the Chemical Corps Technical Command. Mr. Robert H. Buckie reviewed the entire manuscript and assisted with a number of translations. Much information on industrial applications was furnished by my associates throughout the West Virginia Pulp and Paper Company, and I regret that space does not permit detailed mention of the many helpful individual contributions. Finally, I wish to express my deep appreciation to Mr. Joseph Wafer, for without his help and encouragement, the text would never have been started and carried through to completion.

February, 1951

John W. Hassler
TABLE OF CONTENTS

Part I Introduction
Chapter 1: History and Market Review 1
Chapter 2: Elementary Aspects of Adsorption 10

Part II Application To Industrial and Environmental Liquid Systems
Chapter 3: Basic Aspects and Concepts 23
Chapter 4: Interpretation and Evaluation of Adsorption Data 52
Chapter 5: Adsorption-Desorption Operations 63
Chapter 6: Unit Operations 74
Chapter 7: Representative Industrial Applications 87
Chapter 8: Purification Domestic and Industrial Waste Waters 126

Part III Applications to Other Systems
Chapter 9: Gas and Vapor Phase Application 142
Chapter 10: Diverse Applications 163

Part IV Preparation of Activated Carbon and Physico-Chemical Properties
Chapter 11: Manufacture of Activated Carbon 169
Chapter 12: Regeneration 200
Chapter 13: Nature of Activated Carbon 205
Chapter 14: Contact Catalysis 248

Part V Biochemical Properties
Chapter 15: Biochemical Aspects of Activated Carbon 274

Part VI Laboratory Procedures
Chapter 16: Adsorption of Gases and Vapors Laboratory Procedures 298
Chapter 17: Laboratory Adsorption Test Procedure for Liquid Systems 308
Chapter 18: General Properties of Activated Carbons 341

Part VII
Chapter 19: Final Gleanings 355
Index 380
PART I

INTRODUCTION

1

History and Market Review

“For there is nothing good or bad but thinking makes it so”
Shakespeare Hamlet

1. INTRODUCTION

Purity is a subjective concept. Salt is desirable on a breakfast egg, but not in a glass of drinking water. Pesticides benefit a growing crop, and detergents help in the laundry, but both are considered contamination when discharged into waterways.

No substance—of itself and by itself—is an impurity. Conversely, any substance can become contamination, if on entering a system, it damages desirable properties and characteristics.

Some types of contamination can be converted into acceptable forms, for example, the bleaching of an unwanted color with chlorine. But in general purification is accomplished by providing effective means of separation. The separation may be accomplished by removing the desired constituent from the system, as when pure water is distilled from salt brines; and when white sugar is crystallized from a syrup. Alternatively, it may be the contamination that is removed, as when dissolved mercury salts are precipitated and separated from the solution by filtration; or when acid gases are removed from air by contact with an alkaline solution. Some separations are accomplished through the ability of fluid molecules to adhere to the surfaces of solids—a phenomena known as adsorption. For practicable use, certain requirements must be met. A large surface area is essential because only a very small weight of molecules adheres to each square meter of surface.
The needed surface exists on porous solids known as adsorbents. Activated carbon adsorbents contain a myriad of micropores, the walls of which have surface areas that range from 400 to over 1800 square meters per gram in the various commercial brands. But more than large surface area is needed. To provide a means of separation, it is obvious that adsorption must be selective; certain species of molecules should be adsorbed in preference to others. To provide adequate purification, an adsorbent should be able to take up and hold molecules of the substance to be removed without disturbing other constituents in the system. Moreover no single type of adsorbent surface will be appropriate for all diverse forms of contamination; therefore a variety of adsorbent surfaces should be available to handle the different needs.

