CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Sand

Sand is a material composed of grains of mineral matters ranging from approximately 2 to 0.05 mm (1/12 to 1/500-in.) in diameter. This definition makes no reference to the mineral composition of the grains but common foundry sands are composed largely of silica (silicon dioxide, SiO_2) (The American Foundrymen's Society, 1978). High grade specialty sands are available for cores and molds where special characteristics unique to these minerals are required. The common specialty sands include zircon ($ZrSiO_4$), chromite ($FeCr_2O_4$), olivine [$(Mg.Fe)_2SiO_4$], staurolite ($FeAl_5Si_2O_{12}$:OH) and aluminum silicates (The American Foundrymen's Society, 1978).

Sand feels gritty between the fingers and the particles are generally visible to the naked eyes. As sand particles are relatively large, so the voids between them are relatively large and promote free drainage of water and entry of air into the soil. Because of their large size, particles of sand have relatively low specific surface area. Sand particles are considered noncohesive: that is, they do not tend stick together in a mass.

2.2 Clay

Particles smaller than 0.002 mm are classified as clay and have a very large specific surface area, giving them a tremendous capacity to absorb water and other substances. This large adsorptive surface causes clay particles to cohere together in a hard mass after drying. When wet, clay is sticky and can be easily molded.

Clays can originate in three ways 1) formed by the decomposition of rock in place and known as residual clays, 2) formed by the alteration of rocks of igneous origin by underground waters and 3) deposited as sediments and known as sedimentary clays.

The clays used as bonds in synthetic sands, are of four general types (The American Foundrymen's Society, 1978)

1. Fireclays, composed essentially of the mineral kaolinite (Al_2O_3, $2SiO_2.2H_2O$)

2. Bentonite, a plastic clay derived usually by the decomposition of volcanic ash and consisting chiefly of the mineral montmorillonite. The color of bentonite clays varies from white to light green or light blue. When a dried bentonite is immersed in water, the former increases its volume or swells more than any other dried clay. There are two types of bentonites available to the foundry industry. They are referred to as calcium and sodium bentonite. Calcium bentonites carry a larger propotion of calcium ions and sodium bentonites carry larger proportion of sodium ions. When properly conditioned, clays are used in the construction of dams, reservoirs, ponds, or lagoons for preventing seepage of water through them. The swelling property of the clays is utilized here to seal off the voids, thus reducing seepage flow by decreased permeability.

3. Fuller's earth, a clay used primarily because of its bleaching qualities closely related to bentonite and used by some as a bond clay.

4. Illite, a clay mineral found in many clays, sometimes forms a large percentage of the clay deposit.

2.3 Landfill Containment Systems

The concept of containment systems for modern landfills involves the use of barrier layers to prevent leachate from leaving the landfill and contaminating the underlying soil and groundwater, and to prevent water from entering the landfill to create leachate (Reinhart and Townsand 1997). Barrier layers are constructed of materials that possess a low permeability to water. The most common materials include compacted soil (clay) and synthetic membranes (geomembranes). The

containment layer at the bottom of a landfill is known as a liner and the one at the top is referred to as a cap.

Compacted soil barrier layers

Many soils naturally posses characteristics that make them relatively impermeable to water flow. Clayey soils are a good example of a naturally impermeable material. Because of the small particle size and the surface chemistry of clay minerals, clay deposits in the environment greatly restrict the rate of water movement. Natural clay deposits sometimes are used as landfill barrier layers. In most sanitary landfills, however, clay liners are constructed by modifying the structure of the clay soil brought to the site by the addition of water and mechanical compaction to achieve optimum engineering characteristics.

A number of properties make compacted soil amenable to use as a component in a landfill containment system. These include mechanical properties such as shear strength, but most importantly, the permeability of the clay to water. The engineering parameter relating the permeability of a porous media to the flow of water is the hydraulic conductivity. Most engineered clay liners must meet regulatory requirements for hydraulic conductivity of less than 10^{-7} cm/s (Reinhart and Townsand 1997). The hydraulic conductivity of a compacted soil, along with many other parameters, must be tested routinely during soil liner construction.

Synthetic barrier layer

In recent years, an entire field of engineered materials known as geosynthetics has developed (Reinhart and Townsand 1997). These materials are generally composed of plastics, and are used for a wide variety of waste containment applications. One of the most common uses of geosynthetic material at landfills is the geomembrane. A geomembrane is a thin sheet of plastic that possesses the characteristic of being highly impermeable to water and resistant to chemical attack from the waste it is designed to contain. Long strips of geomembrane material may be

attached to one another to form a continuous barrier layer. The most common type of geomembrane used at a landfill is high density polyethylene (HDPE), but other materials in use include polyvinyl chloride (PVC), low density polyethylene (LDPE), and polypropylene (PP). Geomembranes that exhibit the greatest chemical resistance and the lowest water vapor transmission rates (such as HDPE) are normally used as components of bottom liners. Geomembranes that possess a large modulus of elasticity are typically used for components of cap systems.

Geomembranes hold some advantages over clay because they are less permeable to water transport, much less material is required, and they are easy to install. Disadvantages include the fact that they are more susceptible to leaks from damage during installation and their long-term performance is uncertain. For these reasons, many barrier layer applications use combinations of both a geomembrane and a compacted soil liner.

Liner systems

The use of multiple components in the design of a low permeability barrier layer results in the creation of a liner system. As previously stated, the use of a compacted soil layer and a geomembrane provides an effective combination. Such a liner is defined as a composite liner. Current U.S. federal regulations for MSW landfills require a liner system composed of a composite liner with 60 cm of compacted soil at a maximum hydraulic conductivity of 10^{-7} cm/s and a geomembrane (Reinhart and Townsand 1997). The geomembrane must be at least 30 mil in thickness (60 mil in the case of HDPE) and the geomembrane must be in intimate contact with the compacted soil. The composite liner then is overlain by a drainage layer that limits the depth of leachate on the liner to less than 30 cm at all times. In addition to barrier layers, however, other layers must be provided to permit the drainage and removal of leachate away from the liner. These leachate collection systems (LCS) are composed of highly permeable materials, either naturally occurring ones such as a sand or gravel, or synthetic, such as a geonet and geotextile. A cross-section of a RCRA Subtitle D liner (MSW landfill) is presented in Figure 2.1.
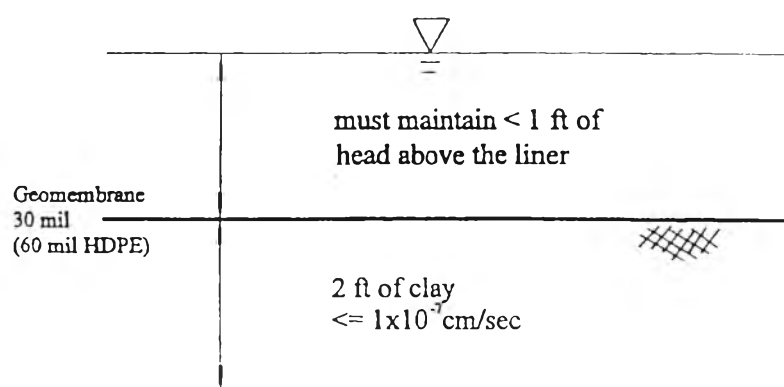
Geomembrane
30 mil
(60 mil HDPE)

must maintain < 1 ft of
head above the liner

2 ft of clay
<= 1x10^{-7}cm/sec

Figure 2.1 Subtitle D landfill liner cross section (Reinhart and Townsand 1997)

