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CHAPTER 13

Filters, Sorbents, and Geotextiles

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CONTENTS

1. AGRO-BASED FILTERS

filtering is the process of separating solid particles from liquids and gases by passing the fluid through a porous, fibrous or granular substance. Fluids are filtered: for clarification, with the solids being discarded; to remove solids from a fluid, with the fluid being discarded; or to separate the fluid from the solids, both being retained. Mathematical models have been developed that can aproximate a given filter media's effectiveness with a given filtrate, but actual experiments or pilot trials are needed to determine definitive results. Some of the important factors affecting filtration include:

1. **Effective filter area**
2. **Pressure drop across the filter**
3. **Resistance of filter medium to fluid flow**
4. **Swelling effect of solvent on filter medium**
5. **Compressibility of filter medium under fluid pressure**
6. **Sizes of suspended particles**
7. **Tendency of particles to flocculate**
8. **Viscosity of slurry**
9. **Temperature of slurry**
10. **Rate of formation of filter cake**
11. **Resistance of filter cake to fluid flow**
12. **Consistency of the slurry (Eaton-Dikeman, 1960)**

Many materials have been used for filter medis, including a range of inorganic and organic materials. Agro-based materials used for filters include woven fabrics of cotton, flax and hemp; nonwoven fibers in mats or columns made of straw, bagasse, kenaf and coir; paper made from wood or cotton; and charcoals made from coir or other materials. Depending on the filter function, these materials are often used in combination and in conjunction with filter aids.

Filters made from intertwined fibrous agro-based materials form intricate network capillary passages that are long when compared to their cross section. In addition, they are nonuniform and tortuous as result of the formation and variations in individual fibers. Usually the material to be filtered is a fluid in which particles of assorted shapes and sizes are suspended. The filtration process removes these solids by several different methods. Often the solids removed are much smaller than the size of the capillaries would indicate. In addition to the above factors, Eaton-Dikeman (1960) identified the ability of a filter to retain solids to be further influenced by:

1. The physical properties of the liquid, such as temperature and viscosity.
2. The chemical properties of the liquid. For example, agro-based materials will swell to different degrees depending upon the liquid with which it contacts. Thus the pore size distribution of the fiIter is dependent on the liquid to be filtered.
3. The duration of trhe filtering operation.
4. The size, shape, and chemical nature of the suspended solids.

1.1 Filter Mechanisms

Three distinct modes of Filtration have been identified. Direct sieving occurs when particles are retained by the entrances or constrictions in the filter pores by an actual physical blocking mechanism. Cake filtration also occurs by is physical blocking mechanism,but it is affected by particles previously retained in the filter by other means. In other words, the particles that have been filtered out of the liquid now serve to filter additional particles. Cake filtration can occur both in and above the filter. Standard blocking is the mechanism whereby particles smaller than the filter pore size are attached to the fibers along or within the pores or to other particles previously retained. Standard blocking is also thought to occur when small particles are trapped in stagnation points in the liquid flow behind individual fibers in the filter. In any case, standard blocking is facilitated by molecular forces. Theoretically, all of the above modes could occur simultaneously in a filter. From a practical standpoint, however, standard blocking and direct sieving tend to occur first, with cake filtration starting as the others are begining to end.

Fluid mechanics teaches that there are two main types of flow: turbulent and streamline. Filters generally operate under streamline flow. In a filter, the rate of flow can be related to the pressure drop and to the properties of the liquid and the solid particles. The capacity of a filter to permit a liquid to pass through it is generally expressed in terms of the permeability or permeabilily coefficient.

Streamline flow in a channel of constant circular cross section is governed by Poiseuille's Iaw. Modified by Kozeny (1927) and Carmen (1937), Poiseuille's law can be applied to liquid flow through a porous media:

$$q = \left[e^3/kS_v^2(1-e)^2\right]\left[A\Delta P g_c/\mu L\right]$$

q = Volumetric rate of flow
A = Cross sectional area of porous bed
L = Thickness of bed
e = Void fraction of porosity, dimensionless
S_v = Specific surface of solid particles on a volume basis
k = A dimensionless constant
μ = Viscosity of the fluid
ΔP = Pressure drop causing the flow
g_c = The gravitational constant

This formula states that the rate of flow is directly proportional to the pressure drop across the bed and to the area of the bed perpendicular to the direction of the flow, and inversely proportional to the viscosity of the liquid and the thickness of the bed in the direction of flow. The constant k is determined empmirically, and most materials range from 3-6. The Kozeny-Carmen relation can be used to accurately predict the flow of liquids in simple systems; however, it has limitations when randomly oriented, highly variable, agro-based materials are considered. The permeability coefficient, k, of a particular filter system is represented by the Kozeny-Carmen relation and can be expressed as:

$$K = \left[e^3 / k S_v^2 (1 - e)^2 \right]$$

Two types of empirical models have been developed to predict the variation of pressure drop in the course of deep filtration of liquids. The first model assumes that the internal surfaces are uniformly coated by small particles. The second assumes that the filter is gradually clogged by large particles. Both models can be fitted to experimental data; they cannot be used, however, to predict the pressure drop in new situations. An empirical equation for constant rate filtration can be written in the following form (Hudson, 1948):

$$\Delta P / \Delta P_0 = 1 / (1 - jR)^m$$

P = Piezometric pressure
R = Retention (volume of deposited particles/unit filter volume)
j, m = Empirically determined constants

The reported values for j and m range from about 30 into the hundreds, with most values falling b etween 30 and 80. Herzig et al. (1970) used the following formula for determining pressure drop when uniform coating of the internal pore surface is assumed:

$$\Delta P / \Delta P_0 = \left[1 / (BR/E)^2 \right]$$

where B = Inverse compaction factor of the retained particles.

1.2 Geotextile Filter Applications

DeBerardino (1993) reported on filtration applications for geotextiles. Geotextile filters are used primarily in civil engineering applications for retaining soil and allowing water to pass. Four filtration criteria were estblished:

1. Soil retention to control piping
2. Sufficient water passage capability to handle excess hydrostatic pore pressure

3. Ability of the filtration system to resist clogging over long periods
4. Survivability and durability of the geotextile (design life of the system is especially important for agro-based applications).