It so happens that activated carbons can meet many of the diverse needs. The adsorptive properties, which exist in primitive form in ordinary wood charcoal, can be developed in various forms by appropriate changes in manufacturing processes. Consequently, brands of commercial activated carbons made by dissimilar processes differ in adsorptive characteristics. Some excel for gas masks, others are superior for sugar refining, still others are best for water purification, and so on. Hence, we can quite properly consider that the term activated carbon comprises a family of adsorbents. That aspect extends and widens the potential utility because if one brand is tried and found wanting, possibilities remain that another brand will be suitable. Also to be considered is that the performance of carbon can often be guided into diverse channels by appropriate conditions. Consider the addition of activated carbon to a mixture of aniline and phenol in dilute aqueous solution: at pH 7, both will be equally adsorbed; at pH 10, aniline will be preferentially adsorbed; at pH 3, phenol will be preferentially adsorbed.

Features to be considered in the selection of carbon for use are considered in later chapters, but at this time we should mention the separate spheres of application of powdered and granular carbon. Powdered carbons are applied in a so-called batch-contact treatment: in this measured amounts of carbon and substance to be treated are mixed and subsequently separated by filtration. With granular carbons, the gas or liquid to be purified is passed continuously through a bed of carbon. For many years granular carbons (except bone char) were used primarily in vapor phase
systems because the early commercial brands lacked adsorptive characteristics needed for most liquid phase purifications. After World War II, new granular brands were developed having a broad spectrum of adsorptive powers, and today are in use in many liquid phase applications. They have opened new markets that offer promise of important future growth.

The adsorptive properties of carbon were well known long before the terms active and activated had been coined. In early literature data on the adsorptive properties appear under many varied names: bone char, blood char, coconut char, and others. More recently the information appears under decolorizing carbon and also under individual commercial brand names.

2. HISTORY

Early history\textsuperscript{1-2} The use of charcoal for purposes other than as a fuel and in metallurgy is very old; the use in medicine being mentioned in an Egyptian papyrus from 1550 B.C. In the time of Hippocrates wood chars were used to treat various ailments. Kehl in 1793 discussed the use of char for removal of odors from gregarious ulcers.

The earliest date at which adsorptive powers were definitely recognized was 1773 when Scheele\textsuperscript{1} described experiments with gases. In 1785, Lowitz\textsuperscript{4} called attention to decolorizing effects of charcoal on solutions. A few years later, wood char was employed to purify cane sugar, and in 1808 was applied to the then infant beet-sugar industry. Figuers\textsuperscript{1} discovery in 1811 of greater decolorizing power of bone char led to its almost immediate adoption by the sugar refiners. At first, pulverized bone char was applied on a single use and discard basis, but limited supplies made regeneration necessary. A method of regenerating granular bone char was developed and that process is still in general use in refining cane sugar.

During the 19th century, many studies were made to develop decolorizing carbons from other source materials. Bussy\textsuperscript{5}, in 1822, heated blood with potash and produced a carbon with with 20 to 50 times the decolorizing power of bone char. Blood char so produced was used for years in many laboratory studies. Hunter\textsuperscript{6}, in 1865, reported the the gas-adsorbing power of cocoa-
INDEX

Abrasion, resistance to 351
Absorption, distinguished from adsorption 364
Accelerated tests 303
Acid washed carbons, 182, 342
Activated adsorption 212
Activated carbon, definition 2, 169
  general properties 341
  history 3
  inorganic constituents 345
  pH 347
  structural characteristics 348
  types 2, 170, 226
Activation. See also manufacture.
  Environmental control 324
  methods of 172
  non-carbon constituents influence 189, 191
  oxidizing agents 174, 188
  porosity 220
  source materials 169
  surface area change 221
  temperature of 173, 174, 180, 181, 188
  theories 184
Active centers 223
Activity changes, effect of age 368
  chemical agents 223
  drying 173, 182, 342
  pulverization 183
Adsorbates 10
  chemical changes in 68, 277
Adsorbed layer, nature 233
  stability of 68, 277
  thickness 210, 211, 234
Adsorbents 2

