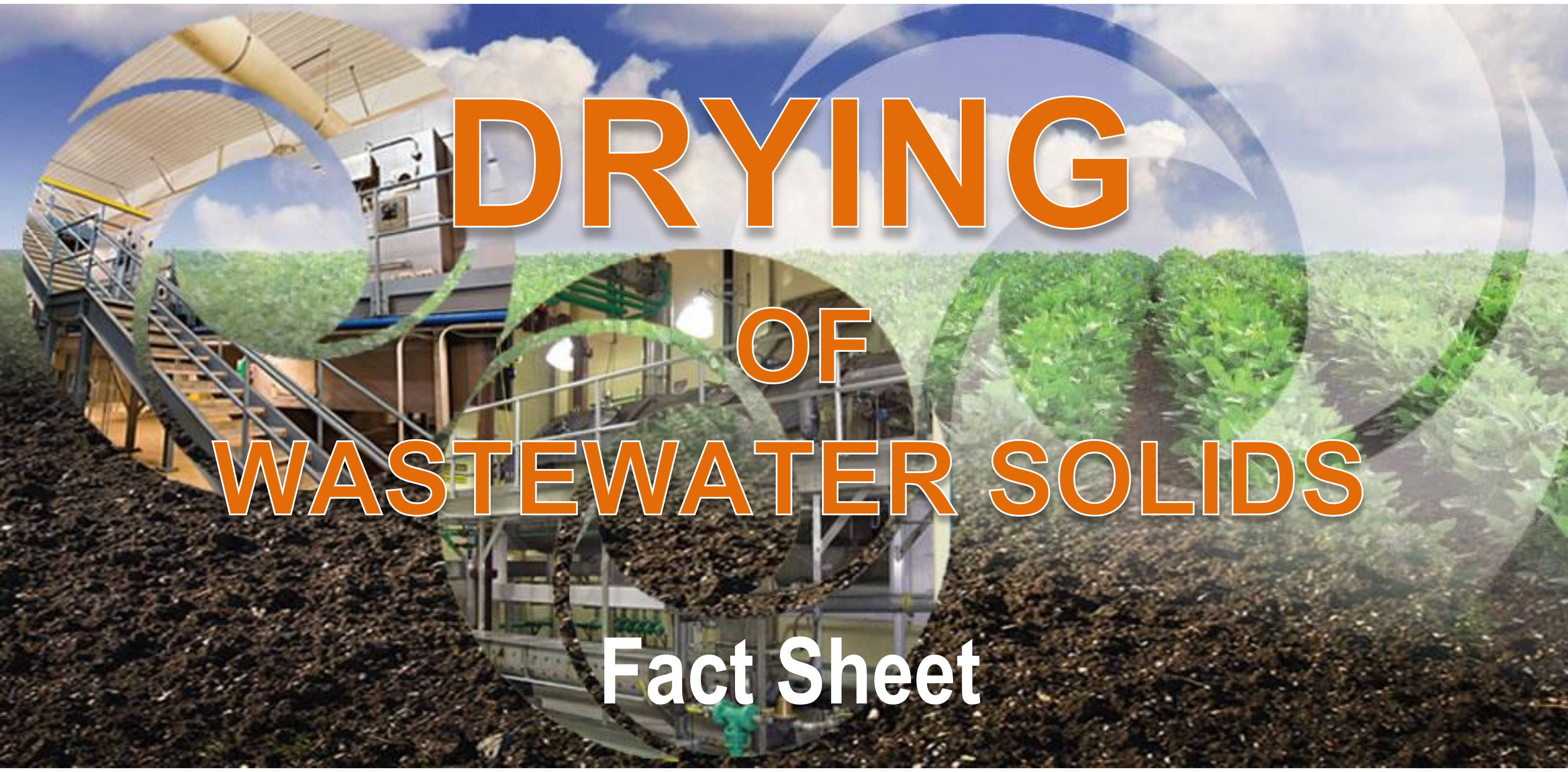

January 2014

Water Environment Federation
Residuals and Biosolids Committee
Bioenergy Technology Subcommittee

This Fact Sheet is an update of the “Drying of Wastewater Solids” White Paper (January 2004)

2012-2013 Update Team

Archis Ambulkar, Brinjac Engineering
Amber Barritt, CDM Smith
Robert Bates, Louisville MSD
Jason Boyd, Kruger
Scott Carr, CDM Smith
Bill Holloway, Kurita America
Christopher Komline, Komline Sanderson
Hari Santha, Black & Veatch
Frank Sapienza, CDM Smith
Dieter Weinert, Huber Technology

