4.1 Types and Composition of Geosynthetic Clay Liners

As with most types of manufactured products within a given category, there are sufficient differences such that no two products are truly equal to one another. Geosynthetic clay liners (GCLs) are no exception. Yet, there are a sufficient number of common characteristics such that the current commercially available products deserve a separate category and a separate treatment in this manual. GCLs can be defined as follows:

"Geosynthetic clay liners (GCLs) are factory manufactured, hydraulic barriers typically consisting of bentonite clay or other very low permeability clay materials, supported by geotextiles and/or geomembranes which are held together by needling, stitching and/or chemical adhesives."

Other names that GCLs have been listed under, are "clay blankets", "clay mats", "bentonite blankets", "bentonite mats", "prefabricated bentonite clay blankets", etc. GCLs are hydraulic barriers to water, leachate or other liquids. As such, they are used to augment or replace compacted clay liners or geomembranes, or they are used in a composite manner to augment the more traditional clay liner or geomembrane materials.

Cross section sketches of the currently available GCLs at the time of writing are shown in Fig. 4.1. General comments regarding each type follow:

- Figure 4.1(a) illustrates a bentonite clay mixed with a water soluble adhesive which is supported by individual geotextiles on both its upper and lower surfaces.

- Figure 4.1(b) illustrates a stitchbonded variation of the above type of product whereby the upper and lower geotextiles are joined by continuous sewing in discrete rows throughout the machine direction of the product as well as a recent product which consists of bentonite powder alone with no admixed adhesive.

- Figure 4.1(c) illustrates a bentonite clay powder or granules, containing no adhesive, which is supported by individual geotextiles on its upper and lower surfaces and is needle punched throughout to provide for its stability. Several variations of this type of GCL are available including styles with clay infilled in the voids of the upper geotextile.

- Figure 4.1(d) illustrates a bentonite clay which is admixed with an adhesive and is supported by a geomembrane on its lower surface, as shown, or it can be used in an inverted manner with the geomembrane side facing upward. Variations of this product are also available with textured or raised geomembrane surfaces.

All of the GCL products available in North America use sodium bentonite clay (predominately smectite) powder or granules at as-manufactured mass per unit areas in the range of 3.2 to 6.0 kg/m² (0.66 to 1.2 lb/ft²). The clay thickness in the various products vary between the range of 4.0 to 6.0 mm (160 to 320 mils). GCLs are delivered to the job site at moisture contents which...
(a) Adhesive Bound Clay to Upper and Lower Geotextiles

(b) Stitch Bonded Clay Between Upper and Lower Geotextiles

(c) Needle Punched Clay Through Upper and Lower Geotextiles

(d) Adhesive Bound Clay to a Geomembrane

Figure 4.1 - Cross Section Sketches of Currently Available Geosynthetic Clay Liners (GCLs)
vary from 5 to 23%, depending upon the local humidity. Note that this is sometimes referred to in the technical literature as the "dry" state. The types of geotextiles used with the different products vary widely in their manufacturing style (e.g., woven slit film, needle punched nonwoven, spunlaced, heat bonded nonwovens, etc.) and in their mass per unit area [e.g., varying from 85 g/m² (2.5 oz/yd²) to 1000 g/m² (30 oz/yd²). The particular product with a geomembrane backing can also vary in its type, thickness and surface texture.

GCLs are factory made in widths of 2.2 to 5.2 m (7 to 17 ft) and lengths of 30 to 61 m (100 to 200 ft). Upon manufacturing GCLs are rolled onto a core and are covered with a plastic film to prevent additional moisture gain during storage, transportation, and placement prior to their final covering with an overlying layer.

4.2 Manufacturing

This section on manufacturing of GCLs will discuss the various raw materials, manufacturing of the rolls, and covering of the rolls.

4.2.1 Raw Materials

The bentonite clay materials currently used in the manufacture of GCLs are all of the sodium montmorillonite variety which is a naturally occurring mineral in the Wyoming and North Dakota regions of the USA. After the clay is mined, it is dried, pulverized, sieved and stored in silos until it is transported to a GCL manufacturing facility.

The other raw material ingredient used in the manufacture of certain GCLs (recall Section 4.1) is an adhesive which is a proprietary product among the two manufacturers that produce this type of GCL. Additionally, geotextiles and/or geomembranes are used as substrate (below the clay) or superstrate (above the clay) layers which are product specific as was mentioned in the previous section.

