*Kirk-Othmer Encyclopedia of Chemical Technology.*

# DIATOMITE

Diatomite is a naturally occurring, porous, high surface area form of hydrous silica that is used as a filter aid and as a mineral filler. Diatomite products may be classified according to manufacturing method into three categories: natural diatomite [7631-86-9], calcined diatomite [91053-39-3], and flux-calcined diatomite [68855-54-9]. Products from all three categories find widespread use in industrial filtration (qv) applications as a filter aid for achieving higher clarity, longer filter cycles, and removing high solids concentrations. Products from all three categories are also used as functional fillers (qv) where diatomite properties add to the performance of paints, plastics, rubber, catalysts, agricultural chemicals, pharmaceuticals (qv), toothpastes, polishes, and other chemicals.

Diatomite, also known as diatomaceous earth, or kieselguhr, consists mainly of accumulated shells or frustules of intricately structured amorphous hydrous silica secreted by diatoms, which are microscopic, one-celled golden brown algae of the class Bacillariophyceae. Diatoms exist in many different environments and are abundant in regions of oceanic upwelling: 12,000 to 16,000 species of diatoms live in fresh, brackish, or saline waters. Diatom species can live both solitarily and colonially; some are mobile, others stationary. All diatom species have an elaborately ornamented siliceous skeleton, which results in accumulations of uniquely porous particles.

Diatoms are single-celled photosynthetic plants consisting of two shells that fit together in the same manner as the two halves of a pill box (1). Reproduction is by division at such a rate that it is estimated that one diatom can produce $10^{10}$ descendants in 30 days under the most favorable conditions. The diatom plants extract silica from the water to form an encasing shell or exoskeleton. Ocean floor mapping has revealed that diatoms accumulate in areas of oceanic upwelling, where nutrient-rich waters circulate near the sunlit surface, such as along the West Coast and most continents and at the equator (2, 3). Freshwater diatoms accumulate most commonly where silica-rich springs have contributed enough nutrients to foster diatom blooms.

At the end of a brief life, the diatom settles to the bottom of the body of water where the organic matter decomposes, leaving the siliceous skeleton. These fossil skeletons, or frustules, are in the shape of the original diatom plant and have designs as varied and intricate as snowflakes. Examples are shown in Figure 1.

In AD 532 the Roman emperor Justinian used diatomite bricks for lightweight construction of the dome when building the Church of St. Sophia in Constantinople (Istanbul). The names bergmehl, fossil flour, farine fossile, and mountain flour apparently originated when early poverty-driven peoples extended supplies of meal and flour by dilution with diatomaceous earth. Tripoli is a name given to diatomite formerly mined in Tripoli, North Africa. Kieselguhr, the name given to the diatomite first mined in Hanover, Germany, in 1836 or earlier, is still used as a general name for all diatomite products in Europe. An incorrect name that persisted for many years was infusorial earth; incorrect because *Infusoria* comprises a group of the animal kingdom (1). Nobel developed the first important industrial use of diatomite as an absorbent for liquid nitroglycerin in the making of dynamite late in the nineteenth century.

The first commercial shipment of diatomite in the United States was made in 1893 and consisted of material from a small quarry operation in the vast deposit near Lompoc, California. It went to San Francisco to be used for pipe insulation. Small-scale operation of parts of the Lompoc deposit continued until it was