Water Environment Federation
Residuals and Biosolids Committee
Bioenergy Technology Subcommittee

Ron Sieger, CH2M HILL, Chair
Peter Brady, Alpine Technology, Vice Chair

John Donovan, CDM, Primary Reviewer
Tim Shea, CH2M HILL, Primary Reviewer

Thermal Drying Technology Team (2004)

Frank Sapienza, CDM, Chair (Principal Author)
Tim Bauer, CH2M HILL, Vice Chair (Principal Author)
Saeed Assef, Louisville MSD
Andrew Bosinger, Synagro
Mark Hoey, Tighe & Bond
Bill Holloway, Andritz
Terry Logan, N-Viro
Dirk Eeraerts, Seghers
Steve McDonough, Hankin
Jeff Berk, USFilter
Jon Orr, Virginia Tech
Wilfried Schnabel, Bird Machine
Virginia Grace, NEFCO
Tom McGowan, TMTS
Mike Sweeney, Louisville MSD
Perry Schnuck, Synagro
Bruce Miller, USFilter
Rich Chaney, Dupps Company
Robert Pepperman, United Water
David Dahlstrom, Alstom Power

Fact Sheet Contents

Drying of Wastewater Solids

Introduction

In January 2004, the Water Environment Federation's (WEF) Bioenergy Technology Subcommittee developed a Whitepaper on "*Thermal Drying of Wastewater Biosolids*". The paper provided an overview of the status of biosolids drying systems, including various technology descriptions, use of dried biosolids products, sustainability of the drying process, and associated safety issues. A Subcommittee taskforce was formed in 2011 to update the Whitepaper to include information from operating facilities as well as to update the state of the technology in the U.S. municipal market. The update team also expanded the thermal drying aspect to include solar drying, hence the name change to *"Drying of Wastewater Solids."* This Fact Sheet provides key highlights from the revised Whitepaper, but the full revised paper can be accessed through the following link: http://www.wrrfdata.org/NBP/DryerFS/DryingWWsolids.html.

Drying is one of the alternative technologies available for processing of biosolids produced at municipal wastewater treatment plants (WWTPs). This technology has been successfully implemented at WWTPs since the 1920s' and produces a marketable dry solids product that can be used as a fertilizer or biofuel. As of 2012, there were more than 60 drying systems operating in the U.S., and more than 100 in Europe.

Drying is based on the removal of water from dewatered solids, which accomplishes both volume and weight reduction. At municipal WWTPs, dewatered biosolids are conveyed to the drying system where the temperature of the wet solids mass is raised and most of the water is removed via evaporation, resulting in a product with approximately 90% or higher total solids. This drying process does not significantly alter the nutrient content of the biosolids.

During drying, a significant amount of thermal energy needs to be transferred to the wet solids (cake) to evaporate the water. Energy is required not only to evaporate water, but also to heat the solids and remaining water. This energy can be provided by combustion of various fuels (such as natural gas, digester gas, heating oil, wood, etc.), by reusing waste heat, via solar radiation, or by conversion of electrical power into thermal energy.

For most systems, the high temperatures used in drying assure that the US EPA time and temperature requirements for pathogen kill are met. Drying also meets the EPA vector attraction reduction standards by desiccating the wastewater solids to greater than 90% solids (or to greater than 75% solids if the solids have been previously stabilized). Although high temperatures are used in many drying systems, the temperatures are generally low enough to prevent oxidation (burning) of the organic matter. Thus, most of the organic matter is preserved in the dried material.

Material produced in the drying process generally has a dry solids content ranging from approximately 75% for solar drying systems to greater than 90% for systems using fossil fuels or other heat sources. Drying systems may produce a variety of forms of dry material, including fine dust, flakes, small pellets, or larger fragments, depending on the type of drying system used, the characteristics of the solids processed, and the intended use of the final product.

Thermal drying typically must be preceded by, or done in conjunction with a dewatering process, and drying is usually the last stage in processing of solids at municipal WWTPs. After the drying process, dried material can be used for a variety of purposes.

