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SCOPE

This subsection covers thermal treatment of soils and sludges. In a broad sense, thermal treatment encompasses a wide range of technologies, including drying, thermal desorption, incineration, cokers, and cement kilns. However, only thermal drying and thermal desorption are covered here because incinerators, cokers and cement kilns are typically not part of the environmental waste treatment area of responsibility. Pretreatment to prepare wastes for incinerators, cokers, and cement kilns is covered generally in [Section XX-A](#), Guidelines and Considerations for Managing Solid and Liquid wastes and in [Section XX-A3](#) Mechanical Sludge Dewatering.

This design practice provides guidelines for preparation of a duty spec for a thermal treatment system. It is not intended to provide information to allow design of these facilities. The duty spec applies to purchasing or leasing the facilities.

REFERENCES

DESIGN PRACTICES

- [Section XX-A](#) Guidelines and Considerations for Managing Solid and Liquid Wastes
- [Section XX-A3](#) Mechanical Sludge Dewatering
- [Section XX-B4](#) Guidelines For Selecting Soil Remediation Technology

OTHER REFERENCES

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DEFINITIONS

Autogenous - Self-generated; produced without external influence. Autogenous sludge is capable of sustaining combustion without auxiliary fuel. This is a combustible material.

Dewatering - Dewatering is the removal of water from a sludge slurry, usually by mechanical means, to greater than approximately 15 percent solids. At this point, the sludge may behave as a semisolid or solid. The sludge product from a thickening unit would often be the feed for a dewatering unit.

Drying - The removal of water from a material by evaporation. In practice, drying may also remove hydrocarbon from a material.

Moisture Content - The weight loss from a sludge or soil sample dried to 217 - 221 °F (103 - 105 °C) per Standard Methods for the Examination of Water and Wastewater, 20th ed., Method 2540B. This includes water and some light hydrocarbons.

NAPL - Non-aqueous phase liquid, also known as product and free phase hydrocarbon. This is hydrocarbon which is not dissolved and not adsorbed on soil particles. It may exist in pools. NAPL can be lighter than water (LNAPL) and so will "float" on the water table. NAPL can also be denser than water (DNAPL) and so will "sink" below the water table.

PAH - Polycyclic aromatic hydrocarbons, also known as PNA or polynuclear aromatics. These are multi-ring aromatic compounds such as naphthalene (2-ring), anthracene (3-ring), chrysene (4-ring) and benzo (a) pyrene (5-ring). There are often regulatory limits for the concentration of these compounds in soil. Some are known and suspected carcinogens.

PCB - Polychlorinated biphenyl. A colorless liquid used as an insulating fluid in electrical equipment.

Sludge - The accumulated semi-liquid suspension of settled solids deposited in tanks or basins from raw or treated wastewaters.

Slurry - A suspension of solids in a liquid.

Solids Content - The mass of solids remaining from a sludge or soil sample dried to 217 - 221 °F (103 - 105 °C) per Standard Methods for the Examination of Water and Wastewater, 20th ed., Method 2540B. The solids include inert solids and hydrocarbon (oil) that does not volatilize at 217 - 221 °F (103 - 105 °C).

Stabilization - Stabilization is the addition of chemicals, such as lime, diatomaceous earth, fly ash or silicates to change the consistency of a sludge from liquid to solid. It can be used as an alternative to dewatering, depending on the nature of the sludge and the ultimate disposal method used. The sludge must be fluid enough to mix well with the chemical, but dry enough to prevent excessive chemical use.

Thermal Desorption - Thermal desorption is a process that uses either indirect or direct heat exchange to bring organic contaminants (usually hydrocarbon) to a temperature high enough to volatilize and separate them from a contaminated solid medium. It is a physical separation process that transfers contaminants from one phase to another without causing significant levels of organic destruction.

Thermal treatment unit - The piece of equipment in which moisture and hydrocarbons are removed by heat transfer and evaporation.