Regarding a specification or MQA document for the various raw materials used in the manufacture of GCLs, the following items should be considered.

1. The clay should meet the GCL manufacturer's specification for quality control purposes. This is often 70% to 90% sodium montmorillonite clay from the Wyoming/North Dakota "Black Hills" region of bentonite deposits. A certificate of analysis should be submitted by the vendor for each lot of clay supplied. While the situation is far from established, the certificate may include the various compounds of the clay, per X-Ray diffraction or methylene-blue absorption, particle size per ASTM D-422 or C-136, moisture content per ASTM D-2216 or D-4643, bulk density per ASTM B-417, and free swell.

2. The GCL manufacturer should have a MQC plan which describes the procedures for accomplishing quality in the final product, various tests to be conducted and their frequency. This MQC document should be fully implemented and followed.

3. The MQC test methods that the GCL manufacturer performs on the clay component may include the following; free swell per USP-NF-XVIII or ASTM draft standard, "Determination of Volumetric Free Swell of Powdered Bentonite Clay," plate water absorption per ASTM E-946, moisture content per ASTM D-2216 or D-4643 and (sometimes) particle size per ASTM D-422, fluid loss per API 13B, pH per ASTM D-4972, and liquid/plastic limit per ASTM D-4318.
4. For those products which use adhesives, the composition of the proprietary adhesive is rarely specified. If a statement is required, it should signify that the adhesive selected has been successfully used in the past and to what extent.

5. The geotextiles used as the substrate or the superstrate, or the geomembrane vary according to the particular style of product. Manufacturers current literature should be used in this regard. If a statement is required it should signify that the products selected have been successfully used in the past and to what extent.

6. If further detail is needed as to a specification for the geotextiles, see Chapter 6. Similarly, specifications for geomembranes are found in Chapter 3.

7. The type of sewing thread (or yarn) which is used in joining the products is rarely specified. If a statement is required it should signify that the materials selected have been successfully used in the past and to what extent.

4.2.2 Manufacturing

The raw materials just described are used to make the final GCL product. The production facilities are all relatively large operations where the products are made in a continuous manner. Process quality control is obviously necessary and is practiced by all GCL manufacturers. Figure 4.2 illustrates, in schematic form, the various processing methods used for those GCLs which have adhesives mixed with the clay and those which are stitch bonded and needle punched. Figure 4.2(a) illustrates an adhesively bonded clay product which has an adhesive sprayed in a number of layers with intermittent additions of bentonite. The clay is placed either between geotextiles or on a geomembrane. Figure 4.2(b) illustrates the needle punching or stitch bonding of a bentonite clay powder after it is placed between the covering geotextiles. Windup around a core and placement of the protective covering is common among all GCLs.

There are numerous items which should be included in a specification or MQA document focused on the manufactured GCL product.

1. There should be verification that the actual geotextiles or geomembrane used meet the manufacturer’s specification for that particular type and style.

2. A statement should be included that the geotextile property values are based on the minimum average roll value (MARV) concept. The geomembrane’s properties are generally based on average values.

3. Verification that needle punched nonwoven geotextiles have been inspected continuously for the presence of broken needles using an in-line metal detector. There should also be a magnet, or other device, for removal of broken needles.

4. Verification that the proper mass per unit area of bentonite clay has been added to the product should be provided. At a minimum, this should consist of providing a calculated value based on the net weight of the final roll divided by its area (with deduction for the mass per unit area of the geosynthetics and the adhesive, if any).

5. Thickness measurements are product dependent, i.e., some GCLs can be quality controlled via thickness while others cannot.
Figure 4.2 - Schematic Diagrams of the Manufacture of Different Types of Geosynthetic Clay Liners (GCLs)
6. It is recommended that the overlap distance on both sides of the GCL be marked with two continuous waterproof lines guiding the minimum overlap distances.

7. The product should be wrapped around a core which is structurally sound such that it can support the weight of the roll without excessive bending or buckling under normal handling conditions as recommended by the manufacturer.

8. The GCL manufacturer should have a MQC plan for the finished product, which includes sampling frequency, and it should be implemented and followed.

