
12 Fiber Webs

Roger M. Rowell^{1,2}, James S. Han¹, and Von L. Byrd¹

¹USDA, Forest Service, Forest Products Laboratory, Madison, WI and

²Biological Systems Engineering Department, University of Wisconsin, Madison, WI

CONTENTS

12.1	Webs and Mats.....	350
12.1.1	Forming Options.....	352
12.1.1.1	Layering.....	352
12.1.1.2	Fiber Mixing.....	352
12.1.1.3	Use of Additives.....	353
12.1.1.4	Scrim Addition.....	353
12.1.1.5	Card Combined with Air Forming.....	353
12.1.1.6	Melt Blown Polymer Unit (MBP) Combined with Air Forming.....	353
12.2	Pulp Molding.....	353
12.3	Geotextiles.....	355
12.3.1	Erosion Control.....	355
12.4	Filters.....	357
12.4.1	Types.....	357
12.4.1.1	Physical Types.....	357
12.4.1.2	Chemical Types.....	357
12.4.2	Applications.....	357
12.4.3	Testing Protocols for Filters.....	359
12.4.3.1	Kinetic Tests.....	359
12.4.3.2	Isotherms.....	359
12.4.4	Biofilters for Organic Compounds.....	360
12.5	Sorbents.....	360
12.5.1	Density.....	360
12.5.2	Porosity and Surface Area.....	360
12.5.3	Selectivity.....	360
12.5.4	Retention.....	361
12.6	Mulch Mats.....	361
	References.....	361

Wood fibers can be used to produce a wide variety of low-density three-dimensional webs, mats, and fiber-molded products. Short wood fibers blended with long fibers can be formed into flexible fiber mats, which can be made by physical entanglement, nonwoven needling, or thermoplastic fiber melt matrix technologies. The most common types of flexible mats are carded, air-laid, needle-punched, and thermobonded mats. In carding, the fibers are combed, mixed, and physically entangled into a felted mat. These are usually of high density but can be made at almost any density. Air-laid webs are made by laying down layers of wood fibers combined with a low-melting

thermoplastic fiber, then passing the webs through a heated chamber that melts the thermoplastic. The heated web is then passed through calender rolls that press the melted fibers together with the wood fibers, holding the web together. A needle-punched mat is produced in a machine that passes a randomly formed machine-made web through a needle board that produces a mat in which the fibers are mechanically entangled. The density of air-laid webs and needled mats can be controlled by the amount of fiber going through the processes or by overlapping webs or mats to give the desired density. A thermobonded mat is made by combining natural fibers with a thermoplastic fiber in the needled mat technology that is then melted in a heated press holding the mat together. The webs and mats can be used as filters, geotextiles, sorbents, and mulch mats.

Wood fibers can also be formed into fiber-based products using air or water as a carrier. Fibers can be sprayed in an air stream and used as insulation or ground cover. Fibers can be slurried in water, molded into wide variety of shapes (pulp molding), and dewatered to form the final dry product.

12.1 WEBS AND MATS

Early information indicates that the Russians experimented with air forming during the 1930s. During this period, a patent was issued to two Russians describing a method for the production of a dry web using synthetic fiber and air (Pusyrev and Dimitriev 1960). In the early 1960s, a patent was issued to James Clark for the air forming of fibrous material and consolidating it into a web or sheet (Clark 1960). Later in the decade, a Finnish inventor named H.J. Hieldt developed an air forming method that involved the use of an electrostatic current to help guide the fibers.

In the mid-1960s, the Rando Corporation in the United States developed a different system in order to process long synthetic fibers for use in medium density fiberboard (Curlator Corp. 1967). The Rando system is shown in Figure 12.1. Section A in Figure 12.1 is where the fiber is fed into the system. Section B is a fiber opener where fiber bundles are separated and mixed with other fibers. Between A and B, the fibers are formed into a continuous mat, which is fully formed at C. There are several options at C. A liquid or powdered adhesive can be added if the final product is a web to be thermally formed into a three-dimensional composite. Another option is to place a seed applicator here to incorporate different types of seeds into the mat to be used as seeding geotextiles. At D, the web can go on through a needle board where the web is “needled” together in a nonwoven process. Some of the Rando systems were modified to make lighter weight webs

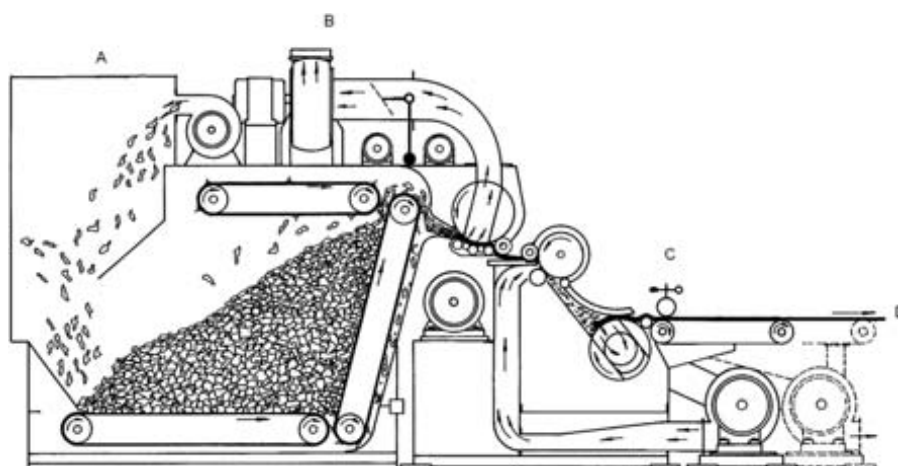


FIGURE 12.1 Schematic of Rando fiber mat forming system.

