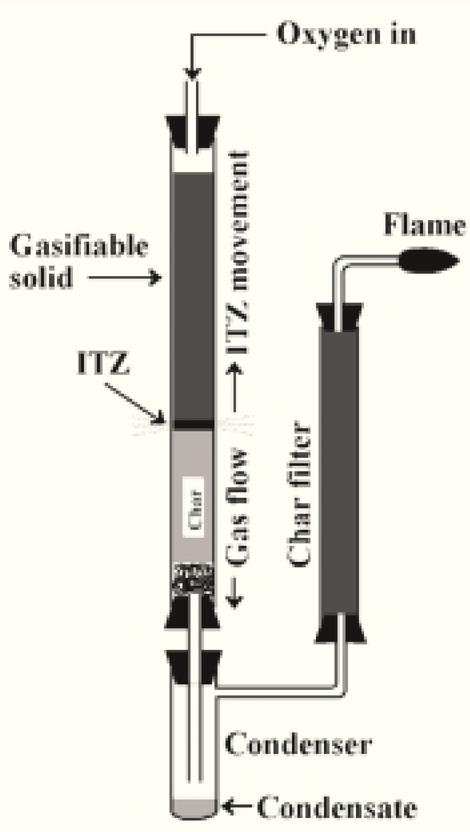
By Brendan McAuley, Julie Kunkel and Stanley E. Manahan

A New Process for the Drying and Gasification of Sewage Sludge

In recent years, methods formerly used for the disposal of sewage sludge, including landfill, incineration, ocean dumping and disposal on agricultural land have become much less acceptable. Ocean dumping of sewage sludge has been outlawed in the United States since 1998. Space for agricultural land disposal is not available in many urban areas and is meeting with increased opposition from farmers largely because of concern over potential heavy metal contamination from sludge.[1] Cost-effective and environmentally sound alternatives to existing means of sewage sludge disposal clearly are needed.

Figure 1: Laboratory-Scale Gasifier Used to Gasify Sludge, Char and Sludge/Char Mixtures



Gasification provides an attractive alternative to incineration for the thermal treatment of sewage sludge.[2] Gasification is the thermal conversion of carbonaceous solids to combustible gas and ash in a net reducing atmosphere. This technique has all the advantages of incineration for sewage sludge treatment including complete sterilization of the sludge and reduction of mass to the minimum possible mass of ash. Moreover, gasification can circumvent problems commonly encountered with incineration such as the need for supplemental fuel, emissions of sulfur oxides, nitrogen oxides, heavy metals and fly ash and the potential production of chlorinated dibenzodioxins and dibenzofurans.[3] These advantages are possible because gasification is a net chemically reductive process in contrast to incineration, which is oxidizing.[4]

The ChemChar hazardous waste gasification process is a cocurrent flow process in which solids, reactant gas (oxygen) and product gases all flow in the same direction through a continuous flow gasification reactor.[5] The principles of this process are shown in Figure 1 for a batch operation commonly used for laboratory studies. Gasification of solids occurs in a relatively narrow thermal zone (i.e., the incandescent thermal zone [ITZ]) reaching temperatures up to an estimated 1,200° C that moves through a bed of granular solids in a direction counter to the flow of oxygen. (In a continuous-feed gasifier, the ITZ remains stationary and the solids are fed through the gasifier.) In a single pass of the ITZ through the solids, only about 20 percent of the solids are converted to gas leaving a carbonaceous (char) residue containing the mineral matter present in the sewage sludge. This char product has excellent properties as a drying and conditioning medium for the treatment of additional sludge to produce a mixture of char and sludge that can be gasified, thus completing a complete cycle of dewatering and gasification.