Thickening - Thickening is a process that aims to increase the solids content of a dilute slurry by removing some of the water content by gravitational means. It is commonly used to concentrate biological solids or filter backwash solids where the free water content is greater than 95%, and is usually placed upstream of dewatering processes. The sludge produced is usually pumpable by conventional means and has most of the characteristics of a liquid.

Total Suspended Solids - Total suspended solids (TSS) is the amount of suspended matter removed by a filter paper (which is dried at 217 - 221 °F (103 - 105 °C) per unit volume of sludge. TSS is expressed as mg/L.

Vadose Zone or Unsaturated Zone - Consists of the soil above the groundwater table.

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BACKGROUND

GENERAL

Thermal treatment (drying or thermal desorption) uses heat to physically remove moisture and hydrocarbon from soils and sludges. While this technology can be applied either in situ or ex situ, it is most often applied ex situ. Thermal treatment is essentially a two step process. In the first step, the contaminated medium is heated to vaporize volatile materials into a carrier gas or vacuum system. In the second step, this gas stream is treated to meet regulatory requirements prior to discharge. The purpose of thermal desorption is to separate contaminants from the solid matrix rather than destroy them. Thus, thermal desorption differs from incineration, which destroys contaminants through high temperature combustion. With thermal desorption, temperature and oxygen levels are controlled to prevent combustion, allowing liquid products to be recovered and recycled.

Ex situ processes differ in the methods used to supply the heat and transport the solid through the unit. Heat is supplied either directly, by exhausting a gas or liquid fueled flame into the reaction vessel, or indirectly, by transferring heat through a physical barrier, such as a steel wall. In either case, the solid is typically transported through the heating vessel by screws, conveyors or rotating drums.

Drying commonly refers to low temperature thermal treatment for the removal of water. Thermal desorption refers to higher temperature thermal treatment for the removal of water and volatile contaminants. Soils and sludges can be thermally treated to reduce volume or mass, to increase heating value, or to remove specific chemical constituents prior to reuse or disposal. Reuse or disposal options include onsite cokers, cement kilns, incinerators, and landfills. The thermal treatment process typically includes ancillary facilities for pretreatment to dewater or size the soil or sludge, offgas treatment, and post treatment to cool or rehydrate the soil or sludge. Rehydration is only used after thermal desorption to control dusting or to prepare soils for return to the site.

In some cases, especially for small, well defined sites, it may be economically feasible to apply thermal desorption technology in situ. Also called Thermally Enhanced Recovery, in situ thermal desorption uses heat to increase the volatilization rate of organics and facilitate extraction. Volatilized contaminants are removed from the vadose zone using soil vapor extraction. Thermally enhanced recovery techniques include radio frequency heating, conductive heating, steam heating, in situ steam stripping, hot air injection, dynamic underground stripping, and electrical resistance heating. The EPA suggests about 5000 cubic yards (3800 cubic meters) as the breakpoint point for considering in situ thermal treatment. The actual breakpoint would, of course, site specific, depending on factors such as local labor costs, proximity of the project to off-site disposal locations, and regulatory acceptance of the technology.

Some examples of ExxonMobil experience with thermal treatment are summarized in [Table 1](#).

THERMAL TREATMENT EFFECTIVENESS

Thermal treatment is a flexible option for preparing soil, sludge, sediments, or filter cakes for recycle or disposal. It has been proven effective for treating a wide range of contaminants, especially organic chemicals, as outlined in [Table 2](#). For the most part, thermal treatment is not effective for treating inorganic or reactive materials, with the exception of some volatile metals.

Thermal treatment operating temperatures can vary from 200 to over 1000 °F (93 - 538 °C), depending on treatment needs. For moisture removal or for vaporizing highly volatile hydrocarbons, temperatures as low as 200°F (93 °C) are sufficient. For heavier hydrocarbons up to the diesel range, temperatures in the medium range of 350-600°F (177 - 315 °C) are required. For fuel oils, lube oils, and heavy crude fractions, temperatures over 1000°F (538 °C) may be required. Typical treatment temperatures required for various petroleum products are summarized in [Figure 1](#).