Process Description

In the most general terms, drying is the use of heat to evaporate water from wastewater residual solids. The drying system, in addition to the dryer itself, generally consists of materials handling and storage equipment, heat generation and transfer equipment, air movement and distribution equipment, emissions control equipment, and ancillary systems. These equipment systems can take many forms, the details of which are beyond the scope of this paper. However, drying systems use different methods for heat transfer, including convection, conduction, and radiation heating. To some extent, multiple methods of heat transfer are used by individual systems, but they are generally categorized by their primary method of heat transfer.

Systems that primarily use convection for heat transfer are often referred to as "direct" dryers. In direct heat dryers, hot air/gas flows through a process vessel and comes into direct contact with particles of wet solids. The contact between the hot air and cold wet cake allows the transfer of thermal energy, which causes an increase in wet cake temperature and evaporation of water. The hot air/gas can be produced by almost any source of heat, but most often is produced by a gas or oil-fired furnace. Examples of direct drying equipment are rotary drum dryers and belt dryers. A schematic diagram of a typical rotary drum drying system is shown in Figure 1.

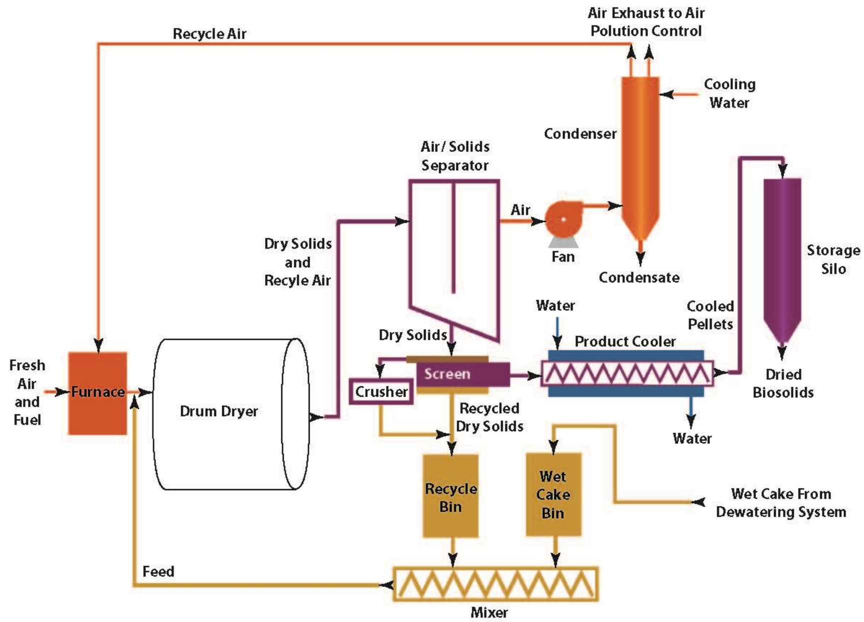

Figure 1: Direct Type Rotary Drum Drying System

In this type of system, the heat supply is via a fuel-burning furnace that exhausts directly to the dryer drum. The dried material is separated from the warm exhaust gas and is then screened and processed for either recycling back to the dryer or routed to storage silos. The exhaust air/gas is cooled and part of it is recycled back to the dryer. The remainder of the air/gas is treated in air pollution control equipment and then vented to the atmosphere. Recirculation of the dryer exhaust accomplishes three important functions. First, it increases the overall thermal efficiency of the dryer system, second, it minimizes the volume of exhaust gas requiring air pollution control (APC), and third, it provides a safety feature by limiting the oxygen concentration in the system, which reduces the risk for explosions. APC systems for drum dryers typically consist of additional particulate removal followed by regenerative thermal oxidation to destroy odors and volatile organic compounds (VOCs). Other methods of APC, such as biofilters, are often used with different drying systems. Present day direct drying systems typically recirculate 70% to 90% of the dryer exhaust, thereby greatly reducing the size of the APC equipment. Direct drying systems vary considerably depending upon the type of equipment used to process the wet and the dried biosolids. Even rotary drum systems as shown in this figure vary considerably in general layout and the equipment used.

Another type of direct dryer that is seeing increased use in the U.S. and Europe is the belt dryer. This is typically a lower temperature system compared to a rotary drum system. The heat supply is usually a fuel-burning furnace, but in contrast to the rotary drum system, the system exchanges its heat to a thermal fluid, hot water or flue gas to air heat exchanger instead of the furnace exhausting directly into the dryer cabinet. The belt drying system distributes dewatered cake onto a slow moving belt, allowing for high surface area exposure to the hot air. Belt drying systems can utilize multiple belts to help minimize the size of the dryer cabinet. High dryer air recirculation (>90%) and low vent rates are common. Due to the gentle handling on the slow moving belts, dust generation within the dryer cabinet is low and the quantity of fines in the dried product should be low. Some belt drying technologies require dried product recycling to elevate the inlet solids composition to above the sticking point, while others inject dewatered sludge cake without additional recirculation equipment. The lower temperature belt drying system can more adequately utilize lower grade waste heat (in addition to high temperature waste heat).