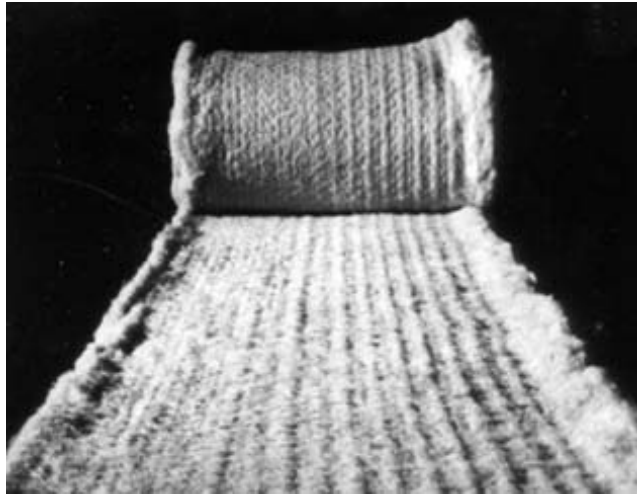


FIGURE 12.2 Fiber mat made using the Rando system.

that include wood pulp (Rando 1993). Both of these early systems were relatively speed limited. Figure 12.2 shows a web that has been made using the Rando system and a needle board.

In the early 1970s, a Japanese firm, Honshu, developed a process for making a variety of nonwovens using wood pulp and synthetic fibers. Most recently, Danweb Forming International, Ltd., developed a drum former capable of utilizing synthetic or natural fibers of various lengths (Danweb 2003, Figure 12.3). In addition, this firm has made use of a new and simpler horizontal machine layout (Wolff and Byrd 1990, Byrd 1990a,b).

The essential features of the drum system comprise two perforated counter-rotating drums (Figure 12.3B) located transversely above the forming wire within a square-section box. These drums are connected to a fixed pipe, such that the drums and their pipes form a track. A series of brush rolls are located inside the drums, transverse to the wire. The box itself is sealed in the transverse direction by means of seal rolls, and in the longitudinal direction with side plates. Figure 12.4 shows a typical mat made using the Danweb system.

In operation, the fibers, dispersed in air, are fed into the rotating drums via the fixed pipes. As the fiber stream passes into the drums, the brush rolls will force the fibers—partly as a result of a centrifugal effect and partly as a result of turbulence—through the perforated walls of the drum. The air from the suction box then draws the fibers onto the forming wire. The supply of single or mixed fibers is connected to the “horse-track” in such a way that a circular movement is ensured within the system. This guarantees a completely uniform distribution.

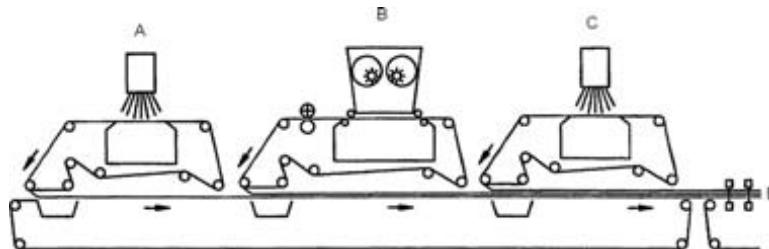


FIGURE 12.3 Schematic of Danweb fiber mat forming system.

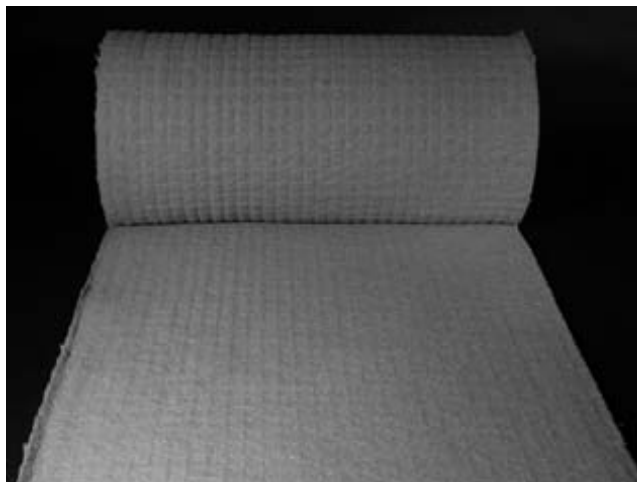


FIGURE 12.4 Fiber mat made using the Danweb system.

The drum system also has the advantage that it allows partially opened fibers to be separated out of the flow, because, as a result of their inertia, they remain on the outer wall of the track. This feature of the system makes it particularly useful in handling recycled fibers.

An additional advantage of the drum-type former is its ability to handle fibers up to 25 mm in length. This permits the addition of regular staple fibers or bonding fibers without modifying the former. Forming capacity remains fairly constant with fiber lengths up to 12 mm and then declines somewhat with fiber length from 12–25 mm.

One of the unique features of modern air forming systems, unlike those of a decade ago, is their flexibility with respect to feedstocks. Much of the early work in air forming centered around recycled and virgin cellulose fibers. This work has advanced to the point where a number of full-scale commercial air forming systems are in operation, producing a wide variety of absorbent and decorative disposables. More recent work with advanced air forming systems has focused on a wide variety of natural and synthetic fibers, which could logically be expected to be used in more advanced composite materials.

12.1.1 FORMING OPTIONS

The identification of forming options and understanding their flexibility can conserve materials as well as process steps throughout the manufacturing process. Some of the composite web or molded product options that would be available with forming unit layouts are discussed next.

12.1.1.1 Layering

By placing different feedstocks in different forming heads, a manufacturer can produce a composite material with high-performance, high-cost materials on the exterior of the web and low-performance, low-cost material on the interior of the web. Figure 12.3 shows a Danweb system with several different options. Section A and/or Section C can be used to add a top or bottom layer of fiber or other film to the fiber mat that is formed in Section B.

12.1.1.2 Fiber Mixing

The inherent ability of the air former to handle streams of mixed fibers of different fiber types, deniers, and lengths permits in-line forming of a composite. Also, the fiber mixture can be varied for each forming head, which provides additional product flexibility.