380
Adsorbers, liquid systems 82, 89, 129
vapor systems 147, 153
Adsorption, affinity 10
apparent 355
capillary condensation 208
chemical and physical 211, 212
definition 10
equations 358. See also under isotherms.
equilibrium relation 53
forms of 10
hydrolytic 228
irreversible 67, 69
Lanmuir theory 209, 214
physical 211
Polanyi potential 211
precipitation associated with 46, 230
solution phenomena and 362
surface tension 206
temperature influence 12, 33
van der Waals forces 10, 12, 212
velocity of 20, 32, 363
Adsorption-desorption processes, liquid phase 63, 68, 70, 335
vapor phase 149
Advance waste water treatment 8, 126
Aerobic and anaerobic 132
Aerosols 148
Age effect on activated carbon 368
Agricultural applications 165
Air purification 6, 143
Alcoholic beverages 95
Alkali hydroxides and carbonates 111
Alum 111
Amorphous carbon 185
Analytical applications 117
Anticorrosion paints 163
Antidote 281
Antioxidants 94
Apparent adsorption 355
Apple storage 157
Application, optimum point of 311
Applications, liquid 15, 87, 163
  vapor 142, 157
Applications, combined with other forms purification, 7, 23, 41, 46,
  48, 50, 51, 87, 88
Atmospheric pollution 159
Auto emissions 160
AWT. See advanced waste water.
Azeotropic mixtures for desorption 66

Bacteria 279
Bandages, surgical 278
Basic concepts 23
Batch-contact operation 2, 75
Beds, fixed and expanded 129
Beer 98
Beet sugar 90
Benefits other than color and odor removal 7
Benzene recovery 155
BET formula 218
Biochemicals, activity in adsorbed state 277
  purification of 283
Biochemistry 274, 282
Blending carbons 324
Blood char 3, 173
Boiling point, relation to adsorbability 12
Bone char 3, 74, 88
Boundary influence 10, 359
Butter 105

Calcium chloride activation process 173
Cane sugar 88
CAP 84
Capillary condensation 208
Caramel test 329
Carbon chloroform extractables 121
Carbon dioxide activation process 174
  purification 157, 164
Carbon tetrachloride activity and retentivity test 306
Carbonization 172
Catalysis 248
  activated adsorption 253
boundary influence 260
concentration theory 252
intermediate compound theory 252
oriented adsorption 256
pH influence 263
poisoning 251
promoters 259
supports 258
theories 249, 254
Catalytic performance activated carbon 261
carrier 262
dechlorination water 265
halogenation 264
hydrogenation 266
isomerization 265
oxidations 267
promoter 262
sulfur compounds 266
Caustic alkali activation process 181
Chemical agents in conjunction with activated carbon 48, 233
Chemicals purification of, inorganic 110, 113
organic 107
Chemisorption. See chemical adsorption 211, 212
Cheney activity test 305
Chewing gum 164
Chromatographic analysis 118
Cigarette filter 157
Clay used with active carbon 51, 93
Coadsorbates 18, 69, 113
Coal, source activated carbon 184, 189
Coconut char 3, 184
Colloidal contamination, influence 41, 44
  protective action 41, 46
  purification 102
Colloidal products, decolorization and deodorization 102
Colorimeters 30, 315
Concentration of liquids for effective purification 35, 311
Condensibility influence 13
Conjunction adsorption with other methods purification 23, 46, 48, 50, 87, 88
Contact batch operation 75. See also batch contact.
Continuous adsorption process (CAP) 84
Continuous application 80, 81, 99
Corn sugars and syrups 92
Corrosive conditions and suggested equipment materials 76
Countercurrent application 59, 65, 79, 80, 82, 309
Crystallites of amorphous carbon 185
Crystallization combined with activated carbon 50, 107, 108, 319
Crystals, adsorption by 215, 223