While the contaminant boiling point is an important consideration in selecting thermal desorption operating conditions, other factors are also important. Just as water can be evaporated at temperatures well below its boiling point, so other chemicals can be vaporized below their boiling point, provided the partial pressure of the given contaminant in the sweep gas is maintained below its vapor pressure in the solid phase. Sometimes this is accomplished by operating at low pressure, using a vacuum system to draw the sweep gas through the desorber. Sometimes additional stripping gas (steam or nitrogen) is added to remove vaporized materials. However, for any configuration, thermal desorption is a time-temperature phenomenon, and the time required for effective contaminant removal is longer at low temperatures. Unless substantial experience is already available for a given feedstock, thermal desorber operating conditions will have to be confirmed in treatability studies designed to mimic commercial conditions. In practice, the process of heating the solid phase to the proper reaction temperature is relatively slow,

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and usually the residence time for treatment is consistent with the time it takes to raise the solid phase to the treatment temperature.

THERMAL TREATMENT TECHNOLOGY

Low Temperature Thermal Treatment

If the sludge or soil is to be routed to a cement kiln or incinerator, typically only moisture removal is needed to reduce the waste volume and increase its heating value. A low temperature steam dryer (200 - 350 °F, 93 - 177 °C) would typically be used in this case. A sludge being routed to a landfill might also need only moisture removal to reduce transportation and disposal costs by reducing volume and mass of the sludge.

Pretreatment with dryers for onsite cokers is not typically needed because the sludge must be pumpable and water is desirable when recycling sludge during the quench cycle. Similarly, oil is desirable in the sludge when recycling sludge during the coking cycle. A case could be made, however, for using a dryer to remove excess water in the sludge before adding oil and recycling the mixture to the coking cycle. One vendor has patented a process (USFilter Scafuel Process) which uses a centrifuge followed by addition of oil in a high energy mixer, followed by a slurry dryer to remove residual water and produce a pumpable cement kiln or coker feed.

Medium Temperature Thermal Treatment

Hydrocarbon contaminated soils may require thermal desorption to meet hydrocarbon removal treatment standards. Depending on the type of contamination, moderate temperature (350 - 600 °F, 177 - 315 °C) thermal treatment may be applicable. The benefit of staying within a moderate temperature range with soils is to avoid destroying the organic components of the soil, thereby retaining the ability of the soil to support future biological activity.

In the U.S., thermal desorption is used for hazardous sludges to meet RCRA Universal Treatment Standards (UTS) for volatile and semivolatile organics. Depending on the sludge, it is sometimes (but rarely) possible to meet UTS with a hot oil dryer at 600 °F (315 °C). Most of the time, significantly higher temperatures are needed. In some cases steam sparging or nitrogen sweeping are used in the steam or hot oil dryers to enhance the removal of organics from the sludge.

High Temperature Thermal Treatment

For heavy oils and other high boiling point contaminants, it may not be possible to meet cleanup criteria at more conventional treatment temperatures. For these more difficult feeds, temperatures of 800 - 1000 °F (427 - 538 °C) may be needed. At these elevated temperatures, semivolatile organics, polycyclic aromatic hydrocarbons (PAH's), PCB, and pesticides can be removed. Whether or not UTS metals limits can be met depends on the individual soil or sludge and would have to be determined by bench or pilot testing. In the early 1990's some service contractors used molten salt dryers to achieve these temperatures. The molten salt was circulated through a thermal screw type dryer instead of steam or hot oil. These units were plagued with corrosivity, maintenance and safety issues. In the latter half of the 1990's molten salt dryers were replaced with indirectly fired rotary calciners, which avoid the issues with molten salt, but can achieve the same high temperatures.