12.1.1.3 Use of Additives

Work has been done that demonstrates how additives, such as superabsorbent powders and binders, can be added to the web during the forming process (Figure 12.2 Section C, Figure 12.3 Section A or C). In the case of superabsorbents, one advantage of this approach is that the superabsorbent powder, when near the area of maximum void space in the web, can absorb liquids faster and in greater quantity than if added to a finished web as part of a laminate in an off-line process. Also, because of their uniform dispersion, powdered binders can perform in much the same manner to ensure maximum strength with a minimum add-on.

12.1.1.4 Scrim Addition

Composite materials can be further enhanced through the addition of an open net or scrim between two of the air forming heads. This can simplify the process and possibly result in the use of less total raw material (Figure 12.3 Section A or C).

12.1.1.5 Card Combined with Air Forming

The first technique discussed is a means of combining a card with an air forming unit. From the standpoint of size and speed, these two processes are quite compatible. The advantages of a process combination such as this for composites are many: combination of long and short fibers, increased uniformity and bulk of composite materials, the ability to adjust the quantity of different fibers to be used in the process and process simplicity. Both are proven processes and compatible in terms of speed and machine trim.

Economic advantages obtained from a combination of air forming techniques include (a) the ability to make a thermally bondable composite for either single or multistage bonding; (b) the ability to substitute low-cost raw materials such as wood pulp and waste synthetic fiber in place of higher cost fibers; and (c) the ability to limit capital expenditures by upgrading an existing card line versus purchasing an entirely new nonwoven line.

12.1.1.6 Melt Blown Polymer Unit (MBP) Combined with Air Forming

Another technique is a combination of melt blown and air forming processes. This approach permits a composite to be produced in-line as a single process. If required, the process could include a provision for blanking out the center wood pulp core where the top and bottom layers of melt blown are thermally bonded.

This technology represents options to produce such products as (a) oil absorbent pads, (b) backing, laminating composites, and (c) wipes.

Air forming systems offer many product and process advantages in the production of both flexible and rigid composite materials. The units are of manageable size and can be combined with other process equipment to offer significant materials flexibility. From a commercial standpoint, air forming is a relatively young technology. We can expect current and improved systems to play an increasing role in future production of composite materials.

12.2 PULP MOLDING

Composites can be made using wood fibers in a wet process that forms a composite by dewatering the slurry (Laufenberg 1996). This is used today to make such products as egg cartons and nesting packaging where products are kept apart with a thin wall of molded pulp. Pulp molding is done using a forming slurry of pulp fibers with a consistency of 0.5 to 5% (dry fiber weight/water weight). Pulp molding is done in two steps: forming a dense fiber network from a wet fiber slurry onto a

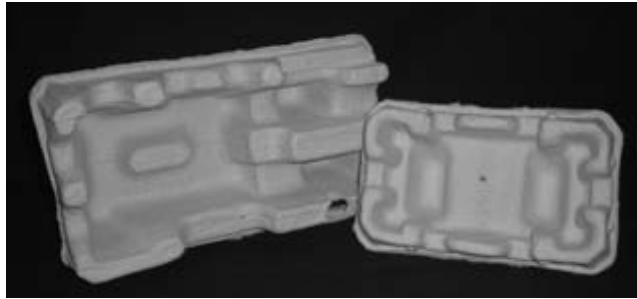


FIGURE 12.5 Products made by pulp molding.

configured surface or mold, and drying. Most of the pulp molding is done using a drainable surface (fine mesh screen), initial dewatering by gravity, vacuum dewatering and finally, heat drying. The pulp slurry is either poured into the mold or the mold is dipped into the pulp slurry and withdrawn or the slurry is pumped into the mold. For highly uniform surfaces, the pulp slurry consistency should be very low (see Figure 12.5).

Drying the wet formed product is done in one of several ways. Densification and drying can be done by applying pressure to the molded product. Minimal density and strength will result without the use of pressure in the drying step. The partially dewatered product can be dried in an oven. The strength of the final product comes from interfiber bonding similar to the bonds formed in the paper-making process. Starch can be added for increased bonding strength; however, since these products were formed in a wet medium, the products have very little wet strength or wet stiffness.

Structural pulp molded products can also be made using a similar process. Setterholm (1985) developed a method of forming a three-dimensional, waffle-like structure using a hard flexible rubber forming head. The product was called “Spaceboard” and could be used for structural applications. Further advancements were made by Hunt and Gunderson (1988) and Scott and Laufenberg (1994), as shown in Figure 12.6.

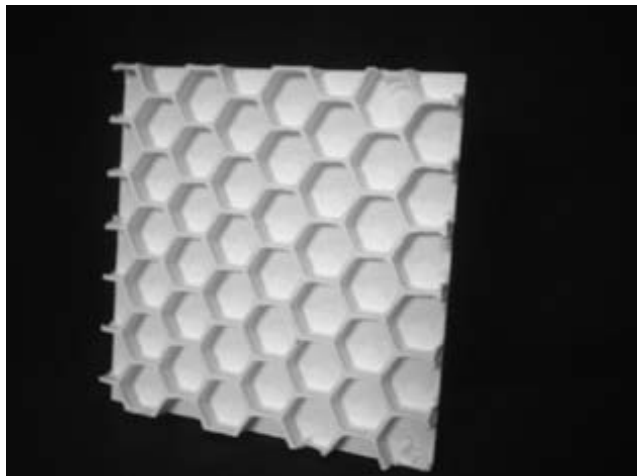


FIGURE 12.6 Spaceboard—A structural pulp molded product.

12.3 GEOTEXTILES

Geotextiles derive their name from the two root words *geo* and *textile*, referring to the use of fabrics in association with the earth. Modern erosion control is mainly done using geotextiles made using synthetic materials such as polypropylene and polyethylene. Wood and other agricultural fibers can be made into geotextiles that can be used to control erosion by using either the Rando or the Danweb process.