All voids in soils are connected to neighboring voids, making flow possible through the densest of soils (Lambe and Whitman, 1969) The following equation was developed by H. Darcy in hte 1850s for fluid flow through soils:

$$Q = KiA$$

Q = The rate of flow
K = Coefficient of permeability
i = The gradient
A = The total cross sectional area of the sample.

Giroud (1988) determined that a criterion to determine acceptable water passage through a soil geotextile/filter system could be expressed as:

$$K_g > i_s K_s$$

K_g = Coefficient permeability of the geotextile
i_s = Hydraulic gradient of the soil
K_s = Coefficient permeability of the soil.

1.3 Removal of Heavy Metal Ions

Randall and Hautalla (1975) reported on the use of agricultural byproducts to remove heavy metal ions from waste solutions. They reported that agricultural residues that were high in tannins, such as peanut skins, walnut expeller meal, redwood bark, and western hemlock bark had a strong iaffinity for lead, copper, mercury, and cadmium. Residues that were low in tannin but high in cellulose, like peanut hulls, wood, and straw had little or no affinity.

In their research, Randall and Hautalla reported that a redwood bark column had been effectively used to remove lead from 38,000 Iiters of waste water from a lead battery plant. The water was clean enough to be discharged into a municipal sewer. Residues that contain soluble organic matter may need to have these soluble materials washed away if used for filters to prevent discolored water and biochemical oxygen demand (BOD) discharge.

1.4 Biofilters for Volatile Organic Compounds

European countries have used biofilters extensively for emission control, while in the United States, their use has generally been Iimited to odor control in applications such as waste water treatment and animal rendering plants. Langseth and Pflum (1994) reported that biofilters could be used to remove volatile organic compounds (VOCs) from a wood composite panel mill with an estimated 95 percent efficiency. Two filters are being used on a pilot scale, handling about 16 percent of the press output gas and 25 percent of the flake dryer exhaust. Each filter is approximately 6.1 m wide × 30.5 m. long × 1.2 m deep.

The VOCs from this mill consist primarily of alcohols, aldehydes, organic acids, and small amounts of low molecular weight volatile organics such as benzene and toluene. The VOCs exist in very dilute amounts, generally around 500 ppm in air. The VOCs enter the biofilter from underneath through a vented concrete slab floor. The bottom 15-20 cm of the biofilter consists of new pine and poplar bark; the remainder consists of partially composted bark and end trimmings amended with 2-4 percent agricultural lime. In the biofilter, the VOCs are attacked by bacteria that occur naturally in decaying wood. The bacteria convert pure hydrocarbon compounds into CO_2 and H_2O. Retention times are quick, with a 90 percent reduction in light molecular weight VOCs in around 10 seconds. Heavier molecular weight VOCs are generally broken down in 30 to 60 seconds. The life of the biofilter media is thought to be 1-2 years, after which pressure drop builds to unacceptable levels.

2. AGRO-BASED SORBENTS

The use of agro-based resources for absorption certainly predates written record. Folk medicine remedies include the use of various plants and their fibers for the stopping of wounds, the production of poultices, and for other purposes as well. When agricuilture began and animals were domesticated, we can be certain that animals were bedded, then as they are now, in agricultural residues. Today, simple economics and environmental concerns are expanding the use of agro-based materials for absorbents.

Short of direct experimentation, no direct way to accruately predict the sorptive capacity of agro-based material has been determined. Several important factors that influence sorbtive capacity, however, are desity, porosity, selectivity, and retention.

2.1 Density

There are two types of density relative to absorption: true density and bulk density. True density is a measure of solids only, regardless of any internal voids or intersticial areas, and, once determined, can be considered constant for a given material. To determine true density, both mass and volume must be known. Volume can be determined by submersing a known mass of the material into a container of known volume of a wetting liquid. The liquid must be allowed to fully penetrate the material and displace any entrapped gasses. It may be necessary to augment the penetration with vacuum or agitation. True density can then be determined by the formula:

$$D_s = D_L \frac{M_s}{M_1 + M_s - M_2}$$

D_s = Density of the solid
D_L = Density of the wetting liquid
M_s = Mass of the solid
M_1 = Mass of liquid required to fill the measuring container without fiber
M_2 = Mass of liquid required to fill the measuring container with M_s in the container.

Bulk density is a measure of density including solids, pores, and interstices, and may vary depending on compaction. Bulk density is a simple measure of mass/unit volume. For fibrous materials, bulk density will vary widely. Uncompacted fibrous materials may have bulk densities as low as, say, 0.01 gm/cm^3. Compacted bulk densities can approach true density.

2.2 Porosity

Porosity, or void volume, is a measure of how much volume is available in a system for absorption. Like bulk density, porosity may vary depending on compaction. Porosity can be expressed as:

$$P_R = \frac{V_t - V_s}{V_t}$$

P_R = Porosity (%)
V_1 = Total volume of the system
V_s = Volume of the solid.

At first glance, porosity may appear to be an indicator of absorptive capacity. In fact, it is a measure of a system's capacity only under ideal conditions. In practice, a sorbent's capacity is often less than its porosity. Fibrous materials often have porosities of 90-95%, while granular material's porosity is often less than 40%.

Porosity is also often expressed as void ratio, p. Void ratio is the ratio of the void volume to the solid volume and is expressed as:

$$p = \frac{V_t - V_s}{V_t}$$

2.3 Selectivity

Selectivity is the ability of a sorptive material to preferentially absorb one material over another. For instance, most agro-based materials will, to varying degrees, selectively absorb oil over water. This makes these materials attractive sorbents in oil spills caused by tanker and off shore oil rig leaks.

The degree of selectivity is influenced by the sorbent's pore size, wettability, and capillary pressure. Past history of the sorbent is also important in selectivity. For instance, in the case of oil spills, the sorbent's ability to preferentially absorb oil over sear water is affected by whether the sorbent was exposed to the oil first or the water.