Systems that primarily use conduction for heat transfer are referred to as “indirect” dryers. With indirect dryers, solid metal walls separate the wet cake from the heat transfer medium (such as steam, hot water, or oil). Thermal energy is transferred from the heat transfer medium into the metal wall and then from the metal wall into the cold cake. The solids temperature is elevated by contact with hot metal surfaces and the solids never come in direct contact with the primary heating medium. Some types of indirect dryers do not require recycle of dried material, simplifying the system. Indirect thermal drying equipment includes paddle dryers with varying configurations, vertical tray dryers, and an indirect-type of fluidized bed dryer. A schematic diagram of a typical paddle drying system is shown in Figure 2.

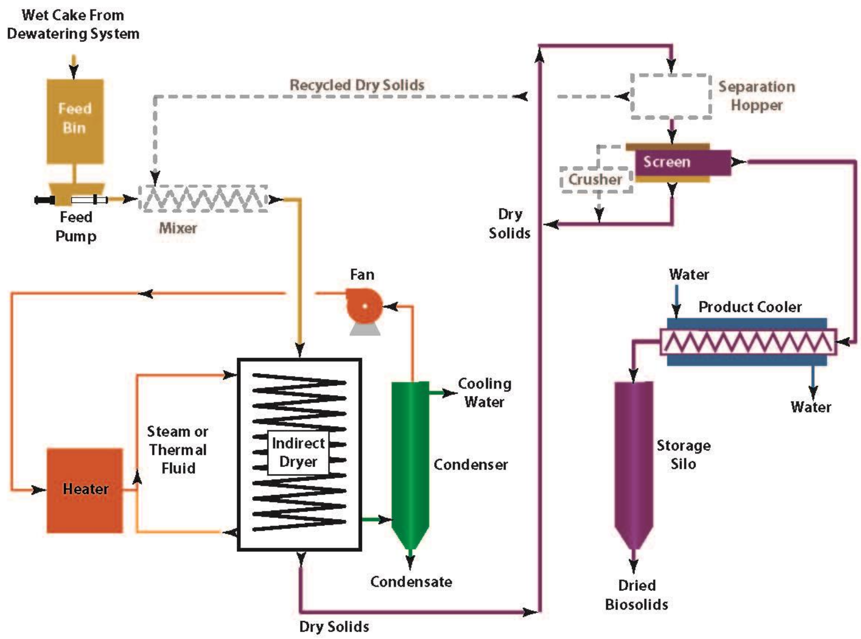

Figure 2: Indirect Type Paddle Drying System

In this type of system, the heat supply is via a fuel-burning furnace that exhausts to a heat exchanger to heat oil, which is recirculated through the dryer. Steam, air, water, or other heat transfer fluids are other media that can be used. The solids are mechanically moved through the dryer and pick up heat from direct contact with the hot surfaces. Following the dryer, the material handling equipment is similar to that used in the direct system. In this system, the dryer exhaust primarily consists of water vapor and a small quantity of air which inadvertently enters the dryer with the wet feed. The exhaust from the dryer is sent to a condenser where the water vapor is condensed and sent back to the WWTP and the small air flow (containing some non-condensable organics) is then treated using various APC methods, depending on the system and supplier. For example, some systems send the exhaust to the furnace for use as combustion air, while others use a wet scrubbing system. Similar to direct drying systems, indirect systems also vary considerably in the type of equipment used to process the wet and dried material through the system (WEF MOP No. 8).