9. The manufacturer's quality control tests on the finished product should be stipulated and followed. Typical tests include thickness per ASTM D-1777 or ASTM D-5199, total product mass per unit area per ASTM D-5261, clay content mass per unit area per ASTM D-5261, hydraulic conductivity (permeability) per ASTM D-5084 or GRI GCL2 and sometimes shear strength at various locations such as top, mid-plane and bottom per ASTM D-5321. Other tests as recommended by the manufacturer are also acceptable.

4.2.3 Covering of the Rolls

The final step in the manufacturing of GCLs is their covering with a waterproof, tightly-fit, plastic covering. This covering is sometimes a spirally wound polyethylene film approximately 0.05 to 0.08 mm (2 to 5 mils) thick and is the final step in production. The covering can also be a plastic bag, or sheet, pulled over the product as a secondary operation. Figure 4.3 shows the factory storage of GCLs, with their protective covering, before shipment to the field.

Some items for a specification or MQA document with regard to the covering of GCLs are the following:

1. The manufacturer should clearly stipulate the type of protective covering and the manner of cover placement. The covering should be verified as to its capability for safe storage and proper transportation of the product.

2. The covering should be placed around the GCL in a workmanlike manner so as to effectively protect the product on all of its exposed surfaces and edges.

3. The central core should be accessible for handling by fork lift vehicles fitted with a long pole (i.e., a "stinger") attached. For wide GCLs, e.g., wider than approximately 3.5 m (11.5 ft), handling should be by overhead cranes utilizing two dedicated slings provided on each roll at approximately the one-third points.

4. Clearly visible labels should identify the name and address of the manufacturer, trademark, date of manufacture, location of manufacture, style, roll number, lot number, serial number, dimensions, weight and other important items for proper identification. Refer to ASTM D-4873 for proper labeling in this regard. In some cases, the roll number itself is adequate to trace the entire MQC record and documentation.
4.3 Handling

A number of activities occur between the manufacture of a GCL, its final positioning in the field and subsequent backfilling. Topics such as storage at the factory, transportation, storage at the site and acceptance/conformance testing will be described in this section.

4.3.1 Storage at the Manufacturing Facility

Storage of GCLs at the manufacturers facility is common. Storage times typically range from days to six months. Figure 4.3 illustrated typical GCL storage at a fabrication facility.

Some specifications or MQA items to consider for storage and handling of GCLs are the following:

1. GCLs should always be stored indoors until they are ready to be transported to the field site.

2. Handling of the GCLs should be such that the protective wrapping is not damaged. If it is, it must be immediately rewrapped by machine or by hand. In the case of minor tears it may be taped.
3. Placement and stacking of rolls should be done in a manner so as to prevent thinning of the product at the points of contact with the storage frame or with one another. Storage in individually supported racks is common so as to more efficiently use floor space.

4.3.2 Shipment

Rolls of GCLs are shipped from the manufacturers storage facility to the job site via common carrier. Ships, railroads and trucks have all been used depending upon the locations of the origin and final destination. The usual carrier within the USA is truck, which should be with the GCLs contained in an enclosed trailer as shown in Fig. 4.4(a), or on an open flat-bed trailer which is tarpaulin covered as shown in Fig. 4.4(b). Some manufacturers have their own dedicated fleet of trucks. The rolls are sometimes handled by fork lift with a stinger attached. The “stinger” is a long tapered rod which fits inside the core upon which the GCL is wrapped, see Fig. 4.4(a). Alternatively, rolls can be handled using the two captive slings provided on each roll.

Insofar as a specification or MQA document is concerned, a few items should be considered.

1. The GCLs should be shipped by themselves with no other cargo which could damage them in transit, during stops, or while offloading other materials.

2. The method of loading the GCL rolls, transporting them and offloading them at the job site should not cause any damage to the GCL, its core, nor its protective wrapping.

3. Any protective wrapping that is damaged or stripped off of the rolls should be repaired immediately or the roll should be moved to a enclosed facility until its repair can be made to the approval of the quality assurance personnel.

4. If any of the clay has been lost during transportation or from damage of any type, the outer layers of GCL should be discarded until undamaged product is evidenced. The remaining roll must be rewrapped in accordance with the manufacturer’s original method to prevent hydration or further damage to the remaining roll.