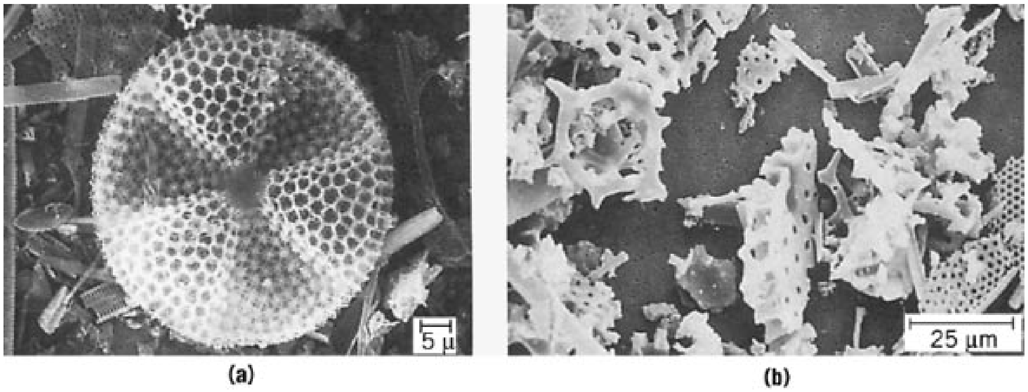

**Fig. 1.** (**a**) Scanning electron photomicrograph of a diatom of the genus *Actinoptycus*, illustrating the ornate and porous nature of the diatom frustule. (**b**) Photomicrograph of a diatomite product showing the variety of shapes and pores that give the products high surface area and ability to trap solids for separation from clear liquids.

acquired by the Kieselguhr Co. of America, which later became the Celite Co. (4). Since that first work, the industry has grown immensely, and diatomite products are used in almost every country.

## 1. Origin of Deposits

Diatoms inhabit fresh, brackish, or sea waters. Environmental changes in the bodies of water where diatoms flourish are reflected by the different types of diatoms that may appear at different levels of the same deposit.

Most commercial marine diatomite deposits exploit accumulations resulting from large blooms of diatoms that occurred in the oceans during the Miocene geological epoch. Diatomite sediments older than the Jurassic period are rare in the fossil record. Commercial deposits of diatomite are accumulations of the fossil skeletons, which can occur in beds as thick as 900 m in some locations (5). Marine deposits must have been formed on the bottom of protected basins or other bodies of quiet water, undisturbed by strong currents, in an environment similar to the existing Santa Barbara Channel or Gulf of California (3, 6).

The main deposits of freshwater diatomite were laid down in large lakes. Many of these deposits in the western United States formed during glacial times, when the local climate was wetter. Several tens of square kilometers in Nevada west of Tonopah are covered with diatomite as are other large areas in the Great Basin.

The principal marine deposits were formed during the Tertiary period and more particularly the upper Miocene epoch. Deposits of freshwater origin date from the Pliocene to Miocene epochs to more recent times, dating to as late as 100,000 years ago. U.S. commercial deposits are at or comparatively near the surface. Bog deposits are exploited and lake beds are dredged for use in other parts of the world.

### 1.1. Location of Deposits

Deposits of diatomite are known to exist on every continent and in nearly every country. Over half of the states in the United States reportedly contain diatomaceous earth deposits. In some cases, deposits of marine and freshwater origin occur almost side by side as do deposits of widely varying ages (5). Most of the deposits are not large enough or sufficiently pure to have commercial value. Production figures show the location of the deposits that meet commercial standards in both respects (7).

In the United States the most extensive commercial deposits are located in California, Nevada, Oregon, and Washington. The U.S. Bureau of Mines also reports the commercial operation of diatomite deposits in Arizona (7).

California contains the largest formation of diatomite in the United States; the Monterey Formation extends from Point Arena in Mendocino County in the north to San Onofre in the south (7). The most extensive deposit is near Lompoc, Santa Barbara County, and is of marine origin. A freshwater deposit is being mined near Burney, Shasta County. Other important deposits (not mined as of this writing) are located in Monterey, Fresno, Inyo, Kern, Orange, San Bernadino, San Joaquin, Sonoma, and San Luis Obispo counties.

Oregon production of filter aids is from a deposit near Ontario, Oregon, and of pet litter from near Christmas Valley. An extensive deposit near Terrebonne, Oregon, was operated from 1936 to 1961. Four different companies operate at least five deposits in Nevada. Of the several comparatively large deposits in Washington, only one, near Quincy, is being operated on a commercial scale (7).

In Canada, large freshwater deposits are found in British Columbia, and small deposits are located in Nova Scotia, New Brunswick, Quebec, and Ontario. A small amount of diatomite production has been reported in Costa Rica, Chile, Brazil, and Argentina. Although deposits exist on other continents, the most important are in Europe, Africa, and Asia, primarily in Japan and Korea. Large deposits have been reported in the Caucasus Mountains of the former USSR. The leading producers in Europe operate in Romania, Germany, Italy, Iceland, and Denmark. Both Danish and Romanian diatomite production, although high in terms of tonnage, is of comparatively low value. Most Romanian diatomite is used as a binder in the construction industry and the Möler earth of Denmark is used as an absorbent, for bricks, and in agriculture (8). African deposits are located in Algeria and Kenya, and there are some small operations in the Republic of South Africa. Diatomite deposits also have been developed in Japan and China.