2.4 Retention

Retention is the ability of a saturated sorptive material to retain fluid when conditions are conductive to drainage. Retention is important because, in practice, sorbents are often used in one location and transported to another for disposal or fluid removal. A sorbent with high degree of retention will be able to transport more fluid. Retention levels are based largely on conditions related to capillary action.

Generally, at equilibrium, a saturated sorbent will hold more fluid after drainage than an unsaturated sorbent will take in. This is because the capillary nature of sorbent systems, especially those made of irregular agro-based materials, is not regular. During drainage, fluid will stop when a neck in the capillary system is small enough so that the pressure difference is enough to keep the liquid column in place. During absorption, the liquid will only enter the sorbent until it reaches a wide area where the pressure drop is insufficient to take it any further into the sorbent system. Because agro-fibers vary widely, the equilibrium point will vary throughout the sorbent system.

2.5 Agro-Based Sorbent Applications

Coghlan (1992) reported that researchers at Virginia Polytechnic institute and State University in Blacksburg, Virginia were able to absorb more oil with kenaf, cotton, and milkweek floss sorbent systems than with commercial polypropylene fiber systems. The researchers reported that milkweed floss in particular was a good sorbent, absorbing about 40 times its weight in oil, compared to ten times with polypropylene fibers. The great ability of milkweed floss to absorb oil was attributed to a waxy coating on the milkweed fiber surface. It was reported that the milkweed floss retained 75 percent of its ability to absorb oil after three cycles of soaking the fibers in oil and then mechanically removing the oil by squeezing. Agro-based absorvents are seeing commercial use as oil absorbent socks and booms for oil spill clean up.

Using modified wheat straw to remove emulsified oil from water was reported on by Fanta et al. (1986). The wheat straw was treated by first heating the wheat straw in a sodium hydroxide solution and then subjecting it to an ion exchange reaction with hexadecyltrimethylammonium bromide (CTAB). The researchers showed that sufficient NaOH is needed to disrupt the straw particles to produce a high surface area sorbvent, but that too much NaOH removed hemicellulose. Minimizing hemicellulose removal is important because the uronic acid substituents of hemicellulose are responsible for much of the ion exchange capacity of the straw. The researchers thought that the simplicity of their straw-CTAB preparation make the process commercially attractive.

3. AGRO-BASED GEOTEXTILES

Geotextiles are any textile like material, either woven, non-woven, or extruded, used in civil engineering applications to increase soil structural performance. The main structural performance functions geotextiles provide are aggregate separation, soil reinforcement and stabilization, filtration, drainage, and moisture or liquid barriers (Dewey, 1993). The market for geotextiles is growing, with worldwide sales of over 700 million square meters annually (Sen Gupta, 1991). Polypropylene is the material of choice for about 80% of all geotextiles. Polyester accounts for about 15%, and polyethylene and nylon about three percent. The remaining two percent consists of agro-based materials. Even then, only a few are 100% natural fiber-based. Many of these contain some portion of synthetic material to hold the geotextile together. This is normally a polypropylene net or polyester scrim sheet that sandwiches the agro-based component. Most geotextiles applications are perment, such as landfill liners and roadway construction, and the use of agro-based, biodegradable materials would have adverse results. Other applications, though, are temporary or short term, and the use of agro-based, biodegradable materials is worthy of consideration.

Commercially, there is a good variety of geotextiles available that contain a majority percentage of agro-based materials. The agro-based materials are used because of their low cost, biodegradability, moisture-holding abilityy, and environmentally friendly image. Most are, used in erosion control where they serve to stabilize the soil surface while natural vegetation is established. Some of them contain seeds to accelerate and control the re-growth. Other applications include mulches, and the related products of filters and sorbents.

Data conflicts on the amount of erosion control geotextiles sold, with estimates for North America ranging from 22-73 million square meters. According to Homan (1994), agro-based materials make up about 60 percent of the erosion control market. Regardless of the number, erosion control geotextiles markets are growing at 10-15% a year overall.

3.1 Erosion Control

Sediment accounts for roughly two thirds of pollution in United States waterways. Most commercial agro-based geotextiles target this problem (Figure 13.1) As mentioned elsewhere, erosion control geotextile markets are expanding rapidly. Spurring this growth is increasing regulation concerning run-off from all manners of construction sites. Typical applications include roadbank stabilization, reinforcement of waterways, construction site slope stabilization, and silt fences (Figure 13.2).

Figure 13.1 Bio-based geotextiles are typically installed to control erosion.

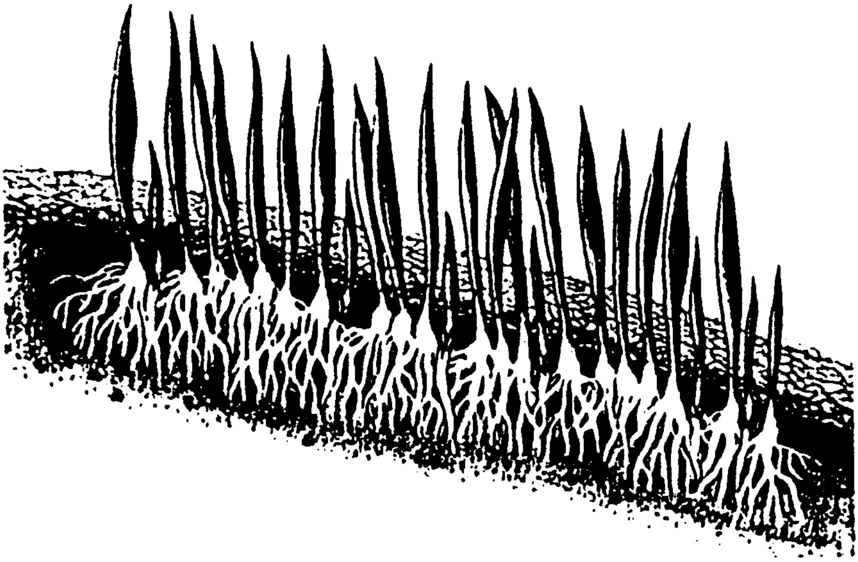

Figure 13.2 As geotextiles degrade, they provide mulch and conserve moisture for plant growth. Eventually, plant growth takes over the soil protection function.