Data of adsorption, methods of expressing 52, 53, 58
Dechlorination of water 36, 265
Decolorizing carbons, factors on selection 30
Degassing 299, 363
Density 350, 365
Depolarization dry cell batteries 269
Desorption 7, 63, 66, 67, 68, 71, 200, 201
Disinfectants, disinfecting power reduced in presence of adsorbents 279
Distillation combined with activated carbon 50
Dolomite process of activation 179
Dry cleaning solvents 115
Dubinin theory 211, 222
Dust from carbon, means of control 78, 367
Dye test solutions 326

Edible oils 92
Electrical conductivity 85, 353
Electrode, use of activated carbon 268
Electrophoresis 237
Electroplating solutions 114
Electrowinning 167
Environment 126
Enzymes 276
Equipment, constructional materials 76, 77, 89
Eutrophication 127
Evaluation of carbons for removal impurities of unknown identity 314
Evaporation, foaming 7
Expanded bed 129
Explosive mixtures of organic vapors 150
Fermentations 282
Filter aid 78
Filters 77
Filtration, laboratory studies 317, 352
Fire prevention and control 85
Fixed bed 129
Flotation 114, 166
Foam control 317
Foaming 317
Folic acid 69, 288
Food products 105
Freundlich. See isotherm.
Fruit juices 106
Fruit storage 157
Fuel cells 164
Fungicides 72
Future research 339, 375

Galvanizing baths 163
Gas and vapor industrial systems 11, 142, 157, 158
  test methods 298
Gas masks 5, 142
Gelatin 106
Glucose 92
Glutamic acid 110
Glycerol 108
Gold 112
Granular carbons, hardness-resistance to abrasion 183, 351
  in gas and vapor systems 142
  in liquid systems. See percolation.
  manufacture 184
  tests 334
Granular vs powdered carbons 2, 75, 101, 183

Handling and storage precautions for carbon 84
Haze in liquids, cause and prevention 43, 45
Heat of adsorption 212, 240, 305
Heat of wetting (immersion) 219, 243, 304
Herreschoff furnace (multiple hearth) 202
Honey 107
Hormones 290
Hydrocarbons, separation 156
Hydrogen ion. See pH.
Hydrogen sulfide 266
Hydrolytic adsorption 228
Hydrophilic and hydrophobic surfaces 237, 359
Hysteresis 300

Ignition temperature activated carbons 353
Indoor living quarters 143
Infrared spectrometry 372
Inhibitors chemical reactions 48
Inorganics, adsorption of 15, 46
Insulin 290
Interfaces 11, 359
Intestinal infections 278
Iodine 18, 111
test 330
Ionic exchange properties 343
Ionization influence 17, 235
IRE (Iodine test relative efficiency) 314, 321, 323, 332, 338
Iron 34, 46, 311, 345
Irreversible adsorption 67, 69
Isatin 49
Iseelectric point 239
Isosteres 358
Isotherms, deviations 356
in countercurrent adsorption 60
in desorption 64, 71
method plotting 53, 54

Kiln for activation and regeneration 202

Laboratory procedures for impurities of unknown identity 314, 316, 317, 318
for liquid systems 308, 325, 335, 337
for miscellaneous properties 341
for vapor and gas systems 298
requirements 308
INDEX

Lactic acid and lactates 108
Langmuir theory 209
Lard 95
Layer filtration 90, 92
Low temperature production 158

Macropores 220
Manufacture activated carbon 169, 324. See also activation.
Maple syrup 107
Market review 5
Mayonnaise 105
McBain-Bakr balance 298
Medicines administered with carbon 280
Memory of activated carbon 174, 325
Mercuric chloride 18
Micelles 104
Micropores 220
Milk 105
Mixtures different types carbon 312
Moisture in carbon 341
Moisturized carbon 367
Molasses test method 327, 338
Molecular architecture adsorbates, influence of 16, 235
Molecular sieve carbon 182
Mono- and multi-layers 234
Monosodium glutamate 110
Mother liquors 331
Moving bed (Pulse bed) 83, 130
MRE molasses test relative efficiency 314, 321, 322, 332
MTZ (Mass transfer zone) 81
Multimolecular layer theory 235
Multiple hearth furnace 202
Multiple objectives 312
Multiple solutes 17, 29
Multiple tests 323, 332