12.3.1 EROSION CONTROL

Soil type and vegetation coverage are critical factors in the ability of the land to sorb water. With a healthy forest, where at least 60–75% of the ground is covered with vegetation, only about 2% or less of rainfall becomes surface runoff and erosion is low (less than 0.05 tons loss per acre). When the vegetation cover is between 35 and 50%, the surface runoff increases to 14% with a soil loss of 0.5 tons per acre. Finally, when the vegetation cover is less than 10%, the surface runoff increases to 73% with a soil loss of 5.55 tons per acre (Sedell et al. 2000). From these simple statistics, it is easy to see the effect catastrophic forest fires can have on our fresh water supply.

When there is a severe fire and little ground vegetation remains, surface runoff can increase over 70% and erosion can increase by three orders of magnitude (Bailey and Copeland 1961). There are three components to erosion: detachment, transport, and deposition. The rate of erosion will depend on the geology, topography, vegetation, and climate. In flat terrain, erosion may be minimal after a fire. However, in steep terrain, surface soil loss can be severe following a fire (Figure 12.7).

After the fire, burned land usually sorbs water more slowly than unburned land (Anderson and Brooks 1975). A severe fire in a forest can easily create a ground condition in which surface runoff can lead to flash floods, and erosion can result in not only loss of soil but also in badly contaminated water. Increases in water flow after a fire can result in more solids and dissolved materials in the water (DeBano et al. 1998). Water-soluble and insoluble nutrients can increase aquatic plant growth that may decrease water flow. Inorganic compounds leaked into the water increase the soluble ions that may increase both turbidity and toxicity of the water (Robichaud et al. 2000).

The addition of such chemicals could be based on silvicultural prescriptions to ensure seedling survival and early development on planting sites where severe nutritional deficiencies, animal and fire damage, insect attack, and weed problems are anticipated. Medium-density fiber mats can also



FIGURE 12.7 Example of severe soil erosion.



FIGURE 12.8 Application of fiber-based geotextiles.

be used to replace dirt or sod for grass seeding around new homesites and along highway embankments and stream beds. Grass or other types of seed can be incorporated in the fiber mat. Fiber mats promote seed germination and good moisture retention. Low- and medium-density fiber mats can be used for soil stabilization around new or existing construction sites. Steep slopes, without root stabilization, lead to erosion and loss of top soil.

In one type of geotextile, seeds are added to the geotextiles while the web is being formed. Grass and wildflower seeds can be added so that the geotextiles not only prevent erosion by forming a surface physical barrier but also allow grass to grow, establishing a new layer of plant growth with a root system to stabilize the soil after the geotextiles have degraded. Seeds can also be planted under the geotextile so that the seeds can germinate and grow above the geotextile. This type of geotextile should have enough physical strength to endure strong wind and at the same time about 30% of sunlight should pass through the geotextiles. Wood fiber-based geotextiles can hold moisture to help germinate the seeds. Other chemicals, such as fertilizers, can also be added to the web during its formation. Figure 12.8 shows a geotextiles application on a very steep embankment beside a highway.

Medium- and high-density fiber mats can also be used below ground in road and other types of construction as a natural separator between different materials in the layering of the backfill. It is important to restrain slippage and mixing of the different layers by placing separators between the various layers. Jute and kenaf geotextiles have been shown to work very well in these applications, but the potential exists for any of the long agro-based fibers.

Geotextiles in general are expected to be biodegraded within a given period of time. The timing of the biodegradation is dependent upon the materials used. High lignin content contributes to the biodegradability. Other factors such as density, hydrophobicity, extractive contents, etc. also play a role. Usually, the geotextiles are expected to last until the germination of seeds—between 4 and 6 weeks. The biodegradability can be controlled by addition of preservatives to prolong the decay and addition of fungi to speed up the decay.

It has been estimated that the global market for geotextiles is about 800 million square meters, but this estimate has not been broken down into use categories, so it is impossible to determine the portion that is available for natural geotextiles.

12.4 FILTERS

12.4.1 TYPES

12.4.1.1 Physical Types

Fiber-based filters can be used to remove suspended solids from both air and water. The physical types of wood fiber filters can be in several forms. Fibers can be made into webs or mats, or packed into a column or chamber. Webs or mats increase the surface area of the filter and stabilize hydraulic pressure. The suspended solids are physically captured and held in the webs until the filters are cleaned.

12.4.1.2 Chemical Types

Fiber-based filters can also remove dissolved inorganic ions, organic chemicals, and other soluble contaminants from water. Most of the wood fiber-based mats have limited capacities for removing soluble contaminants from water but their capacity can be greatly improved with chemical or plasma modification.

12.4.2 APPLICATIONS

We live in a water-based world. Water sculpts our landscape, provides navigational opportunities, transports our goods, and is the medium of life. Water is the basis of all life on earth, so it is not surprising that one of humankind's highest priorities is to ensure a long-term supply of clean water.

Seventy percent of the earth's surface is covered with water. Most of this water, 97.5%, is in the oceans and seas and is too salty to drink or to use to irrigate crops. Of the remaining 2.5%, 1.73% is in the form of glaciers and icecaps, leaving only about 0.77% available for our fresh water supply. Said another way, of the total water on earth, only 0.0008% is available and renewable in rivers and lakes for human and agricultural use. This is the water that falls as rain or snow or that has been accumulated and stored as groundwater that we depend on for our "clean" water resource.

For 1.5 to 2.5 billion people in the world, clean water is a critical issue (Lepkowski 1999). It is estimated that by the year 2025, there will be an additional 2.5 billion people on the earth that will live in regions already lacking sufficient clean water. In the United States, it is estimated that 90% of all Americans live within 10 miles of a body of contaminated water (Hogue 2000b). The U.S. Environmental Protection Agency (EPA) is working on guidelines and regulations to establish total maximum daily load (TMDL) for each pollutant that remain a problem (Hogue 2000a). The materials that the EPA has listed as water impairments include sediments, nutrients, pathogens, dissolved oxygen, metals, suspended solids, pesticides, turbidity, fish contamination, and ammonia. Other conditions to be considered for clean water on the list include pH, temperature, habitat, and noxious plants. Of these, sediments, nutrients, pathogens, and dissolved oxygen contribute the greatest to our contaminated water (1998 EPA data, cited in Hogue 2000a).