3.1.1 Mechanism of Erosion

Erosion is caused by glaciers, marine activity, rivers, wind, and water. Erosion control geotextiles are being used to provide protection against all but glacial. Of these, control of erosion caused by water flow relating to rain is the most common. Rain-caused soil erosion is a function of soil detachment by raindrop impact and transport capacity of thin sheet flow (Meyer et al., 1975).

When raindrops impact the soil surface, they dislodge and lift soil particles. If the soil is level, the net dislodgment is zero. On a slope however, the dislodged soil particles tend to go down the slope, resulting in soil movement. If the rainfall intensity is sufficiently high, the ability of the soil to absorb the rainfall will be compromised, and thin sheet overland flow will occur. Overland flow carries away soil particles dislodged by raindrop impact and also particles dislodged from the soil surface by imparted shear stress. This condition is known as "sheet erosion."

Gully erosion occurs when overland flow becomes concentrated in grooves or channels in the soil surface. The concentrated flow becomes turbulent, and soil particles are dislodged from the channel sides and bottom, Ieading to larger and larger channels.

3.1.2 Role of Erosion Control Systems

The role of erosion control systems is to prevent sheet and gully erosion by any or all of the following strategies: reducing raindrop impact energy, reducing overland flow velocities, protection of the bare soil to prevent the surface Iayer from being washed away, containment and reinforcement of the top soil layer, or retainment of moisture to create a highly saturated and heavy surface zone (Ruston and Wegget, 1993). Erosion control systems exist on a continuum from natural vegetative cover, to hybrid natural/synthetic systems, to entirely synthetic systems. An example of a purely synthetic system would be rubble placed along a river bank or a concrete Iined drainage system. A hybrid system might consist of a naturally reinforcing vegetative root system augmented by a nondegradable synthetic geogrid placed in the soil. Selection of an erosion control systems is based on a variety of factors, soil type, degree of slope, flow conditions, budget, and others. The role of agro-based biodegradable geotextiles is to provide erosion control while vegetation is established to perform the erosion control function.

3.1.3 Design of Erosion Control Systems

Ingold and Thomson (1990) suggest using the Universal Soil Loss Equation (USLE) for selecting the type of erosion control strategy to use. The USLE has been expressed in several different forms. One common one is:

$$E = R \times K \times L \times S \times P_c \times C$$

E = Mean annual soil loss (mass/area) acceptable
R = Rainfall erosivity index

K = Soil erodibility index
L = Slope length factor
S = Slope steepness factor
P_C = Conservation practice factor
C = Crop factor.

The crop factor, C, represents the ratio of soil loss or yield under a given crop to that for bare soil. Often quoted C or yield factors for various crop and forest cover range from 0.001-0.02. Various agro-based geotextiles and mulches are often given the value 0.01, although the actual number must be determined experimentally. It should be noted that agro-based systems are designed to degrade, and thus become less effective erosion control systems, as vegetration is established to take over the erosion control function.

Two things affect the yield factor of any erosion control system. They are the run off factor of the system and the erodibility factor of the underlying soil. It is possible for a particilar system, such as a tightly woven fabric, to have a high run off factor, but because much of the water is carried on top of the textile, little soil is eroded. Conversely, very porous systems may allow all of the water to pass through, and if ground contact is not good, sheet and gully erosion can take place under the geotextile.

Water diversion channels are often designed around a maximum condition known as a 100-year storm event. In severe conditions bed scour and undermining of slopes must be prevented by proper channel design. Austen and Theisen (1994) reported that the U.S. Soil Conservation Society's volumetric approach can be used to estimate watershed flow. From this estimate, water velocity can be calculated using the Continuity Equation expressed as:

$$Q = A V_{ave}$$

Q = Design discharge in the channel, (m^3/sec)
A = Flow area in the channel, (m^2)
V_{ave} = Average velocity in the cross section, (m/sec).

After an initial cross section area is selected, actual flow conditions and depth of flow can be calculated using Mannings Equation expressed as:

$$V_{ave} = 1/n \, R^{2/3} S_f^{1/2}$$

V_{ave} = Average velocity in the crosssection (m/sec.)
n = Mannings roughness coefficient
R = Hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P
S_f = Friction slope of the channel approximated by the average bed slope (for uniform flow conditions).

The velocity of flow is not the only engineering factor used to determine the erosion control system. Hydraulic tractive forces, or shear stress imparted by the moving water must be taken into account. Shear stress is calculated using the Tractive Force Equation:

$$Y_{ave} = WRS_f$$

Y_{ave} = Average shear stress in crosssection (kg/m²)
W = Unit weight of water (9.8 KN/m³)

Most erosion control system manufacturers can provide useful data for using the above equations to determine erosion control systme application. In addition, some manufacturers provide computer software to help design systems using their products. However, most testing is not yet standardized and used and installation of systems are very site specific. In addition, installation contractors may not always use manufacturer recommended installation techniques. As such, safety factors are normally incorporated into any design function. Complete discussion of all of the factors in the above equations is beyond the scope of this document, and they are presented solely to give a picture of the relationship between the variables affecting erosion and related control systems.

3.2 Agro-Based Erosion Control Systems

Commercially, there are three main agro-based erosion control systems. They are geotextiles, hydromulches and silt fences. Geotextiles include various mats, blankets or nets, of both woven and non-woven materials (Figure 13.3). Geotextiles are supplied as roll goods and are installed in the field with various anchoring schemes (Figure 13.4). Hydromulches are applied *in situ.* They consist of various agro-based materials in a water slurry that are spray applied. Hydromulches almost always include seeds, while not all geotextiles do. Silt fences are temporary "curtains" placed around a construction site to trap or filter sediment from run-off. Table 13.1 shows general agro-based geotextile application parameters. A laundry list of various agro-based erosion control systems might look like this: .