Cap systems

A cap system functions in a similar manner as a liner system, except the purpose is to keep water from entering the landfill. The RCRA Subtitle D MSW landfill regulations (Reinhart and Townsand 1997) require closure when the permitted capacity of a landfill is reached. The closure process requires, among other things, that a cap system be installed to prevent entrance of water into the landfill, as well as gas migration. While no technical standards have been issued for the specific components of the cap system, the barrier layer in the cap system must not have a hydraulic conductivity of greater than that of the bottom component of the liner system. A suggested cap design by the U.S. EPA is presented in Figure 2.2. Drainage layers are also included as part of the cap system to serve as gas venting layers to facilitate gas transport to collection wells. A vegetative layer is located above the barrier layer to prevent surface soil erosion.
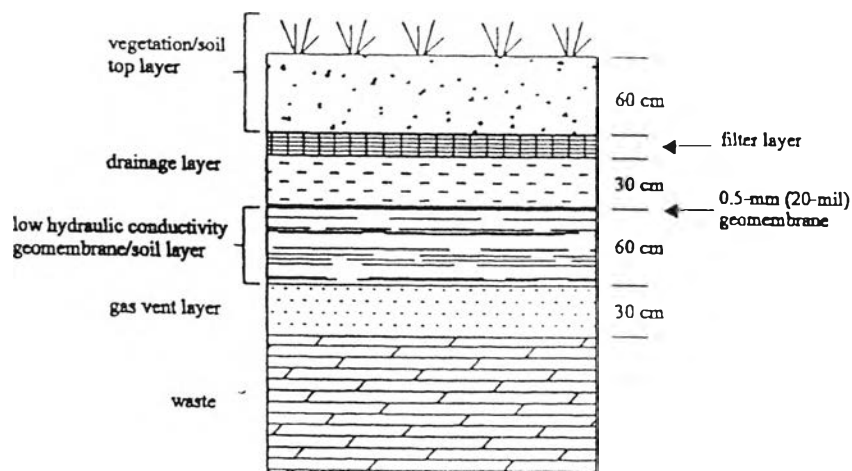
Figure 2.2 EPA recommended landfill cap system (Reinhart and Townsand 1997)

2.4 Metal Casting Process

Many different metal casting techniques are in use today. They all have in common the construction of a mold with a cavity in the external shape of the desired cast part followed by the introduction of molten metal into the mold.

The metal casting process has been divided into the following five major operations: (Office of Enforcement and Compliance Assurance U.S. Environmental Protection Agency, 1997)

1. Pattern Making
2. Mold and Core Preparation and Pouring
3. Furnace Charge Preparation and Metal Melting
4. Shakeout, Cooling and Sand Handling
5. Quenching, Finishing, Cleaning and Coating

Pattern making

Pattern making, or foundry tooling, requires a high level of skill to achieve the close tolerances required of the patterns and coreboxes. This step is critical in the casting process since the casting produced can be no better than the patterns used to

make them. In some pattern making shops, computer-aided drafting (CAD) is used in the design of patterns. Cutter tool paths are designed with computer-aided manufacturing (CAM). Numerical output from these computers is conveyed to computer-numerical-controlled (CNC) machine tools, which then cut the production patterns to shape. Such computer-aided systems have better dimensional accuracy and consistency than hand methods (LaRue, 1989).

Patterns and corebox materials are typically metal, plastic, wood or plaster. Wax and polystyrene are used in the investment and lost foam casting processes, respectively. Pattern makers have a wide range of tools available including wood working and metal machining tools. Mechanical connectors and glues are used to join pattern pieces. Wax, plastic or polyester putty are used as "fillet" to fill or round the inside of square corners (LaRue, 1989).

Very little waste is generated during pattern making compared to other foundry operations. Typical pattern shop wastes include scrap pattern materials (wood, plastics, metals, etc.) and particulate emissions from cutting, grinding and sanding operations. Waste solvents and cleaners may be generated from equipment cleaning.

<u>Mold and core preparation and pouring</u>

The various processes used to cast metals are largely defined by the procedures and materials used to make the molds and cores. A mold and cores (if required) are usually made for each casting. These molds and cores are destroyed and separated from the casting during shakeout (see Shakeout, Cooling and Sand Handling). Most sand is reused over and over in other molds; however, a portion of sand becomes spent after a number of uses and must be removed as waste. Mold and core making are, therefore, a large source of foundry wastes.

For most sand casting techniques, the following summary of the process applies (see Figure 2.3). First, engineers design the casting and specify the metal or

alloy to be cast. Next, a pattern (replica of the finished piece) is constructed from either plastic, wood, metal, plaster or wax. Usually, the pattern is comprised of two halves. The molding sand is shaped around the pattern halves in a metal box (flask) and then removed, leaving the two mold halves. The top half of the mold (the cope) is assembled with the bottom half (the drag) which sits on a molding board. The interface between the two mold halves is called a parting line. Weights may be places on the cope to help secure the two halves together. The molten metal is poured or injected into a hole in the cope called a sprue or sprue basin which is connected to the mold's gating system, which is designed to carry molten metal smoothly to all parts of the mold. The metal is then allowed within the space defined by the mold.
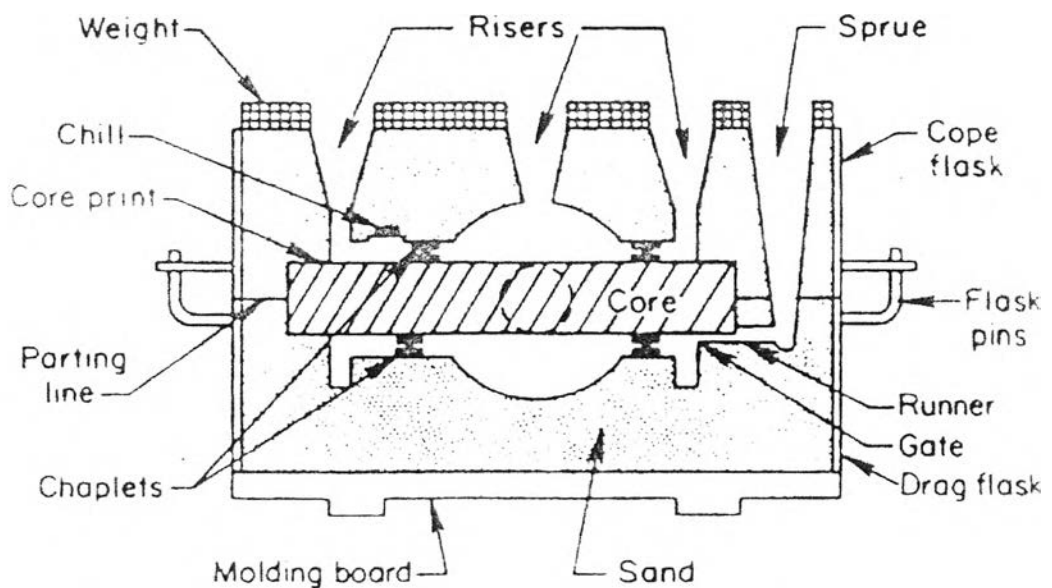

Figure 2.3 Sand mold and core cross section (American Foundrymen's Society, 1981)

Since the molds themselves only replicate the external shape of the pattern, cores are placed inside the mold to form any internal cavities. Cores are produced in a core box, which is essentially a permanent mold that is developed in conjunction with the pattern. So that molten metal can flow around all sides of the cores. They are supported on core prints (specific locations shaved into the mold) or on by metal supports called chaplets.