## 2. Physical and Chemical Properties

Chemically, diatomite consists primarily of silicon dioxide [7631-86-9], $SiO_2{\cdot}nH_2O$, and is essentially inert. It is attacked by strong alkalies and by hydrofluoric acid but is virtually unaffected by other acids. The silicon dioxide has a unique structure, resulting from the intricate form of the diatom skeletons. The chemically combined water content varies from 2 to 10%. Impurities that are often found mixed with the diatomite are other aquatic fossils such as sponge residues, Radiolaria, silicoflagellata, sand, clay, volcanic ash, mineral aerosols, calcium carbonate, magnesium carbonate, soluble salts, and organic matter. The types and amounts of impurities are highly variable between the deposits and depend on the conditions of sedimentation at the time of diatom deposition. Variations also exist within deposits. Typical chemical analyses of diatomite products are given in Table 1.

The color of pure diatomite is white, or near white, but impurities such as carbonaceous matter, clay, iron oxide, volcanic ash, etc, may darken it. The refractive index ranges from 1.41 to 1.48, almost that of opaline silica. Diatomite is optically isotropic.

Individual diatom frustules are porous. The diatoms are highly variable in shape and size, having particles that range in effective diameter from 0.75 to 1000 $\mu$m, but most are 50 to 100 $\mu$m in diameter. Diatom shapes can range from simple cylinders and disks to complex, highly variable, but always punctate, forms. The highly variable array of shapes gives marine diatomite an advantage in certain filtration applications over freshwater diatomite. The latter usually contains fewer genera and less variation in size and shape.

The bulk density of powdered diatomite varies from 112 to 320 kg/m$^3$. The true specific gravity of diatomite is 2.1 to 2.2, the same as for opaline silica, or opal (1). The thermal conductivity of bulk quantities of diatomite is low but increases with higher percentages of impurities and a higher density. The fusion point depends on the purity but averages about 1430°C for pure material, which is slightly less than for pure silica. The addition of chemical agents, such as soda ash, reduces the fusion point.

**Table 1. Spectrograpic Analysis of Diatomite Products**[a, b]

| Constituent, wt % | Diatomite Natural | Diatomite Calcined | Diatomite Flux-calcined |
|---|---|---|---|
| $Al_2O_3$ | 4.06 | 3.54 | 3.63 |
| $Fe_2O_3$ | 1.54 | 1.45 | 1.40 |
| CaO | 0.91 | 0.69 | 0.71 |
| $Na_2O$ | 0.53 | 0.59 | 3.86 |
| $P_2O_5$ | 0.27 | 0.18 | 0.17 |
| MgO | 0.67 | 0.54 | 0.60 |
| $K_2O$ | 0.67 | 0.62 | 0.62 |
| $SiO_2$ | 89.90 | 90.80 | 87.90 |
| $TiO_2$ | 0.21 | 0.20 | 0.21 |
| *Total* | *98.76* | *98.61* | *99.10* |

[a] Refs. (9, 10).
[b] On a dry basis.

Diatomite has only weak adsorption (qv) powers but shows excellent absorption (qv) because of its structure and high surface area. Acids, liquid fertilizers (qv), alcohol, water, oils, and other fluids are absorbed by diatomite.

## 3. Mining and Processing

Diatomite deposits are usually discovered by observation of outcrop, and the value of the deposits is determined by geological prospecting and exploration. Samples are taken from the surface outcrops by digging or trenching; underground samples are secured from test holes, core drill holes, or tunnels. Samples are examined chemically, physically, and microscopically to determine the suitability of the diatomite for various uses.

### 3.1. Mining

Most diatomite is mined by open-pit methods. Layers of crude are cleaned by bulldozers or scrapers, and overburden is removed. Samples are obtained and analyzed. After the material has been assigned a grade, the diatomite is broken up using bulldozer scarifiers and then is loaded into trucks by belts, hydraulic excavators, or scrapers. Stockpiles are used at the mine or plant site for air drying, storing, or blending the crudes. Underground mining techniques were used in the United States for a short time and are still in use in countries where low cost labor is available.