On one specific issue, that of arsenic in drinking water, the EPA has proposed lowering the maximum allowed level of arsenic from 50 ppb to 5 ppb due to concerns about bladder, lung, and skin cancer (Hileman 2000). Meeting these targets will not be easy. Arsenic in water is a global concern especially in countries like Bangladesh where most of their water wells are contaminated with arsenic (Lepkowski 1999).

About 80% of the fresh water in the United States originates on the 650 million acres of forestlands that cover about one third of the nation's land area. The nearly 192 million acres of national forest and grasslands are the largest single source of fresh water in the United States. In

many cases, the headwaters of large river basins are located in national forests. In 1999, the EPA estimated that 3400 public drinking-water systems were located in watersheds contained in national forests and about 60 million people lived in these 3400 communities (Sedell et al. 2000).

The structure of wood and bark is very porous and has a very high free surface volume that should allow accessibility of aqueous solutions to the cell wall components. One cubic inch of a lignocellulosic material, for example, with a specific gravity of 0.4, has a surface area of 15 square feet. However, it has been shown that breaking wood down into finer and finer particles does increase sorption of heavy metal ions.

Lignocellulosics are hygroscopic and have an affinity for water. Water is able to permeate the noncrystalline portion of cellulose and all of the hemicellulose and lignin. Thus, through absorption and adsorption, aqueous solutions come into contact with a very large surface area of different cell wall components.

Laszlo and Dintzis (1994) have shown that wood has ion-exchange capacity and general sorptive characteristics, which are derived from their constituent polymers and structure. The polymers include extractives, cellulose, hemicelluloses, pectin, lignin, and protein. These are adsorbents for a wide range of solutes, particularly divalent metal cations (Laszlo and Dintzis 1994). Wood contains, as a common property, polyphenolic compounds, such as tannin and lignin, which are believed to be the active sites for attachment of heavy metal cations (Waiss et al. 1973, Masri et al. 1974, Randall et al. 1974, Bhattacharyya and Venkobachar 1984, Phalman and Khalafalla 1988, Verma et al. 1990, Shukla and Sakhardande 1991, Maranon and Sastre 1992, Lalvani et al. 1997, Vaughan et al. 2001). Sawdust has been used to remove cadmium and nickel (Basso et al. 2002) and several types of barks have been used to remove heavy metal ions from water (Randall 1977, Randall et al. 1974, Kumar and Dara 1980, Pawan and Dara 1980, Vazquez et al. 1994, Seki et al. 1997, Tiwari et al. 1997, Gaballah and Kibertus 1998, Bailey et al. 1999) from aqueous solution. Cellulose can also sorb heavy metals from solution (Acemioğlu and Alma 2001). Isolated kraft lignin has been used to remove copper and cadmium (Verma et al. 1990, Cang et al. 1998) and organosolv lignin has been used to remove copper (Acemioğlu et al., unpublished data) from aqueous solutions.

Acemioğlu et al. postulate that metal ions compete with hydrogen ions for the active sorption sites on the lignin molecule (Acemioğlu et al., unpublished data). They also conclude that metal sorption onto lignin is dependent on both sorption time and metal concentration. Basso et al. (2002) studied the correlation between lignin content of several woods and their ability to remove heavy metals from aqueous solutions. The efficiency of removing Cd(II) and Ni(II) from aqueous solutions was measured and they found a direct correlation between heavy metal sorption and lignin content. Reddad et al. (2002) showed that the anionic phenolic sites in lignin had a high affinity for heavy metals. Mykola et al. (1999) also showed that the galacturonic acid groups in pectins were strong binding sites for cations.

Extracting fibers with different solvents will change both the chemical and physical properties of the fibers. It is known, for example, that during the hot water and 1% sodium hydroxide extraction of fibers, the cell walls delaminate (Kubinsky 1971). A simple base treatment has been shown to greatly increase the sorption capacity of wood fibers (Tiemann et al. 1999, Reddad et al. 2002). At the same time, some of the amorphous matrix and part of the extractives, which have a bulking effect, are removed (Kubinsky and Ifju 1973), so that the individual microfibrils become more closely packed and shrunken (Kubinsky and Ifju 1974). Therefore, delamination and shrinkage may also change the amount of exposed cell wall components that may affect the heavy metal ion sorption capacity of the fibers.

Shen et al. (2004) have shown that phosphorus can be removed from water using a juniper-fiber-based web that is first saturated with a heavy metal. Figure 12.9 shows a plot of phosphorus uptake versus time with webs made of juniper fiber, base-treated juniper fiber, and juniper fiber that has been saturated with iron. The filter made using the heavy metal-loaded fiber removed much more phosphorus than the webs without the heavy metal.

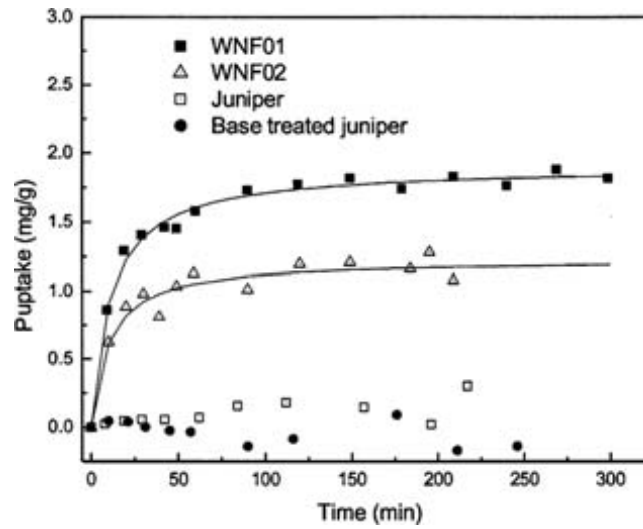


FIGURE 12.9 Plot of phosphorus removal from solution using juniper fiber filters.