4.3.3 Storage at the Site

Storage of GCLs at the field site is cautioned due to the potential for moisture pickup (even through the plastic covering) or accidental damage. The concept of “just-in-time-delivery” can be used for GCLs transported from the factory to the field. When storage is required for a short period of time i.e., days or a few weeks, and the product is delivered in trailers, the trailers can be unhitched from their tractors and used as temporary storage. See the photograph of Fig. 4.5(a). Alternatively, storage at the job site can also be acceptable if the GCLs are properly positioned, protected and maintained, see Fig. 4.5(b).

If storage of GCLs is permitted on the job site, offloading of the rolls should be done in an acceptable manner. Some specification or CQA* document items to consider are the following.

1. Handling of rolls of GCLs should be done in a competent manner such that damage does not occur to the product nor to its protective wrapping. In this regard ASTM D-4873, “Identification, Storage and Handling of Geotextiles”, should be referenced and followed.

* Note that the designations of MQC and MQA will now shift to CQC and CQA since field construction personnel are involved.
Figure 4.4(a) - Fork Lift Equipped with a "Stinger"

Figure 4.4(b) - GCL Rolls on a Flat-Bed Trailer
Figure 4.5(a) - Photograph of Temporary Storage of GCLs in their Shipping Trailers

Figure 4.5(b) - Photograph of Temporary Storage of GCLs at Project Site
2. The location of temporary field storage should not be in areas where water can accumulate. The rolls should be stored on high flat ground or elevated off of the ground so as not to form a dam creating the ponding of water. It is recommended to construct a platform so that GCL rolls are continuously supported along their length.

3. The rolls should not be stacked so high as to cause thinning of the product at points of contact. Furthermore, they should be stacked in such a way that access for conformance testing is possible.

4. If outdoor storage of rolls is to be longer than a few weeks particular care, e.g., using tarpaulins, should be taken to minimize moisture pickup or accidental damage. For storage periods longer than one season a temporary enclosure should be placed over the rolls, or they should be moved within an enclosed facility.

4.3.4 Acceptance and Conformance Testing

Upon delivery of the GCLs to the field site, the CQA officer should see that conformance test samples are obtained. These samples are then sent to the CQA Laboratory for testing to ensure that the GCL conforms to the project plans and specifications. The samples are taken from selected rolls by removing the protective wrapping and cutting full-width, 1 m (3 ft.) long samples from the outer wrap of the selected roll(s). Sometimes one complete outer revolution of GCL is discarded before the test sample is taken. The rolls are immediately re-wrapped and replaced in the shipping trailers or in the temporary field storage area. Alternatively, conformance testing could be performed at the manufacturer's facility and when completed the particular lot should be identified for the particular project under investigation.

Items to consider for a specification or CQA document in this regard are the following:

1. The samples should be identified by type, style, lot and roll numbers. The machine direction should be noted on the sample(s) with a waterproof marker.

2. A lot is usually defined as a group of consecutively numbered rolls from the same manufacturing line. Other definitions are also possible and should be clearly stated in the CQA documents.

3. Sampling should be done according to the project specification and/or CQA documents. Unless otherwise stated, sampling should be based on a lot basis. Different interpretations of sampling frequency within a lot are based on total area or on number of rolls. For example, sampling could be based on 10,000 m² (100,000 ft²) of area or on use of ASTM D-4354 which is based on rolls.

4. Testing at the CQA laboratory may include mass per unit area per ASTM D-5261, and free swell of the clay component per GRI-GCL1. The sampling frequency for these index tests should be based on ASTM D-4354. Other conformance tests, which are more performance oriented, could be required by the project specifications but at a reduced frequency compared to the above mentioned index tests. Examples are hydraulic conductivity (permeability) ASTM D-5084 (mod.) or GRI GCL2 and direct shear testing per ASTM D-5321. The sampling frequency for these performance tests might be based on area, e.g., one test per 10,000 m² (100,000 ft²).
5. If testing of the geotextiles, or geomembrane, covering the GCLs is desired it should be
done on the original rolls of the geotextiles, or geomembrane, before they are fabricated
into the GCL product. Once fabricated their properties will change considerably due to
the needling, stitching and/or gluing during manufacturing.

6. Peel testing of needle punched or stitch bonded GCLs should be done in accordance
with ASTM D-413 (mod.). The sampling frequency is recommended to be one test per
2000 m² (20,000 ft²).