Solar drying systems rely on radiant energy from the sun. Dewatered solids are distributed into the greenhouse uniformly, either by automated mechanical means or by a manually operated tractor or truck. The sun's radiant energy passes through the greenhouse enclosure (walls and roof) to heat and evaporate moisture from the sludge. The greenhouse enclosure prevents rain from adding water to the sludge and allows for a semi-controlled greenhouse environment, including air convection to help accelerate evaporation and enclosure of odors that can be processed through an odor control system. Solar drying systems are sensitive to local weather conditions, including solar radiation (considering typical cloud cover), relative humidity, temperature and wind speed and require thorough analysis during the design process. The solar drying system design will need to consider seasonality and historical weather data to ensure adequate design, and for some deviation from "average" weather years, some overdesign may be necessary. Solar drying processes are typically designed to provide solids compositions to exceed 75% dry solids, but can be difficult to sustain above 80-85%, depending on how loaded the system is. Solar drying systems typically provide a mechanical means for mixing and aerating the sludge periodically to promote the drying process. Solar drying is most viable in the southerly latitudes, for municipalities who have land available, and where snow cover is minimal. Radiant heat flooring can also be incorporated into the concrete greenhouse floor to reduce required greenhouse space and reduce the effects of weather variations to process performance. There are multiple solar drying systems available and vary in their equipment supply and how they operate.

Energy Use

Drying systems are a net energy consumer. By virtue of the inherent need to evaporate water (which theoretically requires 970 Btu/pound of water), an external source of heat is required. The most common energy sources are natural gas, digester gas, and fuel oil. However, in some instances waste heat from a nearby combustion source or thermal process can be used, including the combustion of dried biosolids. Solar systems use radiant energy primarily, but the fans and other equipment consume electric power.

Energy consumed in a thermal drying system typically includes fuel/thermal energy, and electrical power to operate equipment. The thermal energy consumption is based on the amount of water to be evaporated and the thermal efficiency of the drying system. The thermal efficiency of drying systems typically ranges from approximately 1,400 Btu per pound of water evaporated to 1,700 Btu per pound of water evaporated. Use of energy recovery systems may be able to further reduce these values. Cost of fuel is one of the largest operating costs for most drying systems, except for solar systems. If digester gas or another waste heat source is available, considerable savings in fuel costs can be realized. For example, in 2011, one utility surveyed indicated they were able to reduce operating costs by approximately $40 per wet ton of cake solids processed by using landfill gas as opposed to natural gas. Lower temperature dryers, such as belt dryers, are more able to utilizing lower temperature waste heat from existing plant operations.

Sustainability

Sustainability is the ability of a process to endure and remain an economically and environmentally sound means of wastewater solids management. The demands and pressures on drying can come from state and federal regulatory agencies, the general public, or from economic conditions. Regulatory agencies are continually scrutinizing pollutant and odorous air emissions from drying plants and imposing tighter emissions criteria on new facilities. Recent drying plants have shown that they can meet the strictest odor and pollutant emissions criteria. Federal and state statutes also regulate the quality of the product. Specifically, for a heat-dried product to be applied to land as an Exceptional Quality (EQ) product, it must meet stringent quality parameters including pathogen density reduction (Class A), vector attraction reduction, and low metals concentrations. These parameters are fully specified in the US EPA Part 503 regulations (40 CFR Part 503). Operating experience at drying facilities has shown that these criteria can be confidently and consistently met.

In the past odors were probably the single most detrimental impact from drying plants. However, present day design of drying plants has incorporated recirculation of dryer exhaust gas and the use of regenerative thermal oxidizers (and other techniques) to deodorize the final exhaust gas such that odorous emissions are no longer a significant impact. Dryers with high air recirculation rates or indirect dryers with low off-gas volumes can tie their low vent flow directly to the plant's existing odor control system. In general, the public now perceives drying as an environmentally acceptable technology for solids processing.

Presently, one of the major pressures on drying systems is the energy demand of the process, particularly the high fuel usage. Drying does use a considerable amount of fuel in comparison with other beneficial reuse technologies; however, the value and acceptability of the final product is much higher for a heat-dried product than a product from these alternate technologies. Thus, the energy demands and associated costs of drying have been acceptable because the municipality is assured that the final product can be safely used and in many cases will generate income. Furthermore, innovations have been developed in the last decade to improve the ability of some systems to use waste heat to reduce energy consumption. Thus drying should continue to be a highly sustainable solids processing technology in the future.

Relative Costs

Because of the large variety in types of drying systems, levels of processing, procurement methods, and general equipment differences, the capital cost of thermal drying systems varies a great deal. Factors that affect capital cost include the type of system selected, existing infrastructure, such as buildings and utilities, conveyance needs for moving dewatered solids to the process, and finished product storage requirements.