3.2.1 *Coir (Coconut Husk) Netting*

Coir has the highest tensile strength of any natural fiber and retains much of its tensile strength when wet (Figure 13.5). Coir is very long lasting as well, with in-field service life of 4 to 10 years. These properties make it uniquely suited for more rigorous erosion control applications that still require biodegradability. Coir netting has an open area of 40 to 70 percent, and it is often used in conjunction with other erosion control systems. For instance, hydroseeding can be performed before or after installation, or individual plantings can be placed through the net. Because of its high tensile and wet strength, coir netting can be used in very high flow velocity

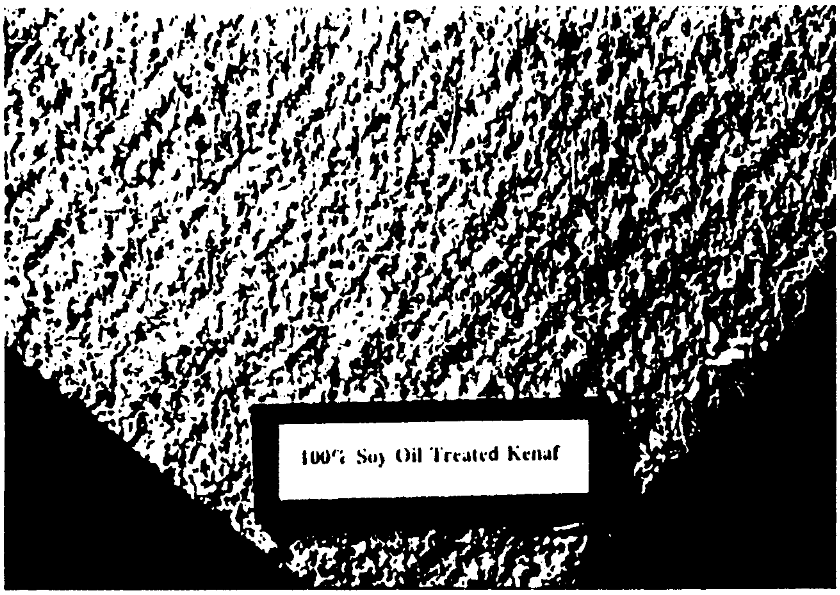

Figure 13.3 A kenaf-based geotextile. The soy oil was added to improve processing of the kenaf fiber.

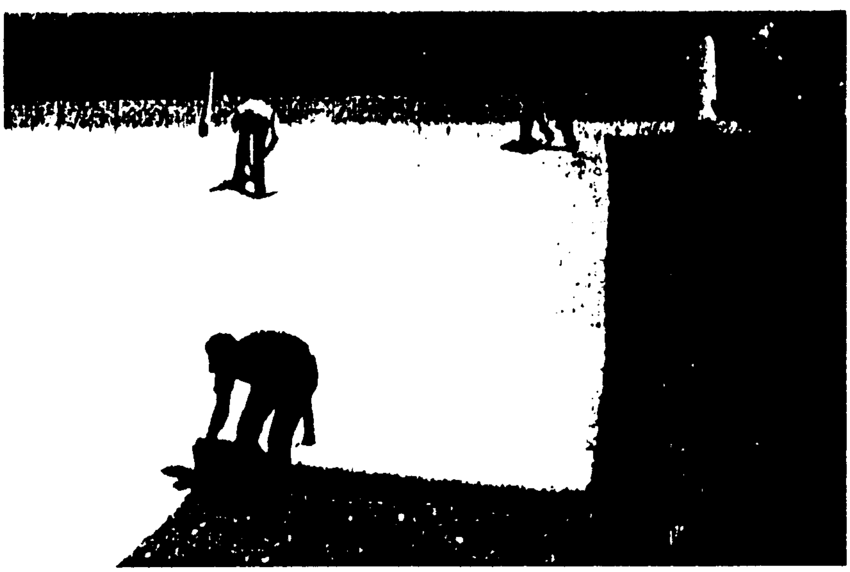

Figure 13.4 Installation of bio-based geotextiles on a steep slope. Metal staples or wood stakes are used to anchor.

Table 13.1 General Bio-Based Geotextile Application Parameters

Geotextile	Durability (seasons)	Maximum Slope	Maximum Flow Resistance	Seeds Incorporated
Coir Netting	4–10	>1:1	very high	no
Jute Netting	1–2	>1:1	very high	no
Straw Mats	1	3:1	moderate	optional
Wood Wool Mats	2–3	1:1	moderate to high	optional
Hybrid Synthetic/Bio-Based Systems	indefinite	>1:1	very high	optional
Silt Fences	1–2	3:1	moderate to high	no

Note: The above table is intended to offer some very general guidelines; variance is likely due to site conditions.

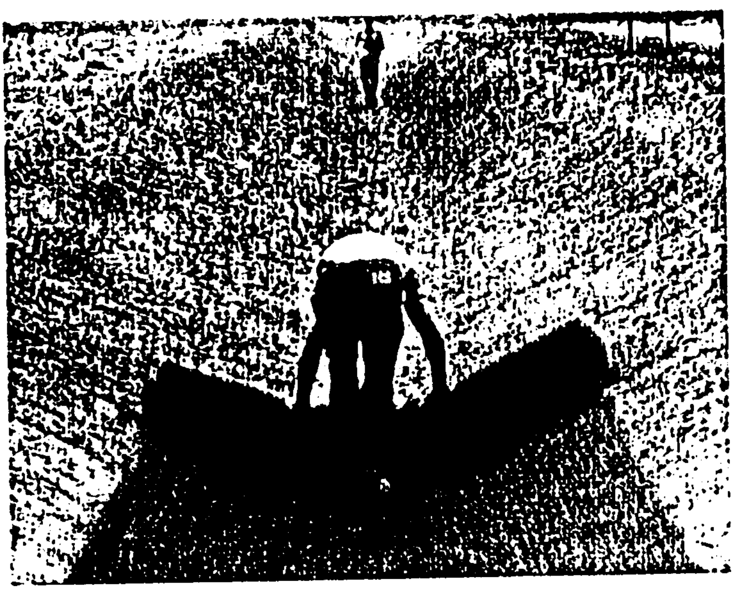

Figure 13.5 Installation of a coir based mat along a drainage ditch.

conditions. Some use of coir in nonwoven geotextiles is found as well, with polyproplene netting used to hold the mat together. Coir netting can be applied on slopes greater than 1:1

3.2.2 Jute Netting

Jute netting is similar to coir netting in appearance and application. The Main differences are that its service life is less, generally 1-2 years, it cannot be used in the high flow conditions that coir can, and it is usually not recommended for slopes greater than 1:1.