7. Conformance test results should be sent to the CQA engineer prior to installation of any
GCL from the lot under review.

8. The CQA engineer should review the results and should report any nonconformance to
the Owner/Operator’s Project Manager.

9. The resolution of failing conformance tests must be clearly stipulated in the
specifications or CQA documents. Statements should be based upon ASTM D-4759
entitled “Determining the Specification Conformance of Geosynthetics.”

4.4 Installation

This section will cover the placement, joining, repairing and covering of GCLs.

4.4.1 Placement

The installation contractor should remove the protective wrapping from the rolls to be
deployed only after the substrate layer (soil or other geosynthetic) in the field has been approved by
CQA personnel. The specification and CQA documents should be written in such a manner as to
ensure that the GCLs are not damaged in any way. A CQA inspector should be present at all times
during the handling, placement and covering of GCLs. Figure 4.6(a) shows the typical placement
of a GCL in the field on soil subgrade and Fig. 4.6(b) shows placement (without heavy
equipment) on an underlying geosynthetic.

The following items should be considered for inclusion in a specification or CQA
document.

1. The installer should take the necessary precautions to protect materials underlying the
GCL. If the substrate is soil, construction equipment can be used to deploy the GCL
providing excessive rutting is not created. Excessive rutting should be clearly defined
and quantified. In some cases 25 mm (1.0 in.) is the maximum rut depth allowed. If
the ground freezes, the depth of ruts should be further reduced to a specified value. If
the substrate is a geosynthetic material, GCL deployment should be by hand, or by use
of small jack lifts or light weight equipment on pneumatic tires having low ground
contact pressure.

2. The minimum overlap distance which is specified should be verified. This is typically
150 to 300 mm (6 to 12 in.) depending upon the particular product and site conditions.
Figure 4.6(a) - Field Deployment of a GCL on a Soil Subgrade

Figure 4.6(b) - Field Deployment of a GCL on an Underlying Geosynthetic
3. Additional bentonite clay should be introduced into the overlap region with certain types of GCLs. There are typically those with needle punched nonwoven geotextiles on their surfaces. The clay is usually added by using a line spreader or line chalker with the bentonite clay in a dry state. Alternatively, a bentonite clay paste, in the mixture range of 4 to 6 parts water to 1 part of clay, can be extruded in the overlap region. Manufacturer's recommendations on type and quantity of clay to be added should be followed.

4. During placement, care must be taken not to entrap in or beneath the GCL, fugitive clay, stones, or sand that could damage a geomembrane, cause clogging of drains or filters, or hamper subsequent seaming of materials either beneath or above the GCL.

5. On side slopes, the GCL should be anchored at the top and then unrolled so as to keep the material free of wrinkles and folds.

6. Trimming of the GCL should be done with great care so that fugitive clay particles do not come in contact with drainage materials such as geonets, geocomposites or natural drainage materials.

7. The deployed GCL should be visually inspected to ensure that no potentially harmful objects are present, e.g., stones, cutting blades, small tools, sandbags, etc.

4.4.2 Joining

Joining of GCLs is generally accomplished by overlapping without sewing or other mechanical connections. The overlap distance requirements should be clearly stated. For all GCLs the required overlap distance should be marked on the underlying layer by a pair of continuous guidelines. The overlap distance is typically 150 to 300 mm (6 to 12 in.). For those GCLs, with needle punched nonwoven geotextiles on their surfaces, dry bentonite is generally placed in the overlapped region. If this is the case, utmost care should be given to avoid fugitive bentonite particles from coming into contact with leachate collection systems. Another variation, however, has been to extrude a moistened tube of bentonite into the overlapped region.

Items to consider for a specification or CQA document follow:

1. The amount of overlap for adjacent GCLs should be stated and adhered to in field placement of the materials.

2. The overlap distance is sometimes different for the roll ends versus the roll edges. The values should be stated and followed.

3. If dry or moistened bentonite clay (or other material) is to be placed in the overlapped region, the type and amount should be stated in accordance with the manufacturer's recommendations and/or design considerations. Index testing requirements for proper verification of the clay should be specified accordingly. Furthermore, the placement procedure should be clearly outlined so as to have enough material to make an adequately tight joint and yet not an excessive amount which could result in fugitive clay particles.