12.4.3 TESTING PROTOCOLS FOR FILTERS

12.4.3.1 Kinetic Tests

A kinetic test determines the time it takes to remove a given concentration of a contaminant. Two approaches are used. One uses a constant weight of sorbent that is applied to various concentrations of solution, and the other uses a constant concentration of solution applied to variable weights of the sorbent (Eaton-Dikeman 1960).

12.4.3.2 Isotherms

Adsorption occurs on the surface of the fibers and when the rate of adsorption equals the rate of desorption, equilibrium has been achieved and the capacity of the fiber has been reached. The theoretical adsorption capacity of the fiber for a particular contaminant can be determined by calculating its adsorption isotherm. Wood samples are carefully weighed (M) and placed in a known volume (V) of standard solution of a given metal ion and shaken at 150 rpm. After 24 hours the mixture of the standard solution and fiber sample are filtered and the final concentration of the solution is determined by ICP.

The quantity of adsorbate that can be taken up by an adsorbent is a function of both the characteristics and concentration of adsorbate and the pH (some authors also include temperature, but pH has more impact than temperature in wood fiber filtration). Generally, the amount of material adsorbed is determined as a function of the concentration at a constant pH, and the resulting function is called an adsorption isotherm. One equation that is often used to describe the experimental isotherm data was developed by the isotherm models of Langmuir and Freundlich (Weber 1970).

A characteristic of the Langmuir isotherm is that the loading of sorbate onto the sorbent approaches a limiting value, $Q_{\max}$, as the concentration increases. This corresponds to monolayer coverage of the adsorbent surface with a Langmuir constant, b , related to the free energy of adsorption:

$$q_e = \frac{bQ_{\max}C_e}{1 + bC_e}, \quad (12.1)$$

where b is Langmuir constant (L/g) and $Q_{\max}$ is maximum adsorbate loading (grams adsorbate/grams adsorbent).

The Freundlich isotherm is empirical and is used for heterogeneous surface energies:

$$q_e = KC_e^{1/n}, \quad (12.2)$$

where K (L/mg), a measure of sorption capacity, and $1/n$, a measure of sorption intensity, are Freundlich constants. To obtain the best estimate of all constants for the Langmuir and Freundlich isotherms, data were fitted with nonlinear regressions using a least-squares fitting program.

12.4.4 BIOFILTERS FOR ORGANIC COMPOUNDS

A biofilter is a filter that contains a microorganism capable of degrading the organic compound that is trapped by the filter. The filter first sorbs the compound by physical or chemical entrapment and then the microorganism decomposes the chemical into smaller chemicals such as carbon dioxide and water. Langseth and Pflum (1994) reported that biofilters could be used to remove organic compounds with an estimated 95% efficiency. The chemicals removed were alcohols, aldehydes, organic acids, and small amounts of low-molecular weight volatile organics such as benzene and toluene. The retention times for small simple volatile compounds are very short, with a 90% reduction in low-molecular weight compounds in about 10 seconds. Higher molecular weight organics decompose at a slower rate (English 1996).

12.5 SORBENTS

Wood-based sorbents have been used for years as cleaning aids. For example, bark has been used to sorb oil from seawater, and treated sawdust and wood shavings have been used to clean industrial floors. There are several important factors that influence sorptive capacity, including density, porosity, surface area, selectivity, and retention (English 1996).

12.5.1 DENSITY

Bulk density is simply a measure of wood mass per unit volume. Wood bulk density varies from about 0.2 gm/cm³ to greater than 1 gm/cm³. In general, the lower the bulk density, the greater the sorption capacity. The true density of the wood cell wall is between 1.3 and 1.5 and does not take into consideration any internal voids.

12.5.2 POROSITY AND SURFACE AREA

Porosity can be defined in several ways. It can be a measure of the size of the voids in the wood or it can be a measure of how quickly and easily a liquid or gas can penetrate through a piece of wood of a given size. Porosity can be measured as the time it takes for a gas or liquid to travel through a piece of wood or it can be a measurement of the sizes of internal voids in the wood. Woods with a low bulk density have a very large internal void space and therefore large internal surface area. One cubic inch of wood with a specific gravity of 0.4 has a surface area of 15 square feet.

12.5.3 SELECTIVITY

Wood is hydrophilic, so it strongly hydrogen bonds to polar liquids such as water. Selectivity is a measure of the ability of wood to preferentially sorb one gas or liquid, or one chemical in a gas or liquid, over another. Selectivity is also influenced by the wood pore size, ability to wet the wood surface, and capillary pressure.



FIGURE 12.10 Fiber-based mulch mat.

12.5.4 RETENTION

Retention is the ability of a saturated wood sample, after it has been used as a sorbent, to retain the sorbed gas, liquid, or specific chemical. Retention can be a critical factor in choosing a sorbent system. If the wood has the ability to remove a given contaminant but quickly releases it upon, for example, exposure to air, the sorbed contaminant will be released into the environment before it can be disposed of.

12.6 MULCH MATS

Mulching materials have been used around plants for many years (Waggoner et al. 1960) and are generally of two types: particle mulches and sheet mulches. Particle mulches, such as bark, wood shavings, or sawdust, are used to heat and hold moisture close to the plant. Sheet mulches are similar to geotextiles but are usually thicker and last longer in the environment. They are used to enhance seedling survival in wood species where the seedling remains in a “grass-like” state for several years, i.e., the southern pines (Figure 12.10). The mulch mats, like the loose mulches, hold moisture and heat as well as reducing weed growth around the seedling. Mulch mats must remain intact for as long as competition from unwanted plants remains. For this reason, many mulch mats are made from plastics such as polyethylene or polypropylene.