### 3.2. Processing

Three general types of diatomite are produced, and a range of grades exists in each. Grade, as used herein, refers not to the quality of the product but designates one of the series of products made for specific uses. Producers often supply custom-made materials for specialized applications.

The crude diatomite, which may contain up to 60% moisture, is first milled in a method that preserves the intricate structure of the diatomite. This material is fed to dryers operating at relatively low temperatures, where virtually all of the moisture is removed (see Drying). Coarse and gritty nondiatomaceous earth material is removed in separators and preliminary particle size separation is made in cyclones. For many producers, all of the manufacturing processes, with the exception of the calcination step, take place while the material is being pneumatically conveyed. The resultant material is termed natural product. This is the only type of diatomite made by some producers.

Calcined diatomite is produced from natural diatomite, which is then subjected to high temperature calcination in a rotary kiln at about 980°C. The calcined material is then again milled and classified to remove coarse agglomerates as well as extreme fines.

The third type of product, flux-calcined diatomite, is obtained by calcination of the natural product in the presence of a fluxing agent, generally soda ash, although sodium chloride can also be employed. Such processing has the effect of reducing the surface area of the particles, changing the color from the natural tan color to a true white, and rendering various impurities insoluble. Some of the diatomite is converted on calcination to cristobalite [14464-46-1]. Most diatomite contains a small percentage of quartz (less than 5%), calcined diatomite can contain up to 25% cristobalite, and flux-calcined diatomite can contain up to 65% cristobalite.

## 4. Economic Aspects

Processed diatomite powders and aggregates in the United States range in price from $20 to $225/t for products in carload quantities. Materials for specialized applications, which are sold in small volumes and require special processing, range up to $900/t in carload quantities. All of these prices are fob the diatomite plant.

Owing to the low bulk density of diatomite, freight and trucking rates (on a weight basis) are high. Domestic finished products are packed and shipped in laminated kraft-paper bags, usually containing 22.5 kg, or the product is shipped in bulk or semibulk bags. Bagged products are shipped by truck or rail boxcar, normal boxcar loading being 27 to 36 metric tons. It may also be palletized and wrapped using a polyethylene shrink wrap. Bulk shipments are also made in pressure-differential trucks of 45 and 74 $m^3$ (1600 and 2600 $ft^3$). These carry 12 to 15 tons and 16 to 21 tons, respectively. Distribution by bulk truck is confined to the economical trucking distance from the producing plant. Semibulk shipments are made in bags holding approximately 1.27 $m^3$.

For longer distances, pressure-differential rail hopper cars can be used, which hold between 36 to 45 metric tons per car. In-plant storage is in conventional silos, usually having a 60° cone bottom. The silo may be pressurized for discharge, but this is exceptional. Normally, diatomite is moved from the silo to an adjacent small pressure vessel for transfer to user sites. The material may be aerated and pumped using a modified diaphragm pump. Bulk handling has the advantage of improved environmental conditions as well as lower handling cost in comparison with bagged material. Care must be taken in all types of conveying not to degrade the diatom structure.

### 4.1. Domestic Producers

A principal company mining diatomite and processing it into finished products is Celite Corp. (Lompoc, California), which has wholly owned mines and processing facilities in Lompoc, California; Quincy, Washington; Jalisco, Mexico; Murat, France; Alicante, Spain; and a joint venture mine in Iceland. Other companies are Grefco, Inc. in Lompoc and Burney, California, and Mina, Nevada, and Eagle-Picher Industries, Inc., in Sparks and Lovelock, Nevada, and Vale, Oregon. Production was also reported by the U.S. Bureau of Mines for 1990 by Whitecliff Industries, Mammoth, Arizona; Canyon Resources Minerals Corp., Fernley, Nevada; and Oil-Dri Production Co., Christmas Valley, Oregon (7, 11).