Foundry molds and cores are most commonly constructed of sand grains bonded together to form the desired shape of the casting. Sand is used because it is inexpensive, is capable of holding detail, and resists deformation when heated. Sand casting affords a great variety of casting sizes and complexities. Sand also offers the advantage of reuse for a large portion of the sand in future molds. Depending on the quantity of castings, however, the process can be slower and require more man-hours than processes not requiring a separate mold for each casting. In addition, castings from sand molds are dimensionally less accurate than those produces from some other techniques and often require a certain amount of machining (USITC, 1984). The pattern making, melting, cleaning, and finishing operations are essentially the same whether or not sand molds are used. Sand molds and cores will, however, require the additional operational steps involved with handling quantities of used mold and core sand.

In general, the various binding systems can be classified as either clay bonded sand (green sand) or chemically bonded sand. The type of binding system used depends on a number of production variables, including the temperature of the molten metal, the casting size, the types of sand used, and the alloys to be cast. The differences in binding systems can have an impact on the amounts and toxicity of wastes generated and potential releases to the environment.

Green sand is the most common molding process, making about 90% of casting produced in the U.S. Green sand is not used to form cores. Cores are formed using one of the chemical binding systems. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 to 95 percent silica (or olivine or zircon) sand, 4 to 10 percent bentonite clay, 2 to 10 percent carbonaceous materials such as powdered (sea) coal, petroleum products, corn starch or wood flour, and 2 to 5 percent water (AFS, 1996). The clay and water act as binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mold, creating a reducing atmosphere which prevents the metal from oxidizing while it solidifies (U.S. EPA, 1992).

Green sand, as exemplified by its widespread use, has a number of advantages over other casting methods. The process can be used for both ferrous and non-ferrous metal casting and it can handle a more diverse range range of products than any other casting method. For example, green sand is used to produce both small precision casting and large castings of up to a ton. If uniform sand compaction and accurate control of sand properties are maintained, very close tolerances can be obtained. The process also has the advantage of requiring a relatively short time to produce a mold compared to many other processed. In addition, the relative simplicity of the process makes it ideally suited to a mechanized process (AFS, 1989).
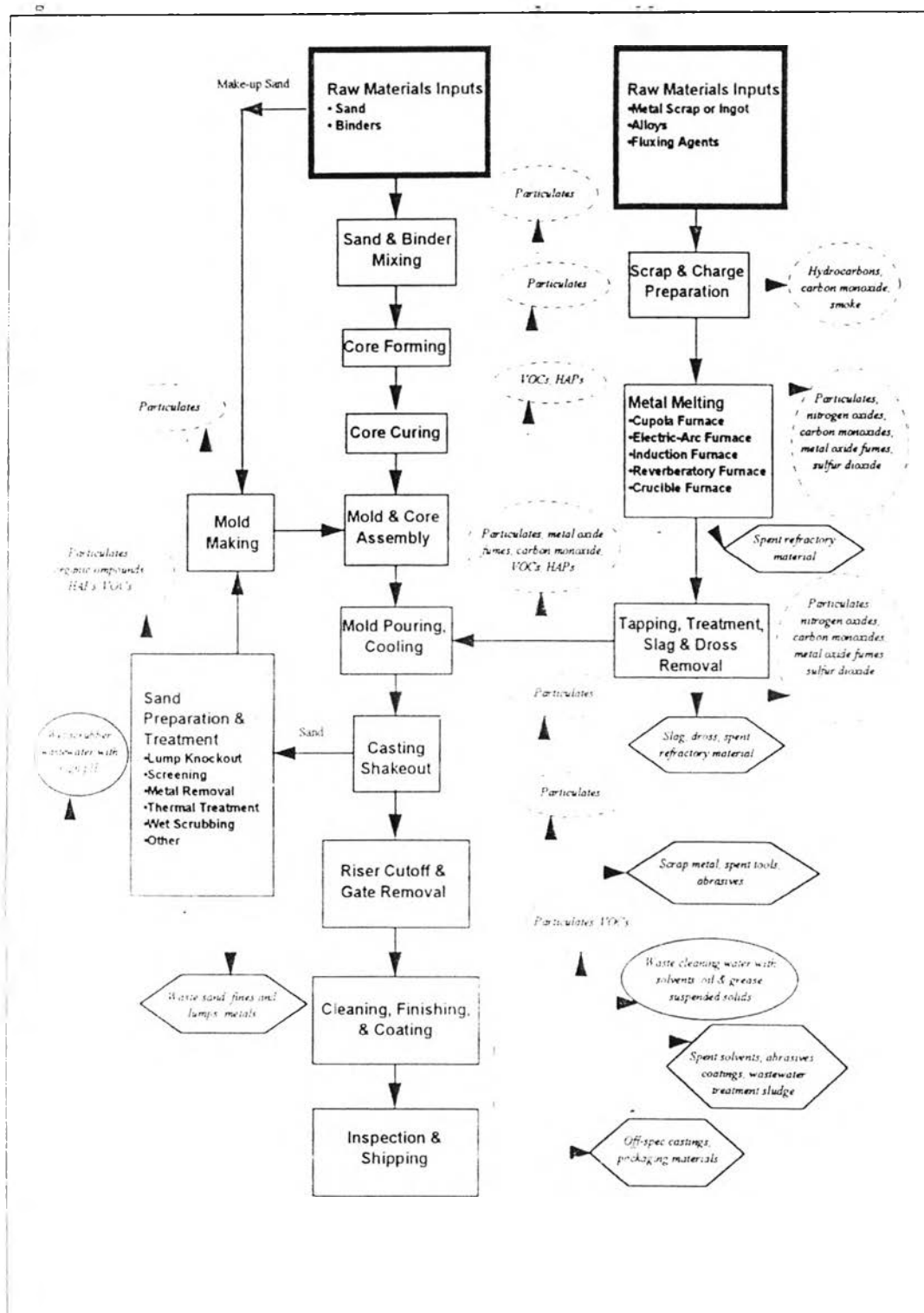
Figure 2.4 Process flow and potential pollutant outputs for typical green sand foundry
(Kotzin, Air Pollution Engineering Manual: Steel Foundries, 1992)

Sand cores that are used in molds break down and become part of the mold sand. Foundries using green sand molds generate waste sand that becomes spent after it has been reused in the process a number of times, as a portion must be disposed of to prevent the build up of grains that are too fine. Waste chemically bonded core sands are also generated. Typically, damaged cores are not reusable and must be disposed as waste.

Particulate emissions are generated during mixing, molding and core making operations. In addition, gaseous and metal fume emissions develop when molten metal is poured into the molds and a portion of the metal volatilizes and condenses. When green sand additives and core sand binders come into contact with the molten metal, they produce gaseous emissions such as carbon monoxide, organic compounds, hydrogen sulfide, sulfer dioxide, nitrous oxide, benzene, phenols, and other hazardous air pollutants (HAPs) (Twarog, 1993). Wastewater containing metals and suspended solids may be generated if the mold is cooled with water.