In Situ Thermal Treatment Technology

In situ thermal treatment methods, in general, are ways of using heat to vaporize potentially harmful chemicals in the soil and remove them through subsurface piping networks. In situ methods are generally applied in the vadose (unsaturated) zone to remove organic chemicals sorbed to the soil, but are also particularly helpful in removing non-aqueous phase liquids (NAPLs). In situ methods can also be applied to groundwater contaminants, which is an added benefit that ex situ methods do not have. In situ thermal treatment technologies differ in the ways they apply heat.

Steam injection: Forces or injects steam underground through wells drilled in the contaminated area. The steam heats the area and mobilizes and evaporates the contaminants.

Hot air injection: Similar to steam injection except hot air is injected through the wells instead of steam. The hot air heats the soil causing the contaminants to evaporate.

Hot water injection: Like steam injection except that hot water is injected through the wells instead of steam. The hot water mobilizes chemicals like NAPLs.

Electrical resistance heating: Delivers an electric current underground through wells made of steel. The heat from the current converts groundwater and soil moisture to steam, which evaporates the contaminants.

Radio frequency heating: Typically involves placing an antenna that emits radio waves into a well. The radio waves heat the soil causing the contaminants to evaporate.

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Thermal conduction: Supplies heat to the soil through steel wells or with a blanket that covers the ground surface. As the polluted area heats up, the contaminants are destroyed or evaporated. The blanket is used where the contaminated soil is shallow. Steel wells are used when the contamination is deep.

In all cases the vaporized chemicals, steam, and gas collected from the heated soil are treated above ground to condense and recover liquids and remove pollutants.

A flow plan to assist in selecting the most appropriate thermal treatment technology is provided in [Figure 2](#).

TYPES OF THERMAL TREATMENT UNITS

THERMAL SCREW DRYERS

The thermal screw type dryers ([Figure 3](#)) have a jacketed trough, a hollow shaft, and in some cases hollow flights that provide heat as well as agitation and movement through the trough. The hollow shaft and flights are shown in [Figure 4](#). Helical screws, paddles, or discs are attached to the shaft to provide axial mass movement. Some dryers have adjustable weirs at the back end of the unit to control the sludge bed height and residence time. The heating medium can be steam or hot oil. Molten salt has also been used, but due to corrosivity issues, maintenance issues, and safety concerns, molten salt is now rarely used. Steam dryers operate from 200 - 350 °F (93 - 177 °C), hot oil dryers from 350 - 600 °F (177 - 315 °C), and molten salt dryers from 800 - 950 °F (427 - 510 °C). Rotary calciners have replaced molten salt for the high temperature applications.

Sticking and fouling of the heat transfer surfaces can occur. Several vendors (Bethlehem's Porcupine Processor and Atlas-Stord Disc Dryers) use breaker or scrapper bars mounted on the side walls of the vessel to break up clumps and promote more intense mixing. Another vendor (Komline Sanderson Paddle Dryer) uses dual, counter-rotating shafts. Metso Minerals' Holo-Flite Processor (formerly Denver) also uses multiple shafts in a single trough. Recycle is also used by several vendors to prevent fouling. Recycling treated material decreases the moisture content of the feed taking it out of the "sticky range," thought to be from 45 - 65% solids content. Whether or not the sludge goes through a sticky phase and at what concentration this occurs can be determined by pilot testing.

Residence time in the dryer is controlled in various ways including feed rate, shaft rotational speed, and weir height. Residence time directly affects sludge outlet temperature, which is the measured parameter typically controlled to meet treatment standards. Thirty minutes is a typical sludge residence time.

ROTARY CALCINER

Indirect fired rotary calciners ([Figure 5](#)) use a rotating, heat jacketed, closed barrel to vaporize water and hydrocarbons. Various fuels are used, including fuel gas, propane, diesel, #2 oil and #6 oil. Soil/sludge residence time in the drum is varied by rotational speed, drum inclination, and feed rate. Residence times vary from 30 - 120 minutes. Various methods are used to help move the material through the drum and minimize sticking, including flights on the internal drum wall, a free floating rotating helix, and loop chains. Residence time affects the material exit temperature, which can be varied from 250 - 1000 °F (121 - 538 °C). These systems are typically used in the 600 - 1000 °F (315 - 538 °C) range, which steam or hot oil dryers can not achieve. The effluent must be cooled for safety reasons. This is discussed further under ancillary facilities below. 99.9% removal efficiency of petroleum hydrocarbons are claimed with this type of dryer, which allows meeting RCRA Universal Treatment Standard hydrocarbon limits.