### 4.2. Production

Annual diatomite production in the United States fluctuated in the 1980s from a high of 689,000 t (1980) to 570,000 t (1986). In 1990, production was 619,000 t. After the United States, Romania, the former USSR,

**Table 2. Annual World Production of Diatomite**[a]

| Country | Production, t | |
|---|---|---|
| | 1989 | 1990 |
| United States | 617,000 | 619,000 |
| Brazil | 20,000 | 20,000 |
| Denmark | 72,000 | 70,000 |
| France | 260,000 | 260,000 |
| Germany | 48,000 | 50,000 |
| Iceland | 25,000 | 25,000 |
| Italy | 28,000 | 30,000 |
| Korea, Republic of | 70,000 | 70,000 |
| Mexico | 35,000 | 35,000 |
| Romania | 260,000 | 260,000 |
| Spain | 100,000 | 100,000 |
| USSR | 260,000 | 260,000 |
| other countries | 43,000 | 45,000 |
| *World Total* | *1,838,000* | *1,844,000* |

[a] Estimated values from Ref. 7.

and France are the largest producers of diatomite. Combined with the United States, these countries account for more than 75% of the world's production. The production totals for the 12 highest diatomite-producing countries are shown in Table 2.

## 5. Specifications, Standards, and Quality Control

Diatomite is tested from the mining bench through the production process to the bag. Methods depend in part on use. For use in pigments, there are ASTM (12) and military (13) specifications. Other specifications relate to use in the pulp (qv) and paper (qv) industry (14), in water (qv) purification (15), and for use in pharmaceuticals (qv) (16).

The diatomite is analyzed for principal element oxides by the wavelength-dispersive x-ray fluorescence spectrometer (xrf), for trace element analysis, and for compliance with *Food Chemical Codex* specifications (17) by inductively coupled plasma spectroscopy (icp) or by atomic absorption spectrophotometry. The material is tested for permeability by timing the passage of a known volume of liquid through a filter cake under a constant pressure differential. The diatomite is tested for wet cake density and for color using a photovolt meter or the Hunter colorimeter. Particle sizes are obtained by sieving, by using a monochromatic light-scattering particle size analyzer, or by using the Hegman fineness test.

## 6. Uses

Diatomite products have unique characteristics of high surface area, low bulk density, high water and oil absorption, and high permeability. Each fossil particle, because of its silica composition, is a rigid but porous and irregular shape. Table 3 lists useful properties of typical diatomite products. In general, diatomite products can be grouped according to use as filter aids, fillers (qv) or extenders, adsorbents, catalyst carriers, insecticide carriers or dilutents, fertilizer conditioners, thermal insulation, and miscellaneous. In physical form, powders make up by far the greatest proportion of diatomite products. Mean particle diameters range from 0.75 to 20 $\mu$m. Aggregates are available for special uses and range from 1.5-cm particles to fine powders.

**Table 3. Property Ranges of Diatomite Products**[a, b]

| | Filter aids | | | |
|---|---|---|---|---|
| Property | Natural | Calcined | Flux-calcined | Fillers, all types |
| permeability range, $\mu m^2$[c] | 0.06 | 0.5–2.0 | 1.0–29.6 | |
| density, $kg/m^3$ | | | | |
| wet cake | 240–350 | 270–350 | 290–380 | |
| bulk | 112 | 120–128 | 144–336 | 104–160 |
| particle size distribution (granulometer), $\mu m$ | | | | |
| 10% less than | 1.5–3.6 | 2.5–4.4 | 7–11 | 2–4 |
| 50% less than | 7.0–13.4 | 10.0–16.1 | 25–37 | 6–20 |
| 90% less than | 25–44.5 | 30.0–58.9 | 65–97 | 14–30 |
| approximate pressure differential[d], kPa[e] | 36.5 | 2.33–4.56 | 1.11–0.058 | |
| specific gravity | 2.00 | 2.25 | 2.33 | 2.0–2.3 |
| porosity, by volume, % | 65–85 | 65–85 | 65–85 | 65–85 |
| median pore size range, $\mu m$ | 1.5 | 3.5–5.0 | 7–22 | [f] |
| surface area, $m^2/g$ | 10–20 | 4–6 | 1–4 | 0.7–30 |
| pH | 6.0–8.0 | 6.0–8.0 | 8.0–10.0 | 6.0–10.0 |
| refractive index | 1.42 | 1.44 | 1.48 | 1.40–1.49 |
| oil absorption, % | | | | 100–210 |
| particle size, retained % | | | | |
| 98 $\mu m$ (150 mesh) | 1–2 | 4–7 | 6–40 | |
| 44 $\mu m$ (325 mesh) | 0–12 | | | 0–14 |
| Moh's hardness | 3.5–4.0 | 4.5 | 5.5–6.0 | 3.5–6.0 |

[a] Values given are typical or estimated values, not specifications.