3.2.3 Straw Mats

Straw mats are a very popular means to provide temporary erosion control to moderate slopes. The straw source may be from wheat, oat, rice or other grains or grasses. Straw is cheap, easy to work with and readily available in most localities. Straw lasts about one growing season, so the site is usually seeded before the mat is installed. Straw works by reducing rainfall impact and retaining moisture to provide an environment for seed germination and plant growth. Some straw mats contain extraneous weed seeds, which may be unwanted in some situations.

All straw mats need some secondary means to hold the straw into the blanket. Various schemes exist. Most have a lightweight polypropylene netting on one or either side of the mat. The netting is generally held in place by takifiers or lightweight cotton chain stitching. The polypropylene netting is often billed as "photo-biodegradable." Some rare instances have been reported of birds or small animals being entangled in the netting, but this does not seem to be a major problem. A larger problem is mower entanglement. This can happen on landscaped sites where the polypropylene netting does not sufficiently degrade before the vegetation is established and mowing begins.

Sometimes straw is used in conjunction with more durable biodegradable or nondegradable grids or nets to form a hybrid system. In these systems, the straw provides the rainfall impact resistance and seed growth environment, while the more durable portion stays in the soil to provide additional reinforcement to the vegetative root system. Lightweight straw mats are effective on 4:1 and 3:1 slopes under low to moderate flow velocities. Many hybrid systems can be used on 2:1 and 1:1 slopes under medium to moderately high flow velocities.

3.2.4 Wood Wool (Excelsior) Mats

Wood wool, or excelsior, consists of thin strands of shavings of virgin wood usually aspen. For erosion purposes, the wood wool is usually 0.5-2 mm in cross sectional dimension and 10-20 cm long. Used for many years as a packing material, wood wool is also used in building materials and filters. Wood wool is more expensive than straw; straw is a crop residue and wood wool is a product manufactured for a specific end use.

Wood wool mat construction is similar to straw mats, with most using stitching or hot melt glue to attach the wood wool to a polypropylene net. Performance differs in longevity and erosion resistance. Wood wool has an effective life of 2-3 growing seasons and can be used effectively on steeper slopes, sometimes up to 1:1, depending on mat construction and flow conditions. Manufacturers offer wood wool in hybrid systems more frequently than straw, probably because of its better performance in more demanding applications.

3.2.5 Hydromulch

Hydromulch and hydroseeding are methods of using water to form a diodegradable mat *in situ* (Figure 13.6). Straw, virgin, and recycled wood fiber, and recycled

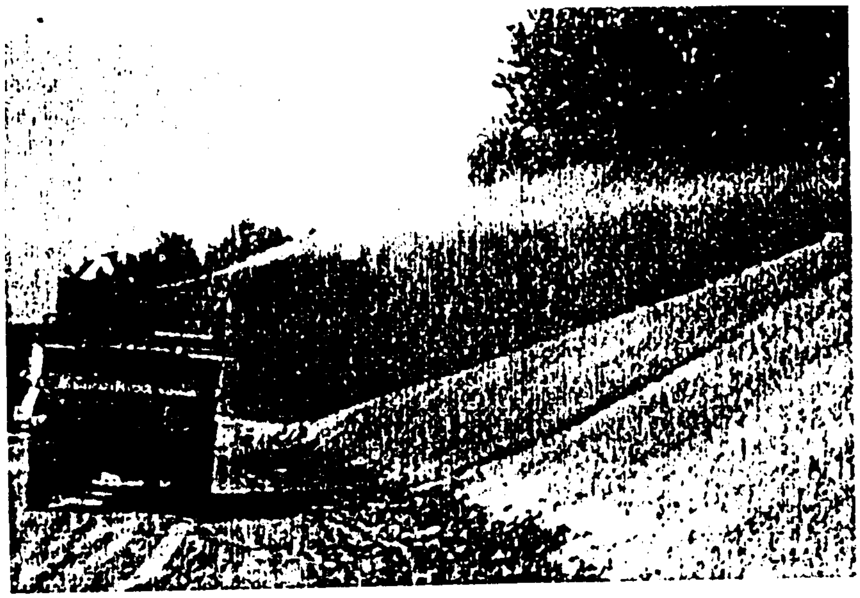

Figure 13.6 Hydromulching is the *in situ* production of a geotextile. Hydromulching offers the ultimate in ground conformance. Seeds, fertilizers, herbicides, and tackifiers are frequently incorporated into the hydromulch.

waste paper are all used in hydromulching applications. To apply hydromulch, agro-based materials, seeds, and water are blended together and sprayed onto the site using a water cannon. Water cannons can spray the hydromulch up to 70 meters. Sometimes the seeds are pre-applied; other times all of the materials are applied simultaneously. Typical application rates are 200 kg of seed and 1,200-2,000 kg of mulch/hectare. Fertilizers, pH adjusters, moisture retention agents, and herbicides can be applied simultaneously with the seed and mulch. In some short term construction applications, such as when top soil is stored in pile for later reapplication, seeds are not incorporated, and hydromulch is applied solely to prevent erosion losses.

Tackifiers are often added or post-applied to the hydromulch to increase erosion resistance and windblown movement of the dried mulch (Wolf et al., 1984). Typical tackifiers include guar gum, seaweed extractives, asphalt emulsions (always post-applied), and synthetic polymers. For large installations, hydromulches are lower in cost than geotextiles, and they offer the ultimate in ground conformance. Hydromulching is especially suitable for steep and irregular slopes where erosion control mat installation would be dangerous or nearly impossible (Salkever, 1994). They are often applied to slopes much greater thatn 1:1 and can tolerate low to moderate velocity water flow. Application of seeds, fertilizers, mulch, and other ingredients can be mixed by the tankfull, and thus, very site specific. Hydromulches are generally considered to be good for one season.