DIRECT FIRED ROTARY DRUM

Direct fired or direct-contact thermal desorption systems generally use a rotary drum to contact solids with the combustion flame. As with the rotary calciner, various fuels may be used, and solids residence time is controlled by rotational speed, drum inclination, and feed rate. A wide range of temperatures can be achieved in direct fired systems, up to 1200 °F (649 °C). The highest temperature range is designed to remove high-boiling-point, chlorinated compounds. An important distinction to make here for U.S. locations is that direct contact thermal desorption has the potential for combustion and therefore would not be included under recycling of sludges by the US EPA.

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TERRATHERM IN SITU THERMAL DESORPTION OF SOIL

Terratherm is an In Situ Thermal Desorption (ISTD) process that removes most contaminants in place without disturbing the soil. The Terratherm process, shown in [Figure 6](#), uses two key components; heat and vacuum, to treat contaminated soils. Heat is applied using high temperature (>1000°F, 538°C) electrical heaters, while a blower is used to keep the soil under vacuum conditions. The vacuum serves as a transport mechanism to remove the vapors from the soil and it also prevents vapors from migrating into adjacent soils. However, the vacuum does not significantly reduce the partial pressure of contaminants in the vapor space; thus, the contaminants must be heated to their boiling point for effective removal. The heat and vacuum are applied simultaneously using either surface blankets or subsurface wells, depending on the depth of contamination. Blankets are used for shallow (0-1.5 ft.) soil contamination, while wells are used for deeper (>5 ft.) soil contamination.

The blankets consist of furnace belts, which resemble a chain-link fence, interlaced with heating rods. The heating element is housed in an 8 x 20 ft. (2.4 x 6.1 m) stainless steel box. After the blankets are put in place, they are covered with 10 inches (25.4 cm) of vermiculite insulation to prevent heat loss to the atmosphere during operation. In addition, a fiberglass-reinforced, silicone-rubber sheet is placed over the insulated heating blankets to prevent vapors from escaping untreated.

The wells consist of a heater element and the monitoring equipment (e.g., thermal couples) inside of a 4-inch stainless steel casing. The wells can be heater-only wells or heater-vacuum wells. In the latter case, a stainless steel screen surrounds the heating element. The wells are typically installed spaced on 5- to 7-ft (1.5- to 2.1-m) centers in triangular patterns. The wells can be in excess of 2000 ft (91 m) below ground surface (bgs) and are generally installed vertically. When necessary, wells can be installed on a slant or horizontally to reach underneath roads, foundations, and permanent structures. Wells can even be drilled through the floors of buildings or through bedrock. If the contamination is present near the ground surface (e.g., 0-2 ft [0-0.9 m] bgs), then the surface must be insulated to prevent heat loss to the atmosphere, and the silicone-rubber vapor barrier must be placed over the area to prevent fugitive emissions. When the contamination is greater than 2 ft (0.9 m) bgs, insulation is generally not required; however, the vapor barrier is typically used as a precautionary measure.

COST COMPARISON

Cost comparisons are always difficult because of generally large effects of site-specific conditions on each technology. Thermal desorption costs are probably more volatile than those of other technologies because the effects of overall economic conditions on the availability and price of TD equipment are substantial. For most projects, thermal desorbers are leased or purchased used, and market influences on pricing can be huge. Nonetheless, typical cost ranges are available, both from literature sources and internal economic studies. The following cost information was obtained from reference 9, and is generally consistent with ExxonMobil studies.