REFERENCES

- Acemioglu, B. and Alma, M.H. (2001). Equilibrium studies on the adsorption of Cu(II) from aqueous solution onto cellulose. *J. Colloid Interf. Sci.*, 243:81.
- Anderson, W.E. and Brooks, L.E. (1975). Reducing erosion hazard on a burned forest in Oregon by seeding. *J. Range Manage.* 28(5):394.
- Bailey, S.E., Olin, T.J., Bricka, R.M., and Adrian, D.D. (1999). A review of potentially low-cost sorbents for heavy metals. *Water Res.* 33:2469.
- Bailey, R.W. and Copeland, O.L. (1961). Vegetation and engineering structures in flood and erosion control. In: Proceedings, 13th Congress, International Union of Forest Research Organization. September 1961, Vienna, Austria. Paper 11-1: 23.

- Basso, M.C., Cerrella, E.G., and Cukierman, A.L. (2002). Lignocellulosic materials as potential biosorbents of trace toxic metals from wastewater. *Ind. Eng. Chem. Res.* 3580–3585.
- Bhattacharyya, A.K. and Venkobachar, C. (1984). Removal of cadmium (II) by low cost adsorbents. *J. Environ. Eng. Division (ASCE)* 110:110.
- Browning B.L. (1967). The extraneous components of wood. In: *Methods of Wood Chemistry*, John Wiley & Sons, New York, pp. 75–90.
- Byrd, V.L. (1990a). Dan-Web process revolutionizes dry-forming. *Nonwovens Ind.* 21(5):74.
- Byrd, V.L. (1990b). New air-laid process revolutionizes industry. *The Business Edition* March, pp. 1,3,5.
- Clark, J.A. (1960). Apparatus and method for producing fibrous structures. U.S. Patent 2,931,076.
- Curlator Corp. (1967). Method of making a random fiber web. British Patent 1,088,991.
- Danweb. (2003). Research and development, Danweb, Aarhus, Denmark.
- DeBano, L.F., Neary, D.G., and Folliott, P.F. (1998). *Fire's Effects on Ecosystems*. John Wiley & Sons, New York.
- Eaton-Dikeman Company. (1960). *Handbook of Filtration*, The Eaton-Dikeman Company, Mt. Holly Springs, PA.
- English, B. (1996). Filters, sorbents and geotextiles. In: Rowell, R.M., Young, R.A., and Rowell, J.K. (Eds.), *Paper and Composites from Agro-based Resources*, CRC Lewis Publishers, Boca Raton, FL, pp. 403–426.
- Gaballah, I. and Kibertus, G. (1998). Recovery of heavy metal ions through decontamination of synthetic solutions and industrial effluents using modified barks. *J. Geochem. Expl.* 62:241.
- Hogue, C. (2000a). Clearing the water. *Chem. Eng. News* March, 31.
- Hogue, C. (2000b). Muddied waters. *Chem. Eng. News* August, 19–20.
- Hileman, B. (2000). Rules in the fast lane. *Chem. Eng. News* October, 43–44.
- Hunt, J.F. and Gunderson, D.E. (1998). FPL Spaceboard development. In: Tappi Proceedings of the 198th Corrugated Containers Conference, Tappi Press, Atlanta, GA, p. 11.
- Kubinsky, E., (1971). Influence of steaming on the properties of *Quercus rubra* L. wood. *Holzforschung* 25(3):78.
- Kubinsky E. and Ifju, G. (1973). Influence of steaming on the properties of red oak. Part I. Structural and chemical changes. *Wood Science* 6(1):87.
- Kubinsky E. and Ifju, G. (1974). Influence of steaming on the properties of red oak. Part I. Changes of structural and related properties. *Wood Science* 7(2):103.
- Kumar, P. and Dara, S.S. (1980). Modified barks for scavenging toxic heavy metal ions. *Indian J. Environ. Health*, 22:196.
- Laufenberg, T.L. (1996). Packaging and light weight structural composites. In: Rowell, R.M., Young, R.A., and Rowell, J.K. (Eds.), *Paper and Composites from Agro-based Resources*, CRC Lewis Publishers, Boca Raton, FL, pp. 337–350.
- Lalvani, S.B., Wiltowski, T.S., Murphy, D., and Lalvani, L.S. (1997). Metal removal from process water by lignin. *Environ. Technol.* 18(11):1163.
- Langseth, S. and Pflum, D. (1994). Weyerhaeuser tests large pilot biofilters for VOCs removal, *Panel World* 3(2):22.
- Laszlo, J.A. and Dintzis, F.R. (1994). Crop residues as ion-exchange materials. Treatment of soybean hull and sugar beet fiber (pulp) with epichlorohydrin to improve cation-exchange capacity and physical stability. *J. Appl. Polymer Sci.*, 52:521.
- Lepkowski, W. (1999). Science meets policy in shaping water's future. *Chem. Eng. News* December, 127.
- Maranon, E. and Sastre, H. (1992). Behaviour of lignocellulosic apple residues in the sorption of trace metals in packed beds. *Reactive Polymers*, 18:172.
- Masri, M.S., Reuter, F.W., and Friedman, M. (1974). Binding of metal cations by natural substances. *J. Appl. Polymer Sci.* 18:675.
- Mykola, T.K., Kupchik, L.A., and Veisoc, B.K. (1999). Evaluation of pectin binding of heavy metal ions in aqueous solutions. *Chemosphere* 38(11):2591.
- Pawan, K. and Dara, S.S. (1980). Modified barks for scavenging toxic heavy metal ions. *Indian J. Environ. Health* 22:196.
- Phalman, J.E. and Khalafalla, J.E. (1988). Use of ligochemicals and humic acids to remove heavy metals from process waste streams. RI 9200, U.S. Department of Interior, Bureau of Mines.
- Pusyrev, S.A. and Dimitriev, M. (1960). Production of paper and board by the dry process. *Pulp Paper Mag. Can.* 61(1):T3.