Furnace charge preparation and metal melting

Foundries typically use recycled scrap metals as their primary source of metal, and use metal ingot as a secondary source when scrap is not available. The first step in metal melting is preparation of the scrap materials. Preparation, which also may be done by the foundry's metal supplier, consists of cutting the materials to the proper size for the furnace and cleaning and degreasing the materials. Cleaning and degreasing can be accomplished with solvents or by a precombustion step to burn off any organic contaminants (Kotzin, 1992). Prepared scrap metal is weighed and additional metal, alloys, and flux may be added prior to adding the metal to the furnace. Adding metal to a furnace is called "charging."

Flux is a material added to the furnace charge or to the molten metal to remove impurities. Flux unites with impurities to form dross or slag, which rises to the surface of the molten metal where it is removed before pouring (LaRue, 1989). The slag material on the molten metal surface helps to prevent oxidation of the metal.

Flux is often chloride or fluoride salts that have an affinity to bind with certain contaminants. The use of salt fluxes may result in emissions of acid gasses.

Five types of furnaces are commonly used to melt metal in foundries: cupola, electric arc, reverberatory, induction and crucible (see Figure 2.5). Some foundries operate more than one type of furnace and may even transfer molten metal between furnace types in order to make best use of the best features of each.

Cupola furnaces

The cupola furnace is primarily used to melt gray, malleable, or ductile iron. The furnace is a hollow vertical cylinder on legs and lined with refractory material. Hinged doors at the bottom allow the furnace to be emptied when not in use. When charging the furnace, the doors are closed and a bed of sand is placed at the bottom of the furnace, covering the doors. Alternating layers of coke for fuel and scrap metal, alloys and flux are placed over the sand. Although air, or oxygen enriched air, is forced through the layers with a blower, cupolas require a reducing atmosphere to maintain the coke bed. Heat from the burning coke melts the scrap metal and flux, which drip to the bottom sand layer. In addition, the burning of coke under reducing conditions raises the carbon content of the metal charge to the casting specifications. A hole level with the top of the sand allows molten metal to be drained off, or "tapped." A higher hole allows slag to be drawn off. Addition charges can be added to the furnace as needed (LaRue, 1989).

Electric arc furnaces

Electric arc furnaces are used for melting cast iron or steel. The furnace consists of a saucer-shaped hearth of refractory material for collecting the molten metal with refractory material lining the sides and top of the furnace. Two or three carbon electrodes penetrate the furnace from the top or sides. The scrap metal charge is places on the hearth and melted by the heat from an electric arc formed between the electrodes. When the electric arc comes into contact with the metal, it is a direct-arc

furnace and when the electric arc does not actually touch the metal it is am indirect-arc furnace. Molten metal is typically drawn off through a spout by tipping the furnace. Alloying metal can be added, and slag can be removed, through doors in the walls of the furnace (LaRue, 1989). Electric arc furnaces have the advantage of not requiring incoming scrap to be clean. One disadvantage is that they do not allow precise metallurgical adjustments to the molten metal.

Reverberatory furnaces

Reverberatory furnaces are primarily used to melt large quantities of nonferrous metals. Metal is placed on a saucer-shaped hearth lined with refractory material on all sides. Hot air and combustion gasses from oil or gas burners are blown over the metal and exhausted out of the furnace. The heat melts the metal and more charge is added until the level of molten metal is high enough to run out of a spout in the hearth and into a well from which it can be ladled out (LaRue, 1989).

Induction furnaces

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces, but all create a strong magnetic field by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across and subsequently an electric current through the metal to be melted. The electrical resistance of the metal produces heat which melts the metal. Induction furnaces are very efficient and are made in a wide range of sizes (LaRue, 1989). Induction furnaces require cleaner scrap then electric arc furnaces, however, they do allow precise metallurgical adjustments.

Crucible furnaces

Crucible furnaces are primarily used to melt smaller amounts of nonferrous metals than other furnace types. The crucible or refractory container is heated in a furnace fired with natural gas or liquid propane. The metal in the crucible melts, and

can be ladled from the crucible or poured directly by tipping the crucible (LaRue, 1989).

Cupola, reverberatory and electric arc furnaces may emit particulate matter, carbon monoxide, hydrocarbons, sulfur dioxide, nitrogen oxides, small quantities of chloride and fluoride compounds, and metallic fumes from the condensation of volatilized metal and metal oxides. Induction furnaces and crucible furnaces emit relatively small amounts of particulates, hydrocarbons, and carbon monoxide emissions. The highest concentration of furnace emissions occur when furnaces are opened for charging, alloying, slag removal, and tapping (Kotzin, 1992). Particulate emissions can be especially high during alloying and the introduction of additives. For example, if magnesium is added to molten metal to produce ductile iron, a strong reaction ensures, with the potential to release magnesium oxides and metallic fumes (NADCA, 1996).

Furnace emissions are often controlled with wet scrubbers. Wet scrubber wastewater can be generated in large quantities (up to 3,000 gallons per minute) in facilities using large cupola furnaces. This water may contain metals and phenols, and is typically highly alkaline or acidic and is neutralized before being discharged to the POTW (AFS Air Quality Committee, 1992). Non-contact cooling water with little or no contamination may also be generated.

Scrap preparation using thermal treatment will emit smoke, organic compounds and carbon monoxide. Other wastes may include waste solvents if solvents are used to prepare metal for charging. Slag is also generated during metal melting operations. Hazardous slag can be generated if the charge materials contain enough toxic metals such as lead and chromium or if calcium carbide is used in the metal to remove sulfer compounds (U.S. EPA, 1992).
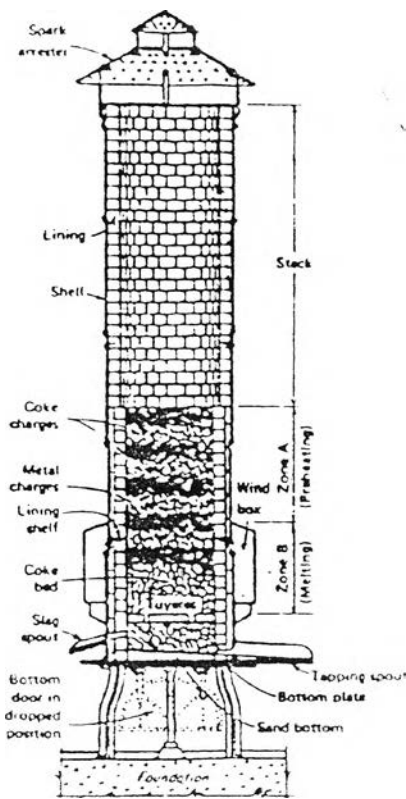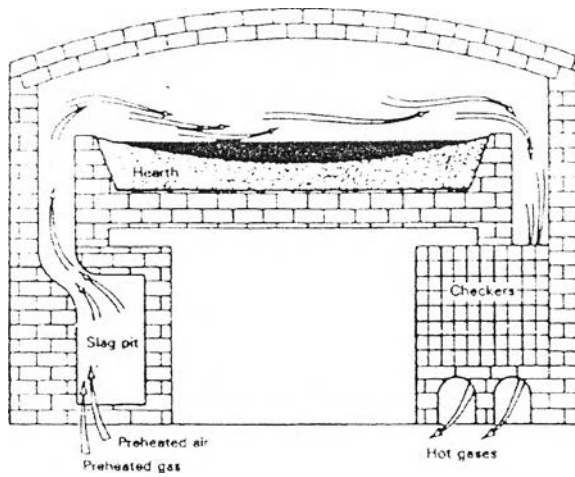
Cupola
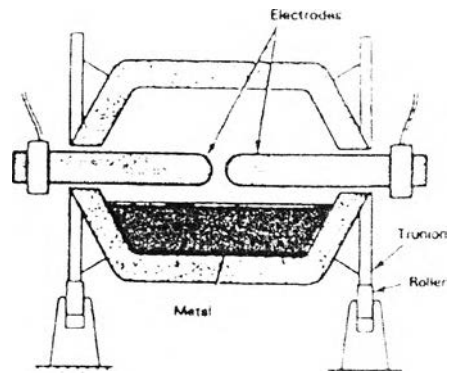
Electric Indirect-Arc
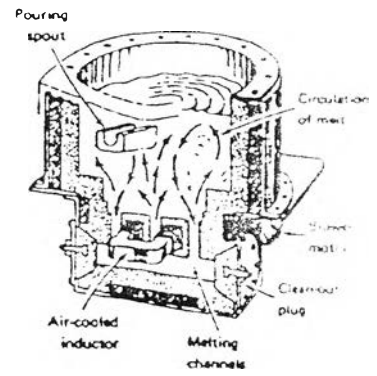
Induction