[b] Refs. (9–11).

[c] To convert from $\mu m^2$ to d'Arcys, multiply by 1.013.

[d] Measurement at 0.034 cm/s and 0.1 $g/m^2$ precoat.

[e] To convert from kPa to psi, multiply by 0.145.

[f] The Hegman gauge readings, useful for paint manufacture, run from 0–55.

There are two principal ways in which finished diatomite products are used in manufacturing plants: either as a filter aid (see Filtration), where the diatomite is expendable, or as a filler, where the diatomite becomes a component and remains as part of the manufactured product. As of 1990, the use of diatomite products was 71% filtration, 15% fillers, and 14% other (7).

### 6.1. Filtration

Diatomite is used as a filter aid for applications with difficult-to-filter solids to improve permeability of the filter cake, to prevent the blinding of filter elements, and where high clarity is required such as in the polish filtration of wine (qv) or beer (qv) before bottling. It is also used in sugar (qv) refining, water treatment, and in the production of fruit juices (qv) and industrial chemicals.

Typically, a filter cake or precoat is built up on the filter septa to prevent blinding, short filter cycle times, and costly cleaning of the septa. Then diatomite is added as body feed to the liquid to be filtered so that the permeability of the filter cake may be maintained. Filler aid permeability of diatomite ranges from 0.06 to 30 $\mu m^2$. At the end of the filter cycle the filtrate is clear and the solids are retained in the solid or semisolid diatomite filter cake. The type and amount of diatomite for precoat and body feed are normally determined by pilot studies (18, 19).

The first use of diatomite as a filter aid was for the filtration of sewage sludge (4). Further use developed in cane sugar refining (20). In this technology, diatomite filter aids are used in the filtration of various liquors in refining cane, beet, and corn sugars and in clarification of syrups (qv), molasses, etc. From the techniques developed in the sugar refining industry, diatomite filtration was applied to a wide range of separation problems involving beer, chemicals, water, solvents, antibiotics (qv), oils and fats, phosphoric acids, and many others. The necessity of producing clean plant effluent has spurred the application of diatomite filtration for solids removal to clarify the waste streams of manufacturing plants (see Wastes, industrial).

### 6.2. Fillers

Diatomite mineral fillers are used primarily (*1*) where bulk is needed with minimum weight increase, (*2*) as an extender where economy of more expensive ingredients is a factor, or (*3*) where the structure of the particle is important. In other applications, diatomite can add strength, toughness, and resistance to abrasion, or it can act as a mild abrasive and polishing agent (see Abrasives).

The paint (qv) and plastics industries are typical of those employing diatomite extensively as fillers and pigment extenders. Diatomite is useful as a filler in paint where it forms a rougher surface, provides a flatting effect, and because of its porous intricate structure, allows faster drying and may improve intercoat adhesion. Also diatomite is extensively used as a polyethylene antiblocking agent where the irregular shapes of the diatom act as a mechanical barrier that prevents sticking of hot polyethylene films during production.

Diatomaceous earth has been used as a chromatographic support since the inception of gas chromatography. A diverse line of products are available. The high surface area and structure of diatomite enables it to carry the liquid phase while an inert surface prevents interference with partitioning. Properly treated diatomite chromatographic supports make use of all its unique properties (10).

### 6.3. Insulation

Diatomite makes an efficient thermal insulator because of its high resistance to heat (fusion point at 1430°C) and its high porosity (see Insulation, thermal). Materials in the form of powders, aggregates, and bricks are most commonly used. At one time, solid bricks were sawed directly from strata in a deposit, dried in a kiln, and then milled to size. In this form, the diatomite can withstand direct service temperatures up to 870°C without undue shrinkage. This type is no longer available, although it was widely used as a brick course in walls, bases, and tops of heated equipment. Diatomite insulating bricks for all temperatures are now formed by adding binder, molding the mixture to sizes and shapes desired, and then firing in a kiln. Diatomite powders and aggregates are often installed loose over tops or in hollow wall spaces of furnaces, kilns, ovens, etc. Calcined aggregates are supplied for mixture with water and Portland cement (qv) for casting bases, doors, baffles, etc, for various types of heated equipment.