3.2.6 Silt Fences

Silt fences are designed to catch sediment around construction sites. Essentially, they are temporary porous "dams" designed to slow down and catch run off so that the sedimane settles out and the water either passes through the fence or percolates into the underlying soil. Almost all commercial silt fences are made from woven polypropylene fabric. From an agro-based perspective, effective silt fences could probably be made from woven jute fabric.

3.3 Geotextile Seed Incorporation Methods

In normal non-agricultural seeding practices, like those found around construction sites, after the soil is prepared, seed is broadcast-spread and raked into the soil. This technique is moderately effective where no erosion takes place and growing conditions are favorable. In practice though, seeds are often dislodged and redistributed by soil or wind erosion. In addition, animal predation can seriously reduce the seed count. The effects of these conditions can often be remedied by the timely application of a mulch in the form of a biodegradable geotextile.

In more severe applications though, where the degree of slope is great enough to make even seed distribution difficult, or where heavy rains or high water flow velocity could redistribute the seeds under the geotextile, seed incorporated geotextiles have application (Figure 13.7). In this respect, the geotextile has three functions The first function is as a vehicle for the even distribution of seeds. The second functrion is to protect the seed placement from wind, rain, and predation after distribution. The third function is to degrade and provide mulch while the vegetation is being established.

Several methods are used to incorporate seeds into biodegradable geotextiles. Commercial seed incorporated kenaf or wood geotextiles are available that use nonwoven polyester scrim sheets on both sides of the mat to hold the seeds in place. These lightweight mats are sold primarily to the home owner for lawn installation and repair. Other seed incorporated sheet mulches are made using cereal straw, kraft paper, and polypropylene netting. The seeds are distributed and held in place between two lightweight sheets of kraft paper, and are stitched in place to the straw and polypropylene. Experimentally, seeds have been incorporated into geotextiles using starch-based glues to hold the seeds in place on a kraft paper backing (English, 1994). The kraft paper is then needlepunched or stitched to the geotextile. Fertilizers and herbicides can also be incorporated using any of the described methods. Commercially, mats using grass seeds or blends of wildflowers are available. Most manufacturers will also make custom blends.

3.4 Geotextiles for Mulching Applications

Mulching, the spreading of materials around the base of a plant to mitigate adverse temperatures or moisture loss, control weeds or enhance soil fertility and tilth, has been a common horticultural practice for centruies (Waggoner et al., 1960). This practice is usually accomplished by spreading loose agricultural residue

Figure 13.7 Application of wildflower seeds to a geotextile backing sheet in the laboratory. Seeds are often incorporated into commercial geotextiles.

between rows of crops. Like other agricultural crops, the survival of tree seedlings is a major concern to tree growers everywhere. Over the last 30 years forest managers in the United States have evaluated the use of mulches for their biological effectiveness, longevity and cost in the establishment of tree seedlings (McDonald and Helgerson, 1990) (Figure 13.8).

Commonly, seedlings are overplanted and thinned as they mature. In low survival rate areas, seedlings may have to be replanted. These practices are clstly and time consuming. Environmental factors that affect seedling survival include moisture, temperature, light, chemical presence or absence, and mechanical damage. Mulches can be used to control most of these factors. Mulches work mainly by suppressing weed growth. This enables the seedling to make full use of light, moisture, and nutrients. The mulch also acts as a soil insulator and as a vapor block. As a soil insulator, the mulch helps keep the soil warm in the early and late part of the growing season. As a vapor barrier, the mulch acts to suppress evaporation.

Historically, the effectiveness of mulches on seedling survival has varied widely. Soil conditions, light, and the longevity of the mulch contribute to this; in especially adverse conditions, survival has increased from near 0% to more than 90%. In more typical situations, survival increases from 40-60%.

mulch materials can be categorized two ways: loose mulches and sheet mulches. Successful application of loose mulches, like bark, sawdust, or straw, is largely dependent on application thickness. Because they are bulky, loose mulches are most successful when seedling access is good, such as in an orchard or nursery. As such, their application in remote sites is limited.

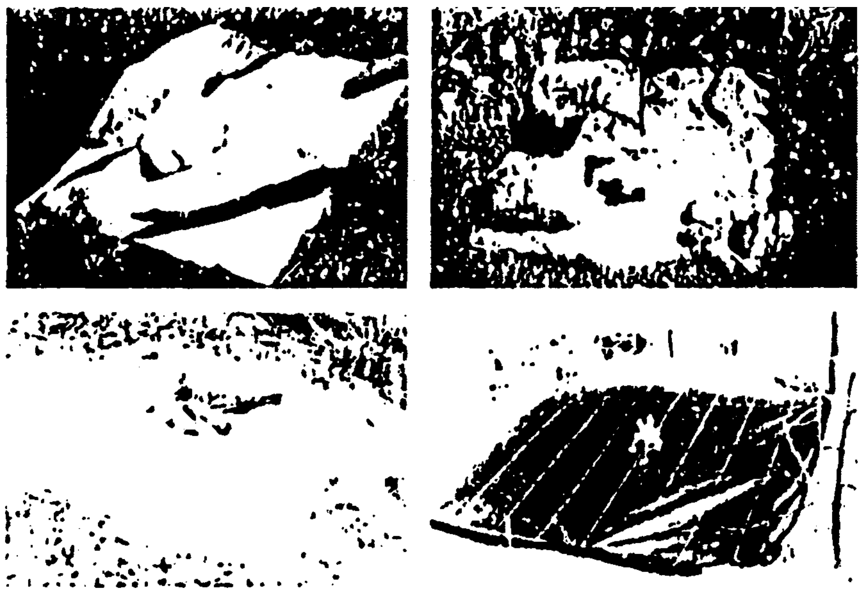

Figure 13.8 Geotextiles can be used around the base of seedlings to increase survival and enhance growth. The top two are lignocellulosic-based.