Reverberatory

Figure 2.5 Sectional views of melting furnaces (American Foundry's society, 1989)

Shakeout, cooling and sand handling

For those foundries using sand molding and core making techniques, castings need to be cooled and separated from the sand mold. After molten metal has been ladled into the mold and begins to solidify, it is transported to a cooling area where the casting solidifies before being separated from the mold. Larger, more mechanized foundries use automatic conveyor systems to transfer the casting and mold through a cooling tunnel on the way to the shakeout area. Less mechanized foundries allow the castings to cool on the shop floor. In the shakeout area, molds are typically placed on vibrating grids or conveyors to shake the sand loose from the casting. In some foundries, the mold may be separated from the casting manually (U.S. EPA, 1986).

Sand casting techniques can generate substantial volumes of waste sand. Many foundries reuse a large amount of this sand and only remove a small portion as waste. Waste sand removed from the foundry is primarily made up of fine grains that build up as the sand is reused over and over. Most foundries, therefore, have a large multi-step sand handling operation for capturing and conditioning the reusable sand. Larger foundries often have conveyorized sand-handling systems working continuously. Smaller, less mechanized foundries often use heavy equipment (e.g., front-end loaders) in a batch process (U.S. EPA, 1992). Increasingly, foundry waste sand is being sent off-site for use as a construction material.

Sand handling operations receive sand directly from the shakeout step or from an intermediate sand storage area. A typical first step in sand handling is lump knockout. Sand lumps occur when the binders used in sand cores only partially degrade after exposure to the heat of molten metal. The lumps, or core butts, may be crushed and recycled into molding sand during this step. They can also be disposed as waste material. A magnetic separation operation is often used in ferrous foundries to remove pieces of metal from the sand. Other steps involve screening to remove fines that build up over time, and cooling by aeration. In addition, some foundries treat mold and core sand thermally to remove binders and organic impurities (U.S. EPA, 1992).

Shakeout, cooling and sand handling operations generate waste sand and fines possibly containing metals. In addition, particulate emissions are generated during these operations. If thermal treatment units are used to reclaim chemically bonded sands, emissions such as carbon monoxide, organic compounds, and other gasses can be expected.

Quenching, finishing, cleaning and coating

Rapid cooling of hot casting by quenching in a water bath is practices by some foundries and die casters to cool and solidify the casting rapidly (to speed the process) and to achieve certain metallurgical properties. The water bath may be plain water or may contain chemical additives to prevent oxidation.

Some amount of finishing and cleaning is required for all castings; however, the degree and specific types of operations will depend largely on the casting specifications and the casting process used. Finishing and cleaning operations can be a significant portion of the overall cost to produce a casting. Foundries, therefore, often search for casting techniques and mold designs that will reduce the finishing needed.

Finishing operations begin once the casting is shaken out and cooled. Hammers, band saws, abrasive cutting wheels, flame cut-off devices, and air-carbon arc devices may be used to remove the risers, runners, and sprues of the gating system. Metal fins at the parting lines (lines on a casting corresponding to the interface between the cope and drag of a mold) are removed with chipping hammers and grinders. Residual refractory material and oxides are typically removed by sand blasting or steel shot blasting, which can also be used to give the casting a uniform and more attractive surface appearance (U.S. EPA, 1992).

The cleaning of castings precedes any coating operations to ensure that the coating will adhere to the metal. Chemical cleaning and coating operations are often contracted out to off-site firms, but are sometimes carried out at the foundries. Scale,

rust, oxides, oil, grease, and dirt can be chemically removed from the surface using organic solvents (typically chlorinated solvents although naphtha, methanol, and toluene are also used), emulsifiers, pressurized water, abrasives, alkaline agents (caustic soda, soda ash, alkaline silicates, and phosphates), or acid pickling. The pickling process involves the cleaning of the metal surface with inorganic acids such as hydrochloric acid sulfuric acid, or nitric acid. Castings generally pass from the pickling bath through a series of rinses. Molten salt baths are also used to clean complex interior passages in casting (U.S. EPA, 1992).

Castings are often given a coating to inhibit oxidation, resist deterioration, or improve appearance. Common casting operations include: painting, electroplating, electroless nickel plating, hard facing, hot dipping, thermal spraying, diffusion, conversion, porcelain enameling, and organic or fused dry resin coating (U.S. EPA, 1992).

Casting quench water may contain phenols, oil and grease, suspended solids, and metals (e.g., copper, lead, zine). Metal-bearing sludges may be generated when quench baths are cleaned out (U.S. EPA, 1995).

Finishing operations may generate particulate air emissions. Wastewater may contain cutting oils, ethylene glycol, and metals. Solid wastes include metal chips and spent cutting oils (U.S. EPA, 1995).

Cleaning and coating may generate air emissions of VOCs from painting, coating and solvent cleaning; acid mists and metal ion mists from anodizing, plating, polishing, hot dip coating, etching, and chemical conversion coating. Wastewater may contain solvents, metals, metal salts, cyanides, and high or low pH. Solid wastes include cyanide and metal-bearing sludges, spent solvents and paints, and spent plating baths (U.S. EPA, 1995).

2.5 Characterization of Virgin and Spent Foundry Sand

The major components in foundry sand are quartz sand (70-80%), clay (5-15%), additives (2-5%), and water (up to 4%). Clean, uniformly sized silica sand is bonded via binder(s) to form molds for ferrous and non-ferrous metal castings. The largest volumes of foundry sand are used as 'green sand' (clay-bonded). Green sand consists of high-quality silica sand, approximately 10% bentonite clay, 2 to 5% water and approximately 5% sea-coal (a carbonaceous ingredient used to improve casting finish). Chemically bonded sand cast systems use one or more organic binders mixed with catalysts and hardeners. Chemically bonded sand is typically 97% silica sand by weight (Chelsea Center for Recycling and Economic Development, 2000).