- Randall, J.M. (1977). Variations in effectiveness of barks as scavengers for heavy metal ions. *Forest Prod. J.* 27(11):51.
- Randall, J.M., Bermann, R.L., Garrett, V., and Weiss, A.C. (1974). Use of bark to remove heavy metal ions from waste solutions. *Forest Prod. J.* 24(9):80.
- Rando Machine Corporation. (1993). Product improvement bulletin, PIB-018. Rando Machine Corporation, Macedon, NY.
- Rando Machine Corporation. (n.d.) Installation, Operation and Maintenance Manual No.631 for the Rando-Webber, The Commons, Macedon, NY.
- Reddad, Z., Gerente, C., Andres, Y., Ralet, M-C., Thibault, J-F., and Cloirec, P.L. (2002). Ni(II) and Cu(II) binding properties of native and modified sugar beet pulp. *Carbohydrate Polymers* 49:23.
- Robichaud, P.R., Beyers, J.L., and Neary, D.G. (2000). Evaluating the effectiveness of postfire rehabilitation treatments. USDA, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-63.
- Rowell, R.M. and Han, J.S. (1999). Changes in kenaf properties and chemistry as a function of growing time. In : *Kenaf Properties, Processing and Products*. Mississippi State University, Ag & Bio Engineering, pp. 33–41, Mississippi State, MS.
- Scott, C.T. and Laufenberg, T.L. (1994). Spaceboard II panels: Preliminary evaluation of mechanical properties. In: PTEC 94 Timber Shaping the Future, Proceedings of the Pacific Timber Engineering Conference, July, Gold Coast, Fortitude Valley, Queensland, Australia, TRADA 632, p. 2.
- Sedell, J. S. (2000). Water and the Forest Service, ES 660. USDA, Forest Service Washington Office, Washington, DC.
- Seki, K., Saito, M., and Aoyama, M. (1997). Removal of heavy metals from solutions by coniferous barks. *Wood Sci. Technol.* 31:441.
- Setterholm, V.C. (1985). FPL spaceboard new structural sandwich concept. *Tappi* 68(6):40.
- Shin, E.W., Han, J.S., and Min, H. (2004). Removal of phosphorus from water using lignocellulosic material modified with iron species from acid mine drainage. *Environ. Technol.*
- Shukla, S.R. and Sakhardande, V.D. (1991). Metal ion removal by dyed cellulosic materials. *J. Appl. Polymer Sci.* 42:825.
- Sun, R-C., Lawther, J.M., and Banks, W.B. (1998). Isolation and characterization of organosolv lignins from wheat straw. *Wood and Fiber Sci.* 30(1):56.
- Tiemann, K.J., Gardea-Torresdey, J.L., Gamez, G., Dokken, K., Sias, S., Renneer, M.W., and Furenlid, L.R. (1999). Use of x-ray absorption spectroscopy and esterification to investigate Cr (III) and Ni(II) ligands in alfalfa biomass. *Environ. Sci. Technol.* 33:150.
- Tiwari, D.P., Saksena, D.N., and Singh, D.K. (1997). Kinetics of adsorption of Pb(II) on used tea leaves and Cr(VI) on *Acacia arabica* bark. *Dev. Chem. Eng. Miner. Process.* 5:79.
- Vaughan, T., Seo, C.W., and Marshall, W.E. (2001). Removal of selected metal ions from aqueous solution using modified corncobs. *Bioresource Technol.* 78:133.
- Vazquez, G., Antorrena, G., Gonzalez, J., and Doval, M.D. (1994). Adsorption of heavy metal ions by chemically modified *Pinus pinaster* bark. *Bioresource Technol.* 48:251.
- Verma, K.V.R., Swaminathan T., and Subrahmanyam, P.V.R. (1990). Heavy metal removal with lignin. *J. Environ. Sci. Health A25(2):242*.
- Waggoner, P.E., Miller, P.M., and DeRoo, H.C. (1960). Plastic mulching-principles and benefits, Bull. No. 634. Connecticut Agricultural Experiment Station, New Haven, CT.
- Weiss, A.C., Wiley, M.E., Kuhnle, J.A., Potter, A.L., and McCready, R.M. (1973). Adsorption of mercuric cation by tannins in agricultural residues. *J. Environ. Quality* 2:369.
- Weber, W.J. (1970). Physicochemical Process: For water quality control. Wiley-Interscience, New York, NY.
- Wolff, H. and Byrd, V.L. (1990). Flexible composite and multicomponent air-formed webs. *Tappi J.* 73(9):159.

HANDBOOK OF WOOD CHEMISTRY AND WOOD COMPOSITES

**Edited by
Roger M. Rowell**



CRC PRESS

Boca Raton London New York Washington, D.C.

Library of Congress Cataloging-in-Publication Data

Handbook of wood chemistry and wood composites / edited by Roger M. Rowell.

p. cm.

Includes bibliographical references and index.

ISBN 0-8493-1588-3 (alk. paper)

1. Wood—Chemistry—Handbooks, manuals, etc. 2. Engineered wood—Handbooks, manuals, etc.

I. Rowell, Roger M.

TS932.H36

620.1'2—dc22

2004057915

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage or retrieval system, without prior permission in writing from the publisher.

All rights reserved. Authorization to photocopy items for internal or personal use, or the personal or internal use of specific clients, may be granted by CRC Press, provided that \$1.50 per page photocopied is paid directly to Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 USA. The fee code for users of the Transactional Reporting Service is ISBN 0-8493-1588-3/05/\$0.00+\$1.50. The fee is subject to change without notice. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

The consent of CRC Press does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from CRC Press for such copying.

Direct all inquiries to CRC Press, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

Visit the CRC Press Web site at www.crcpress.com

© 2005 by CRC Press

No claim to original U.S. Government works

International Standard Book Number 0-8493-1588-3

Library of Congress Card Number 2004057915

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

Printed on acid-free paper