### 6.4. Other Uses

There are many miscellaneous uses of diatomite; some are highly specialized and extensive. As a pozzolanic admixture in concrete mixes, diatomite improves the workability of the mix, permitting easier chuting and placement in intricate forms. Diatomite is also used as a catalyst support (see Catalysis). Diatomaceous earth powders are used as carriers for insecticides and as fluffing agents for heavier dusts. Certain diatomite powders act as a natural insecticide and are used to protect seeds and stored grain (see Insect control technology). The fertilizerindustry uses large quantities of diatomite as an anticaking agent or conditioner, particularly for prilled ammonium nitrate. The diatomite greatly reduces absorption of moisture by the fertilizer, thus preventing caking in the bag and making spreading easier (see Fertilizers).

## BIBLIOGRAPHY

"Diatomite" in *ECT* 1st ed., Vol. 5, pp. 3–37, by H. Mulray, Sierra Talc & Co.; in *ECT* 2nd ed., Vol. 7, pp. 53–63, by E. L. Neu, Great Lakes Carbon Corp.; in *ECT* 3rd ed., Vol. 7, pp. 603–614, by E. L. Neu and A. F. Alciatore, Grefco, Inc.

### Cited Publications

1. R. Calvert, *Diatomaceous Earth, American Chemical Society Monograph Series, Chemical Monograph Series*, J. J. Little & Ives, Co., New York, 1930.
2. A. P. Lisitsyn, *Int. Geol. Rev.* **9**, 631 (1967); **9**, 842 (1967); **9**, 980 (1967); **9**, 1114 (1967).
3. S. E. Calvert, *Geol. Soc. Am. Bull.* **77**, 569 (1966).
4. A. B. Cummins, *The Development of Diatomite Filter Aid Filtration and Separation*, Uplands Press, Ltd., Craydon, UK, 1973.
5. W. W. Wornardt, Jr., *Occasional Papers of the California Academy of Sciences, No. 63*, California Academy of Sciences, Los Angeles, 1967.
6. A. Soutar, S. R. Johnson, and T. R. Baumgartner, in C. Isaacs and J. Garison, eds., *The Monterey Formation and Related Siliceous Rocks of California*, Society of Economic Paleontologists and Mineralogists, 1981, p. 123.
7. L. L. Davis, in L. L. Davis, *Mineral Commodity Summaries, 1991*, U.S. Bureau of Mines, Dept. of the Interior, Washington, D.C., 1991, p. 50.
8. L. Pettifer, *Ind. Minerals* **1** (175), 47 (1982).
9. *Celite Filter Aids for Maximum Clarity at Lowest Cost*, Internal Publication No. FA-84, CELITE Corp., Lompoc, Calif., 1984.
10. *Functional Fillers for Industrial Applications*, Internal Publication No. FF-396, CELITE Corp., Lompoc, Calif., 1984.
11. F. L. Kadey, in S. J. Lefond, ed., *Industrial Minerals and Rocks*, 5th ed., AIME, New York, 1983, p. 677.
12. *ASTM D604-81; D719-86*, American Society for Testing and Materials, Philadelphia, Pa., 1989.
13. U.S. Military Specifications, *MIL-S-15191C*, 1986; *52-MA-522a*.
14. TAPPI, *T658 OS-77*, Washington, D.C.
15. U.S. Military Specification, *MIL-F-52637A*, 1978.
16. *U.S. Pharmacopeia, The National Formulary*, USP XXII, NF XVII, 1990, p. 1738.
17. *U.S. Food Chemical Codex*, 3rd ed., 3rd suppl., 1992, p. 99.
18. C. W. Cain, Jr., in J. J. McKetta, ed., *Encyclopedia of Chemical Processing and Design*, Vol. **21**, Marcel Dekker, Inc., New York, 1984, p. 348.
19. J. Kiefer, *Brauwelt Int.* **6**, 300 (1991).
20. H. S. Thatcher, *Sugar Filtration—Improved Methods Filtration*, Kieselguhr Co. of America, Lompoc, Calif., 1915.

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## Related Articles

Filtration; Insulation, thermal