Physical characteristics of spent foundry sand are similar to that of fine silica sand. Nearly all types of spent casting sands fall in the particle range between 0.1 and 0.6 mm. The uniformity of these byproducts suggests their utility in manufacturing. Precise quantification of physical properties of the residual sand is important for the marketability of the spent foundry sand. The sand wastes from the green sand systems are typically characterized by specific gravity (2.39-2.69 g/cm^3), permeability (10^{-3}-10^{-6} cm/s), and moisture content (0.1-10%) (Chelsea Center for Recycling and Economic Development, 2000).

Binders are used to bond sand grains in mold castings. Chemically bonded systems fall into two broad categories: organic and inorganic systems. The majority of them are self-setting binders. The most common types of bonders include various phenolic urethane resins, "furan" (furfuryl alcohol) resin, alkyd urethane, sodium silicate, phosphate. Composition and relative proportions of materials used in binder systems are often proprietary. Foundry cores and molds are subjected to intense heat from the molten metal. The temperature of the mold-metal interface approaches 1000°C. The nature and distribution of combustion and degradation products are complex and not entirely predictable. Therefore, spent sand, after casting, typically does not contain organic contaminants above regulatory threshold levels.

2.6   Economic Aspect

The suitable in economic, consider from several factors e.g. material cost, transportation cost, and operation cost etc. as following steps:

Assume   - the distant from the source of waste with landfill and material for landfill liner (clay) with landfill are the same distant. So the transportation of waste from the factory to landfill and the transportation of material for landfill liner (clay) to landfill are the same

- waste elimination cost at the current which the factory pay = 400 baht/ton (Siam Nawaloha, 2004)

- cost of landfill liner material (clay) = 550 baht/ton (http://cpairat.tripod.com/Ball_Clay.htm)

From above, if this waste is substitute to clay for landfill liner, the factory will save 400 baht/ton. The contractor will also save operation cost of using clay 550 baht/ton. However, this is based on the assumption that the source of waste with landfill and material for landfill liner (clay) with landfill has the same distant. In reality, the distant may be different. So we have to also consider the transportation cost. This waste suits to reuse for landfill liner in the landfill that is not far from the source e.g. in the same province to save transportation cost.

2.7   Leachate Extraction Procedure

The leachate extraction procedure outlined in the 6th Notification of the Ministry of Industry (1997) is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes. The method is

2.5.1 For liquid wastes (i.e., those containing less than 0.5% dry solid material), the waste, after filtration through a 0.6 to 0.8 μm glass fiber filter, is defined as the leachate extract.

2.5.2 For wastes containing greater than or equal to 0.5% solids

2.5.2.1 The liquid, if any, is separated from the solid phase and stored for later analysis. Prepare the solid portion of the waste for extraction by crushing, cutting, or grinding the waste to pass a 9.5 mm sieve.

2.5.2.2 Weigh 100 gm of waste from 2.5.2.1 add with leachant or synthetic acid rain extraction fluid until the pH of mixture is 5.0

2.5.2.3 Adjust the volume of mixture to the ratio leachant is 20 times of the weigh of waste.

2.5.2.4 Put the extraction fluid to the extractor vessel. Close the extractor bottle tightly and place in rotary agitation device, and rotate at 30 rpm for 18 hours at ambient temperature.

2.5.2.5 Filtrate the fluid through a 0.6 to 0.8 μm glass fiber filter, is defined as the leachate extract.

2.8 Hydraulic Conductivity

Darcy's Law states that the rate of flow is proportional to the gradient

$$Q = kiA$$

$$\text{or} \quad \frac{Q}{A} = V = ki$$

where; Q is the discharge passing through the total section area of the soil (cm^3/s)

A is the total section area of the soil (cm^2)

k is hydraulic conductivity (cm/s)

i is the hydraulic gradient (cm/cm), equals $\Delta h/\Delta l$, if Δh measures the head loss in a short distance along the flow path, Δl

The different types of apparatus used for the determination of the coefficients of permeability of soils in the laboratory are called "permeameters". They are of two main types, the "constant head" and the "variable head" permeameter. As their names imply, in the former seepage takes place through the test sample at a constant head during the experiment; in the latter the head is allowed to fall.

A setup for a constant head permeameter is shown in Figure 2.6. The soil sample is contained in the vertical cylinder between two porous screens. The inside area of the cylinder gives the area of cross-section of the soil sample. A; the length, L, being measured between the two porous plates. The soil sample is first saturated by connecting the source of supply of the bottom- the water rises up through the sample and expels the air in the pores upwards. The constant level of water supply is then connected to the top of the sample so that steady flow conditions develop under a constant head. The soil sample is placed in a constant head chamber which is filled to the brim at the start of the experiment, so that any further water entering into it must overflow. The difference between the water levels in the supply and the constant head chamber gives the constant head, h.

To take an observation, the quantity of water overflowing the constant head chamber is collected in a graduated jar for a known time. The discharge, Q, is obtained by dividing the volume by the time in which it was collected. According to Darcy's Law,

$$Q = kiA$$
$$= k(\Delta h / \Delta l)A$$
$$\text{or} \quad k = (Q\Delta l)/(\Delta hA)$$

To avoid large errors, it is necessary that the quantity of water collected should be large in comparison to the least count of the graduated jar. In relatively impervious soils, this is often not possible, as the quantity of seepage is very small. Hence, the constant head permeameter is suited to porous soils only.
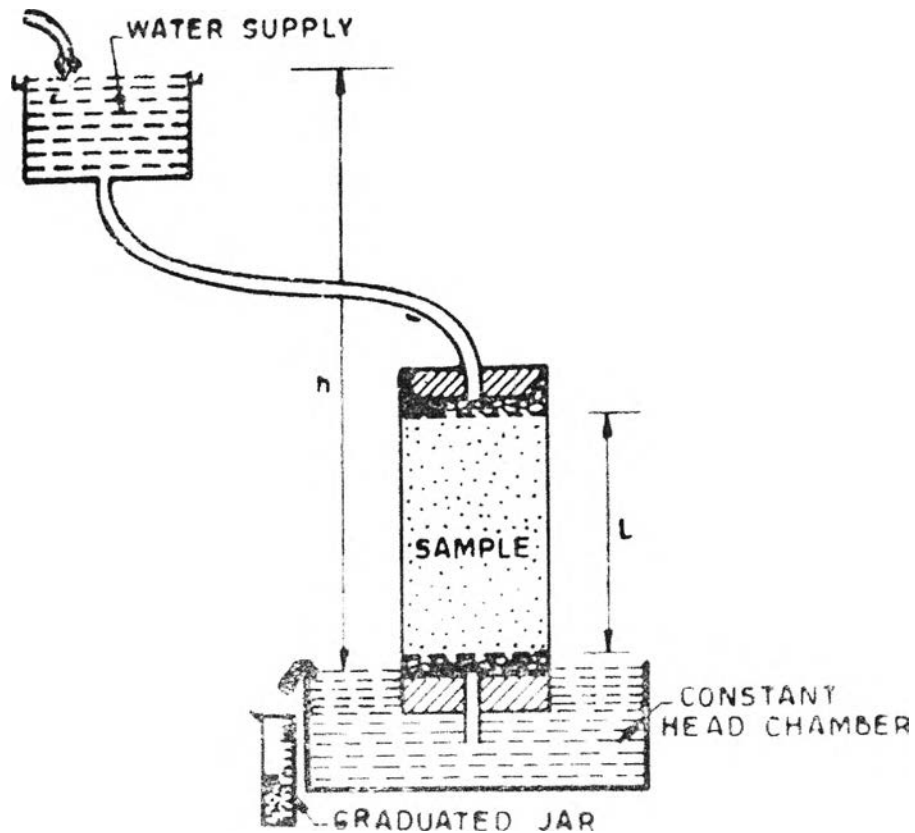
Figure 2.6 Constant head permeameter