The operating and maintenance (O&M) costs of thermal drying systems are also dependent on the type of system selected and the energy source. Systems that rely on combustion of fossil fuels will have significantly higher O&M costs than systems that recover heat from other processes or rely on solar radiation. Energy recovery can make O&M costs very competitive with O&M costs for other methods of solids processing, especially other systems that create Class A stabilized products. The level of mechanization and automation used in the system will also have a significant effect on labor and maintenance costs.

Drying systems should be evaluated on their life-cycle costs as opposed to any single economic parameter. Although drying systems may have higher capital costs than other processes, the substantial reduction in volume of material to be transported off-site, the flexibility of outlets available, and the value of the product can help make these systems cost-competitive with other solids processing systems.

Uses for Dried Biosolids

Heat dried municipal biosolids product has qualities and characteristics that make it suitable for application on land or for use as a biofuel. Most of the heat-dried material produced in the U.S. is applied to land as soil conditioner, fertilizer, or fertilizer supplement. The material is used by agricultural users (farmers), golf courses, nurseries, parks, and is also marketed through retail outlets for home use.

Due to its characteristics, the dried product typically has a positive commercial value at the drying facility. Most of the municipalities or private parties in the U.S. that operate drying systems are able to sell the dried product and generate revenue that offsets a small portion of the costs for operating the drying process.

The market value of dried biosolids as a fertilizer depends on local market conditions, nutrient content, physical characteristics of the product, and other factors. The commercial value of dried biosolids in the U.S. is typically between $0 and $40 per ton of dry material, and varies based on agricultural practices in the region, product characteristics, and marketing strategies of the producer. Obtaining the high range of value for the product is less common and usually requires a significant marketing effort from the producer or a third party.

Some of the specific factors that impact commercial value of dried biosolids as a fertilizer include the following:

- Nutrient content: Most important for the fertilizer industry is nitrogen content, which can range between 2 and 6 percent. The more desirable nitrogen form is organic nitrogen due to its slow release characteristics. Phosphorous content, which ranges between 1 and 4 percent, and potassium content, which ranges between 0.1 and 0.5 percent, are comparatively less important for commercial value. The higher the nitrogen content, the higher the value. Nitrogen content is often the main factor used in price determination.
- Odorous properties: Some dried material (undigested primary solids) is likely to have objectionable odors. Drying of secondary solids or digested primary solids results in a product with significantly less noticeable odor. While slight odor may be noticeable from the dried product, odor tends to increase after the material is wetted following land application. Odors reduce the commercial value of any dried material.
- Hardness and potential for dusting: Usually, the harder the material, the lower the potential for dusting. Dusty material is less desirable and has lower commercial value. Digested solids tend to result in a harder, less dusty product.
- Size and shape of material: Some users require material of certain size and shape. The material may be shaped as small, round pellets or finer, dustier material (particle size ranges between 0.5 and 4 mm). Size classification can be achieved via pre-drying agglomeration and/or post-drying classification using screening and milling equipment.

In recent years there has been a growing interest in the use of biosolids as a biofuel. European facilities have shown this to be a viable practice, burning product in coal fired power plants to a limited extent, and more commonly in cement kilns and waste-to-energy facilities. In the U.S., use of the dried product as a biofuel is still in a developmental stage with the product primarily used in cement kilns. The heat value of the product will vary depending on the feed solids characteristics, with digested solids typically in the 7,000 Btu/dry pound range (3,900 kCal/kg, 3,400 kJ/kg) and raw solids as high as 9,000 Btu/dry pound (5,000 kCal/kg, 4,300 kJ/kg).

Advantages and Disadvantages of Drying

Drying technologies offer relative advantages and disadvantages as compared to other solids processing technologies. Some of these are listed below:

Advantages

- Dried material typically meets the requirements of the US EPA Part 503 for vector and pathogen control and the product is typically classified as Exceptional Quality and Class A with respect to pathogen density levels, but this is dependent on the type of system.
- Drying is a well-proven existing technology.
- Drying process can utilize waste heat from other processes, e.g. cogeneration units.
- Odors arising from the process can be contained and controlled.
- There is a wide range of outlet options for the dried material. Dried material can be used as a fertilizer, fertilizer supplement, soil conditioner, or biofuel.
- The heat-dried product is easily handled, conveyed and stored. The material can be delivered to consumers in bulk, bags, or other containers.
- Drying reduces the volume and weight of wet cake produced at the plant. This results in reduced transportation costs for beneficial use.
- With proper marketing, the product can be sold and can provide a steady stream of revenue which can partially offset the high costs associated with operation of the drying facility.
- Drying has a higher potential for public acceptance than many other processes.
- Drying has reduced regulatory record keeping and reporting requirements, if application to land is desired.