Sheet mulches, in the form of small geotextiles, on the other hand, can be rolled up or folded to allow packing into remote sites. Sheet mulches consist of woven or non-woven materials, or plastic film. Film mulches and most woven plastic mulches are less bulky than non-woven mulches made from agro-based materials, but they have several disadvantages. Plastic mulches need to be very well anchored to keep them from being dislodged by wind or animals. If this happens, the mulch litters the forest or folds over and smothers the seedling. Plastic mulches suppress weed growth reasonably well, but if not perforated, rainfall can be diverted from the seedling. Degradability of the plastics is also limited.

Key mulch characteristics for seedling survival have been identified. The mulch should be dark to create temperatures hot enough to kill germinanats and sprouts that emerge under the mulch, and also possess good insulative characteristics. The mulch should be porous for water infiltration, yet still retard water loss from underneath it. The mulch should be strong and durable enough to last until the seedling is well established, usually about three years. Good ground conformance would keep the mat from being dislodged. A biodegradable mulch will limit forest litter and save removal cost and may increase mulch effectiveness. The mulch should be low in cost and lightweight for ease of transportation and installation. Special properties related to agro-based geotextiles and geotextile mulches in particular are water permeability, absorption and run off.

Of these three properties, permeability is the most important, as this relates to the amount of rainfall immediately available to the seedling. High run-off levels would indicate little water available to the seedling, although if the seedling is on a slope, water might run under the mulch from up the slope. a degree of absorption is probably important; however, an overly absorbent material might trap all of the water made available during a light rain.

Research was conducted at the USDA Forest Products Laboratory to determine the permeability of a variety of commercial and prototype geotextile mulches (English, 1994). Most of the commercial mulches let less than one fourth of the water pass. Of these, a few let no water pass through at all. Best permeability values were obtained by a perforated polypropylene sheet mulch with 81.2% of applied water passing through, and a grass/straw mat held together with a tackifier (making it similar to hydromulch) with 90.0%. Relatively high values for various other agro-based commercial and prototype mulches were found in the 40 to 60% range. Field experience, however, is what really counts, and while this research is still ongoing and for the most part, unpublished, several general trends and conclusions can be identified.

First and foremost, the successful application of mulches to enhance seedling survival is site specific. If the site is especially remote, the bulkiness of the non-woven agro-based geotextiles was a hindrance, and teh plastic mulches were preferred for installation, although they are more difficult to anchor. If reasonably accessible, agro-based mulches offered good ground conformance and biodegradability. Few of the mats that are durable enough to last until the seedling is established have had any adverse effect on seedling survival, although if improperly installed, some plastic mulches will abrade the seedling stem and kill it. Most of the agro-based geotextiles were considered durable enough to last until the seedling is established, although a few did not last one season. The economics of mulch installation are somewhat gray, and again, site specific. Generally, if survival rates are reasonably good and the site is accessible for maintenance, there is no reason to apply mulches. However, if the site has an inherently low survival rate, and is not readily accessible, the use of mulches may have merit.

3.5 Test Methods for Geotextiles

ASTM has established 15 practices and tests to evaluate the properties of geotextiles (1994). Industry often used the results of the following tests for determining applications (IFAI, 1991).

ASTM D 3786-87 *Hydraulic Bursting Strength of Fabries.* This test uses a Hydraulic diaphragm Bursting Tester, commonly called a Mullen Burst Test, to determine resistance to bursting. The test specimen is grabbed by a ring which is located over a diphragm. The diaphragm is then inflated so that it pushes upon the geotextile until it bursts.

ASTM D 3787 *Puncture Strength of Geotextiles.* Like ASTM D 3786-87, this test supports the test specimen in a ring. The specimen is then punctured using a 8 mm rod.

ASTM 4355-84 *Deterioration of Geotextiles From Exposute to Ultraviolet Light and Water*. The level of deterioration is determined by testing the tensile strength of the composite after exposure.

ASTM D 4491 *Water Permeability of Geotextiles by Permittivity.* This test determines water permeability of the geotextiles in an uncompressed state.
ASTM D 4533-85 *Trapezoid Tearing Strength of Geotextiles.* In this test the trapezoid tear method is used to determine tear strength.
ASTM D 4595-86 *Tensile Properties of Geotextiles by the Wide-Width Strip Method.* Used primarily for reinforcement applications, this tensile test method utilizes grips that extend the full width of the test specimen.
ASTM D 4632-86 *Breaking Load and Elongation of Geotextiles (Grab Method).* This test method uses two 2.5 cm by 5 cm test grips to grab and pull a 10 cm by 20 cm test specimen to determine elongation and strength properties.
ASTM D 4751 *Apparent Opening Size of Geotextiles.* Various sized glass beads are sieved by the geotextile to determine the apparent size opening.

For the short term erosion control applications of agro-based geotextiles, tensile and elongation propertiesx are probably the most important. When placed on a slope, gravity tends to pull the geotextile down a slope. When the weightr of the geotextile is increased by water absorption and trapped solids from run-off, this condition is increased. If poorly or improperly anchored, the geotextile can tear and slide down the slope, resulting in failure of hte intended erosion control function. Importantly, standard test procedures for erosion control have yet to be agreed upon by industry (Allllen and Lancaster, 1994). Although much of the testing is done by independent laboratories, different manufacturers may have different test procedures and failure criteria.

For filtration and absorption functions, water permeability and apparent opening size may be the most important properties. Deberardino (1994) effectively argues that for most purposes, the Mullen Burst test described above is an unneeded specification because geotextiles are very rarely subjected to these exact forces. For the instances where it may happen, the value can be directly correlated from tensile data.

Regardless of the testing conducted, the geotextile industry has begun to standardize the reporting of the results of these and other tests as a Minimum Average Roll Value (MARV) (Wayne, 1994). MARVs are roughly estimated as the mean value minus two standard deviations. MARVs; then give a 95% confidence level that can be used when engineers specify geotextiles for critical applications.

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