The variable head permeameter can be adapted to a wide range of permeabilities and is much more convenient and accurate for less permeable soils. An apparatus of this type is illustrated in Figure 2.7. The sample is again contained between porous plates in a cylindrical mould and its length and area are determined as before. For accurate measurement, the mould should be placed in a constant head chamber, as before, which should be full to the brim at the start of an experiment. After all the air has been exhausted from the sample and the mould has been filled upto the top, its cover is fitted and tightened. A graduated standpipe or burette of inside area is connected to the inlet provided in the top cover by a flexible tubing. A stop cock, also provided in the top cover, is then opened for a short time to allow any air bubbles entrapped within to escape. The stop cock is then closed. Seepage now takes place from the burette, through the saturated sample, and into the constant head chamber from which it overflows and spills out. In this case, the head causing the

flow of water through the sample at any instant is the difference between the water level in the standpipe and that in the constant head chamber. While the latter remains constant, the former falls as the water percolates through the sample. An observation consists of measuring the time required for the water level in the burette to fall from a mark at a height, h_2 above the chamber to another mark at a height, h_1 above the same level.
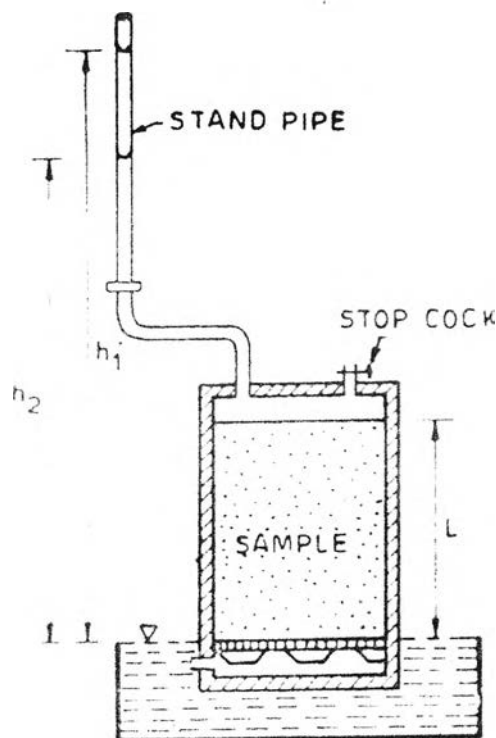

Figure 2.7 Variable head permeameter

2.9 Atterberg Limits

Atterberg limits (liquid limit and plastic limit) were measured in accordance with ASTM D 4318. Tests have been devised to determine the moisture content of a soil when it changes from one physical condition to another. The tests also show the water holding capacity of different types of soils. These tests, conducted on the minus No. 40 sieve-size (medium sand or smaller) material which means material is that

passing the corresponding mesh screen, are widely used as parameters to classify soils for structural purposes.

2.9.1 Liquid Limit

The liquid limit (LL) is the moisture at which a soil passes from a plastic to a liquid state. The test is made by determining, for a soil containing different moisture contents, the number of blows of a standard cup (Figure 2.8) at which two halves of a soil cake will flow together for a distance of about 1.3 cm. Soil moisture versus number of blows are then plotted on arithmetic paper, and the moisture content at which the plotted line (called a flow curve) crossed the 25-blow line is the liquid limit.

The liquid limit can be used to describe the moisture content as a percentage of the oven-dry weight of the soil. For instance, if a soil has a liquid limit of 100%, then the weight of contained moisture equals the weight of dry soil, or the soil (at the liquid limit) is half water and half soil on a weight basis.

Soils with high liquid limits generally indicate high clay content and low load-carrying capacity. A cohesive soil such as silt or clay has liquid limits that may run as high as 100% or greater. Most clays in the United States have liquid limits between 40% and 60%, although clays containing the mineral montmorillonite have a profound influence on the liquid limit.

2.9.2 Plastic Limit

Plasticity is a characteristic of clayey soils which allows them to be deformed and remolded by hand without disintegration. The plastic limit (PL) of soils is the moisture content at which a soil changes from a semi-solid to a plastic state. This condition is said to prevail when the soil contains just enough moisture that it can be rolled into 3-mm diameter threads without breaking. The test is conducted by

trial and error, starting with a soil sufficiently moist to roll into threads 3-mm diameter; the moisture content of the soil is gradually reduced until the thread crumbles.

The plastic limit is governed by clay content. Some silt and sand soils that cannot be rolled into these thin threads at any moisture content have no plastic limit and are termed nonplastic. The plastic limit test is of no value in judging the relative load-carrying capacity of nonplastic soils.

Soils having high plastic limits contain silt and clay, and the moisture content of these soils has a direct bearing on their load-carrying capacity. A very important change in load-carrying capacity of soils occurs at the plastic limit because soil at the plastic limit essentially changes from a solid to a plastic upon addition of water. Load-carrying capacity decreases very rapidly as the moisture content is increased above the plastic limit. On the other hand, load-carrying capacity increased very rapidly as the moisture content is decreased below the plastic limit.

2.9.3   Plasticity Index

The plasticity index (PI) is defined as the numerical difference between liquid limit and plastic limit (PI = LL − PL). The plasticity index gives the range in moisture content at which a soil is in a plastic condition. A small plasticity index, such as 5%, shows that a small change in moisture content will change the soil from a semisolid to a liquid condition; this is an undesirable condition for a foundational material. Such a soil is very sensitive to moisture (unless the silt and clay content combined is very low, on the order of less than 20%). A large plasticity index, such as 20%, shows that considerable water can be added before the soil becomes liquid, and the soil is a desirable foundational material. (On the other hand, soils with very high PI (greater than 35%) may have a high swell capacity) When the liquid limit or plastic limit cannot be determined or when the plastic limit is nearly the same as the liquid limit, the plasticity index is reported as nonplastic.