Neutral spirits 97
Nickle electroplating 114
Non-carbon constituents of activated carbon 188, 191
Nuclear technology 164
Odors. See tastes and odors.
Oil retention 351
Oils, edible 92
Operational difficulties corrected by carbon 7
Oriented adsorption 236, 359, 360

Particle size of activated carbons 346
Pectin 106
Penicillin 7, 70, 284
Peptization 42, 48, 104, 105, 111, 374
Percolation 75, 81, 89, 334
  counter-current 82
  equipment 82, 89
  fixed vs expanded beds 81, 84, 128, 129, 130
  moving (pulse beds) 83, 130
  parallel and series arrangements of adsorbing beds 82, 83, 130
Perfumes, 164
Permanent gases 159
Permanganate, effects on activated carbon 223
  test method 331
pH 34, 37, 91, 94, 183, 346, 347, 348, 366, 373
  method adjustment 183, 347
  method measurement 346
pH of solution influence 34, 37, 347
Pharmacology 278
Phenol test method 331
Phosphates 345
Phosphoric acid activation of carbon 180
Physico-chemical treatment waste waters 132
Plaster bandages and casts 278
Poisoning, activated carbon as an antidote 281
Polanyi theory 211
Pores 218, 219, 220, 221, 351, 364, 365
Potential theory 211
powdered activated carbons 2, 84, 100, 101, 183, 349, 368
Precipitation as a factor in adsorption 46
Precoats for filters 78
Pressure adsorption effect 14
Purification, definition 1, 7
Pyrogens 291
Pyrolysis 172

Quality control activated carbon shipments 321

Rate adsorption 20, 32, 363
Reducing power activated carbons 232
Regeneration 101, 134, 200, 201, 203
Relative efficiency chart 314
Research future 339, 375
Reservoir, carbon as 71
Retentivity 303
Rubber, prevention color migration 164

Safening pesticides 166
Scrap candy 107
Secondary treatment waste water 127
Sewage. See advance waste water treatment.
Shelf life 38, 319
Shipments in bulk 84
   methods quality control 321, 322
Slurry feeding carbon 78
Smog 6, 143
Solubility influence 16
Solutions 15, 17, 235
Solution phenomena, similarities to adsorption 362
Solvent vapor recovery 149
Solvents 19, 47, 235
Sorption 364
Source materials for activated carbon 169
Specifications for shipments 332
Split application 80
Stack gas, removal SO₂ 159, 160
Stage process for applying carbon 35
Standard carbon 333
Storage carbon 84
Streptomycin 70, 285, 338
Sugar refining 88
Sulfate process carbon activation 180
Sulfide process carbon activation 161
Supersaturated solutions, precautions required 50
Surface area 2, 217, 350
Surface condensation 12
Surface oxides 231, 369, 372
Surface tension 206
Synthetic test solutions 325, 336

Tartaric acid and tartarates 109
Taste and odor removal 35, 36, 146, 147, 305, 319
Temperature influence on adsorption 12, 20, 25, 33
Tertiary treatment waste waters 128
Test methods. See laboratory procedures.
Theories, nature of 205
Threshold odor test 100, 320
Toxicological tests 117
Toxins 280
Traubes rule 364

Unit operations, gas and vapor adsorption 142
  liquid phase adsorption 74
Uranium 70
Urine 117

Vacuum, production of 158
Valences primary and secondary 214
Vesicants, protective fabrics 157
Virus 280
Vitamins 285
Volume filling 211

War gases 5
Water industrial supplies 102
Water potable 98
Water vapor adsorption 367
Wettability of surfaces 237
Whiskey 95
White sidewall tires 164
Wild frothing 166
Wine 97

Zinc chloride process for activation 173