Disadvantages

- Safety concerns of drying include the explosive potential of the dust and the potential for product overheating and fires. Current design measures significantly reduce these safety hazards.
- The complexity of some drying systems requires a qualified operating staff. Maintenance requirements are typically high for direct and indirect systems.
- Air emissions are produced at any drying facility. Air permitting and air pollution control may be required.
- Capital and O&M costs of a drying facility are relatively high, typically higher than other solids processing alternatives (land application of digested biosolids, alkaline stabilization, etc.).
- Marketability of the dried material is sensitive to regional conditions. An evaluation of the market for the dried product should be conducted to determine optimum uses and value of the product.
- Drying of certain types of solids (undigested primary) can result in a more odorous product that can negatively affect its marketability.

Operational Safety Considerations

In the past there were serious concerns with the safety aspects of wastewater solids thermal drying plants. These safety concerns included the following:

- Potential for fires in the dryer
- Potential for dust explosions in the process components containing dried material
- Potential for fires in the product storage silos from auto-oxidation of the dried material

As the design of drying plants has evolved, engineers and system suppliers have learned how to design safer drying plants. The potential for fires in direct dryers has been greatly reduced by maintaining an oxygen-deficient atmosphere in the dryer. This is done by recirculating the dryer exhaust gas and limiting the amount of infiltration air such that the oxygen level in the dryer is held at 3% to 9%. Typically, the oxygen level must be greater than 10% to support combustion. Note that one study indicated a maximum permissible oxygen concentration of 6% is necessary to prevent combustion depending on the type of solids (HSE 847/9). In addition, dryers are equipped with quench sprays to extinguish a fire or burning embers in the dryer. Quench sprays are usually automatically activated based on a rise in the dryer exhaust gas temperature indicating that combustion is occurring in the dryer.

The potential for a dust explosion in many of the system components (dryer, solids separator vessel, recirculation duct) has been eliminated by maintaining an oxygen deficient atmosphere in these components. In some plants select equipment is provided with nitrogen blanketing to prevent explosions.

Similarly, the potential for fires in the product storage silo has been addressed by using inert gas (nitrogen) blanketing systems to maintain an oxygen deficient atmosphere in the product silo. In addition, cooling of the product prior to storage has proven to be an effective means of retarding auto-oxidation of the material and preventing fires. Storage silos are typically monitored by thermal sensors hung within the silos to detect any rise in temperature. Another monitoring technique is to use carbon monoxide monitors, which can detect the initiation of any combustion reactions. Thus, through experience and careful engineering the potential safety concerns with thermal drying systems have been satisfactorily addressed.

Feedback from Operating Facilities

As part of the 2012 update, the Taskforce solicited feedback from operators of thermal drying systems related to potential design improvements to assist operators and improve safety. The purpose of the survey was to collect information for use by others considering new drying facilities, or for those that have existing facilities and are interested in what others have done to correct certain issues. Further information regarding the feedback can be found in the full paper, which can be accessed through the following link: http://www.wrrfdata.org/NBP/DryerFS/DryingWWsolids.html

Conclusion

In conclusion, drying of wastewater solids has proven to be a safe, reliable, environmentally acceptable, cost effective, and sustainable processing technology that can produce a high quality biosolids product suitable for use as a fertilizer or biofuel. Furthermore, in comparison with other solids processing alternatives, drying is one of the most environmentally and socially acceptable means of achieving beneficial reuse of wastewater solids.

References

1. WEF Manual of Practice No. 8, *Design of Municipal Wastewater Treatment Plants*, Vol. II, Chapter 19, WEF and ASCE, 1992.
2. Title 40, Code of Federal Regulations, Part 503 – Standards For the Use or Disposal of Sewage Sludge, US EPA, Washington, D.C.
3. National Biosolids Partnership, *Manual of Good Practice for Biosolids*, Interim Final Draft3-13-01, www.biosolids.org.
4. Health and Safety Executive, *Control of Health and Safety Risks at Sewage Sludge Drying Plants*, Information Document HSE 847/9, United Kingdom.

For further Biosolids information, please see http://www.biosolids.org.

CONTACT:

Water Environment Federation
601 Wythe Street
Alexandria, VA 22314
703-684-2400
biosolids@wef.org