In summary, the liquid limit, plastic limit, and plasticity index-along with the shrinkage limit- are called the Atterberg limits. Atterberg limits are affected by the clay composition. In general, among clayey soils, liquid and plastic limits are higher for montmorillonite clays than for kaolinites or illites, mainly because montmorillonites are able to disperse into very fine particles with large water-absorbing volume. Atterberg limits also increase with increasing total clay content.
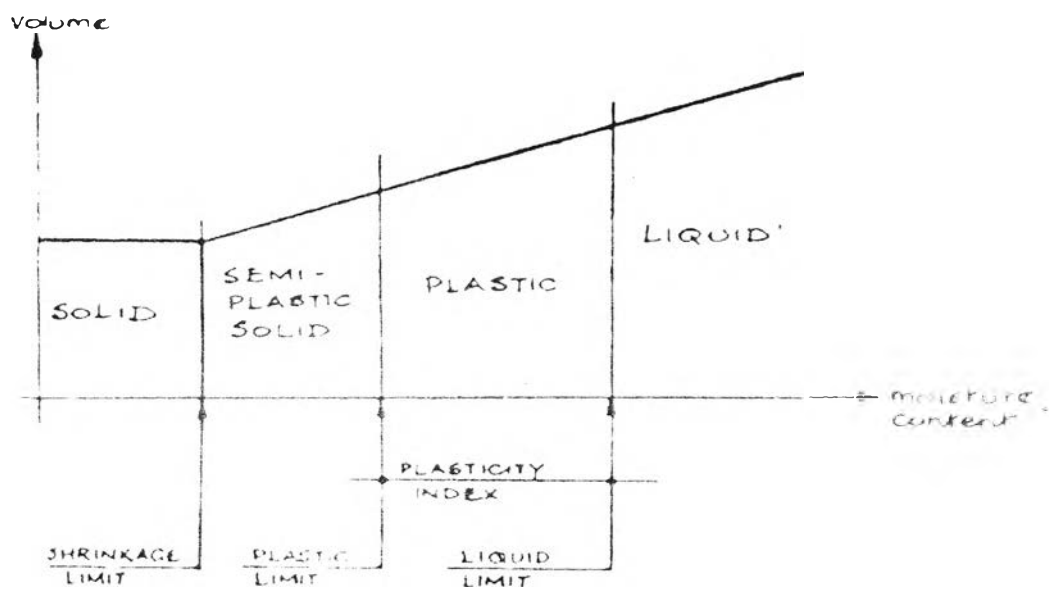

Figure 2.8 Relationship between soil volume and moisture content

2.10 Literature Review

Abichou et al., (1998a) reported that foundry sands having liquid limit greater than 20, plasticity index less than 3, or bentonite content greater than 6% can be compacted to achieve hydraulic conductivities less than 1×10^{-7} cm/sec. The hydraulic conductivity of foundry sands is not as sensitive to compaction water content and compaction energy as the hydraulic conductivity of compacted clays. Similar results have been reported for compacted sand-bentonite mixtures. Consequently, it may be easier to construct barrier layers with foundry sands than with clays.

CWC Publication Order (1996) reported that spent foundry sand has been successfully used throughout the United States in various applications. Some recycling options for spent sand are asphalt concrete, compost additive, concrete, bricks and pavers, portland cement, mineral wool products and flowable fill.

Indiana Department of Environment Management (1998) reported that spent foundry sand can reuse for daily cover at landfill, use as a raw material: flowable fill, concrete, asphalt, brick, block, portland cement, protective cover for landfill leachate collection system, capped embankments, ground and site barriers and structural fill base.

U.S. EPA (1989) reported that clay is the most important component of soil liners because the clay fraction of the soil ensures low hydraulic conductivity. The requirement of soil liners are hydraulic conductivity equal to or less than 10^{-7} cm/sec and plasticity index (PI) should be grater than 10 percent.

Turner-Fairbank Highway Research Center (1999) studied physical properties of spent green foundry sand. The results are shown in Table 2.1.

Table 2.1 Typical physical properties of spent green foundry sand

Property	Results	Test Method
Specific Gravity	2.39 - 2.55	ASTM D854
Bulk Relative Density, kg/m^3 (lb/ft^3)	2590 (160)	ASTM C48/AASHTO T84
Absorption, %	0.45	ASTM C128
Moisture Content, %	0.1 - 10.1	ASTM D2216
Clay Lumps and Friable Particles	1 – 44	ASTM C142/AASHTO T112
Coefficient of Permeability (cm/sec)	$10^{-3} - 10^{-6}$	AASHTO T215/ASTM D2434
Plastic limit/plastic index	Nonplastic	AASHTO T90/ASTM D4318

Bouazza (2002) employed geosynthetic clay liners (GCLs) as a new alternative to compacted clays in cover systems or in some cases bottom lining of waste containment facilities because they often have very low hydraulic conductivity

for water (hydraulic conductivity less than 10^{-10} m/s) and relatively low cost. GCLs are comprised of a thin layer of sodium or calcium bentonite bonded to a layer or layers of geosynthetic. The main adventages of the GCLs are the limited thickness, the good compliance with differential settlements of underlying soil or waste, easy installation and low cost. On the other hand, the limited thickness of this barrier can produce: 1) vulnerability to mechanical accidents, 2) limited sorption capacity, and 3) an expected significant increase in diffusive transport if an underlying attenuation mineral layer is not provided. Moreover, when hydrated with some types of leachates instead of pure water, bentonite will show a minor sweeling that will result in reduced efficiency of the hydraulic barrier.

The hydraulic performance of GCLs depends in most cases on the hydraulic conductivity of the bentonite. In general, laboratory hydraulic conductivities for water of different types of geotextile-supported GCLs vary approximately between 2×10^{-12} and 2×10^{-10} m/s, depending on applied confining stress.

Kitchainukul et al., (1999) studied toxicity and chemical oxide composition of solid waste from molding sand. The preliminary was carried out in order to classify types of solid waste by testing the leaching of heavy metal. The results are shown in Table 2.2-2.3. It was found that these wastes were non-hazardous waste.

Table 2.2 Leachability of metals from foundry sand waste

Parameter	Particle size		Standard	Detection Limit
	< 0.5 mm	0.5 mm – 5.0 mm	(mg/L)	(mg/L)
Heavy Metal (mg/L)				
As	-	-	5.0	0.1400
Cd	-	-	1.0	0.0010
Cr	0.0920	-	5.0	0.0030
Hg	0.0303	-	0.2	0.0050
Pb	-	-	5.0	0.0090

Table 2.3 Spent foundry sand chemical oxide composition

Constituent	Raw Materials		Waste
	Sand	Bentonite	Spent sand
Al_2O_3 (%)	0.67	20.8	4.50
As_2O_3 ($\mu g/g$)	<10	<80	<10
CaO (%)	0.105	1.43	0.32
CdO ($\mu g/g$)	<10	<10	<10
Cr_2O_3 (%)	0.14	<0.0001	0.106
Fe_2O_3 (%)	1.34	3.88	1.90
K_2O (%)	0.31	0.58	0.23
MgO (%)	<0.0001	2.37	0.51
Na_2O (%)	0.027	2.16	0.45
PbO ($\mu g/g$)	<1.0	<1.0	<1.0
SiO_2 (%)	97.17	68.0	91.40
SO_3 (%)	0.019	0.031	0.098
TiO_2 (%)	0.094	0.34	0.121
ZnO (%)	0.0012	0.27	0.0079

Kunes and Smith (1983) investigated the use of foundry sands as a construction material for landfill cover systems. Grain size distribution, compaction curves, and hydraulic conductivity were measured on several samples of foundry sand. They provide little detail about their testing methods, but reported that their compacted foundry sands had hydraulic conductivities in the range of 1.3×10^{-6} to 6.1×10^{-6} cm/s.

Kenney et al. (1992) reported that the hydraulic conductivity decreases at a rapid rate as the bentonite content increases from zero to 8%: thereafter, the hydraulic conductivity becomes comparable to the hydraulic conductivity of bentonite.