4.4.3 Repairs

For the geotextile-related GCLs, holes, tears or rips in the covering geotextiles made during
transportation, handling, placement or anytime before backfilling should be repaired by patching using a geotextile. If the bentonite component of the GCL is disturbed either by loss of material or by shifting, it should be covered using a full GCL patch of the same type of product.

Some relevant specification or CQA document items follow.

1. Any patch, used for repair of a tear or rip in the geotextile, should be done using the same type as the damaged geotextile or other approved geotextile by the CQA engineer.

2. The size of the geotextile patch must extend at least 30 cm (12 in.) beyond any portion of the damaged geotextile and be adhesive or heat bonded to the product to avoid shifting during backfilling with soil or covering with another geosynthetic.

3. If bentonite particles are lost from within the GCL or if the clay has shifted, the patch should consist of the full GCL product. It should extend at least 30 cm (12 in.) beyond the extent of the damage at all locations. For those GCLs requiring additional bentonite clay in overlap seaming, the similar procedure should be used for patching.

4. Particular care should be exercised in using a GCL patch since fugitive clay can be lost which can find its way into drainage materials or onto geomembranes in areas which eventually are to be seamed together.

4.5 Backfilling or Covering

The layer of material placed above the deployed GCL will be either soil or another geosynthetic. Soils will vary from compacted clay layers to coarse aggregate drainage layers. Geosynthetics will generally be geomembranes although other geosynthetics may also be used depending on the site specific design. The GCL should generally be covered before a rainfall or snow event occurs. The reason for covering with the adhesive bonded GCLs is that hydration before covering can cause changes in thickness as a result of uneven swelling or whenever compressive or shear loads are encountered. Hydration before covering may be less of a concern for the needled and stitch bonded types of GCLs, but migration of the fully hydrated clay in these products might also be possible under sustained compressive or shear loading. Figure 4.7 shows the premature hydration of a GCL being gathered up by hand to be discarded in the adjacent landfill.

Some recommended specifications or CQA document items are as follows:

1. The GCL should be covered with its subsequent layer before a rainfall or snowfall occurs.

2. The GCL should not be covered before observation and approval by the CQA personnel. This requires close coordination between the installation crew and the CQA personnel.

3. If soil is to cover the GCL it should be done such that the GCL or underlying materials are not damaged. Unless otherwise specified, the direction of backfilling should proceed in the direction of downgradient shingling of the GCL overlaps. Continuous observation of the soil placement is recommended.

4. If a geosynthetic is to cover a GCL, both underlying and the newly deployed material should not be damaged.
5. The overlying material should not be deployed such that excess tensile stress is mobilized in the GCL. On side slopes, this requires soil backfill to proceed from the bottom of the slope upward. Other conditions are site specific and material specific.

Figure 4.7 - Premature Hydration of a Geosynthetic Clay Liner Being Gathered and Discarded due to its Exposure to Rainfall Before Covering

4.6 References

API 13B, “Fluid Loss of Bentonite Clays”

ASTM B-417, “Apparent Density of Non Free-Flowing Metal Powders”

ASTM C-136, “Sieve Analysis of Fine and Coarse Aggregates”
ASTM D-413, “Rubber Property - Adhesion to Flexible Substrate”
ASTM D-422, “Particle Size Analysis of Soils”
ASTM D-1777, “Measuring Thickness of Textile Materials”
ASTM D-2216, “Laboratory Determination of Water (Moisture) Content of Soil and Rock”
ASTM D-4643, “Determination of Water (Moisture Content) of Soil by Microwave Oven Method”
ASTM D-4873, “Identification, Storage and Handling of Geotextiles”
ASTM D-4972, “Method for pH of Soils”
ASTM D-5084, “Hydraulic Conductivity of Saturated Porous Material Using A Flexible Wall Permeameter”
ASTM D-5199, "Nominal Thickness of Geotextiles and Geomembranes"
ASTM D-5261, “Measuring Mass per Unit Area of Geotextiles”
ASTM D-5321, “Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method”
ASTM E-946, “Water Absorption of Bentonite of Porous Plate Method”
GRI GCL1, “Free Swell Conformance Test of Clay Component of a GCL”
GRI GCL2, “Permeability of Geosynthetic Clay Liners (GCLs)”
USP-NF-XVII, “Swell Index Test”