The ChemChar process has been demonstrated to be effective in destroying a wide variety of wastes, some of which have the potential to be present in biological waste treatment sludges. These include PCBs,[6] surrogate military poisons[7] and highly refractory chlorofluorocarbons.[8] During gasification, sulfur is converted to hydrogen sulfide that can be readily removed from the gas stream[9] and nitrogen is evolved as elemental nitrogen gas.[10] A major advantage of this gasification system is complete retention of heavy metals on the char matrix. Although a fraction of mercury escapes the gasifier as mercury metal vapor, it is completely retained within the gasifier system.[11]

Experiment

An experiment was devised where secondary digester sludge with a solids content of 7 percent (drying for two hours at 150° C) obtained from the Columbia, Mo., wastewater treatment plant was used throughout. Gasification was carried out in a 20 mm I.D., 40 cm-long Vycor (heat resistant silica) tube using the apparatus shown in Figure 1. The sewage sludge used to prepare the initial batches of char was dried for several days under an infrared lamp and ground and sieved to 20–8 mesh size. Carbon dioxide in the offgas was determined by collecting a measured volume of the offgas in a two-liter graduated cylinder initially filled with

Table 1: Characteristics of Sludge and Gasification Products

Substance	Density, g/cm^3	Percent moisture	Percent ash
Sludge	1.0	93.0	2.5
Dried sludge	0.75[a]	---	35.0
Char[b]	0.86[a]	0.0	54.6

a Density of packed, pulverized solid.
b Char prepared by a single reverse-mode gasification of dried sludge.

Table 2: Gasification of Dried Sludge

Mass loss reverse mode gasification[a]	19.6%
Mass loss forward mode gasification[b]	54.5%
Volume of gas product per gram sludge, reverse mode, mL, STP[c]	14.0
Volume of gas product per gram sludge, forward mode, mL, STP[d]	526
Percent by volume combustible gas in reverse mode product[e]	51.9
Percent by volume combustible gas in forward mode product[e]	50.0

a In this mode, only the volatile organics and a fraction of the residual carbon are consumed leaving a char residue.

b In this mode, all combustible material is consumed.

c Volume of gas per gram of dried sludge subjected to reverse mode gasification, of which only a fraction is converted to gas.

d Volume of gas per gram of dried sludge subjected to forward mode gasification, of which 63.5%, including all organic and elemental carbon is converted to gas.

e The combustible fraction of the gas product is normally slightly less than 50% each carbon monoxide and elemental hydrogen with a few percent methane. The burning characteristics of the gas from sewage sludge gasification suggested a relatively higher content of methane with perhaps other hydrocarbons.

water and inverted in a plastic tub of water, registering the total volume of gas, then adding sodium hydroxide to the water to absorb carbon dioxide and measuring the volume of gas remaining. Drying studies were carried out on mixtures of one part sludge to two parts char by mass. Drying of sludge/char mixtures was conducted in a 25 mm I.D., 100 cm long Vycor tube at a flow rate of 4 L/min. Densities of solids were determined by pulverizing the solids with a mortar and pestle, then measuring the volume of a weighed amount of the pulverized solid packed into a graduated cylinder.

Results

The results of the gasification of sewage sludge and of char prepared by a single gasification of sewage sludge are summarized in Tables 1 and 2. Furthermore, it was observed that the mixture resulting from drying sludge mixed with char gasifies well, producing significant quantities of combustible gas. A plot resulting from the drying studies is shown in Figure 2.

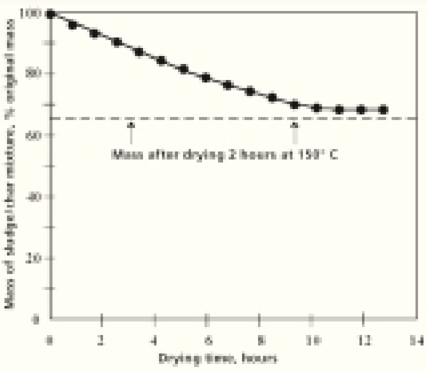
The dried granular sewage sludge gasifies very well with the system used. The condensate removed from the gas product has a strong odor, but is not a problem because it is recirculated through the gasification system to destroy the odor-causing contaminants. The dried gas product burns very well with a luminescent yellow flame that probably is indicative of a higher hydrocarbon content than the gas obtained by gasifying a char material such as that obtained from coal. Analysis of the gas product showed a 50 percent content of carbon dioxide, consistent with preceding gasification studies. The remainder of the gas product is combustible and, based on preceding gasification studies, probably consists of approximately equal quantities of carbon monoxide and elemental hydrogen with smaller, but significant, quantities of methane. This means that the gas product can be used as a fuel for applications such as powering a gas turbine to provide electrical energy for the wastewater treatment plant.

Forward-mode gasification in which the ITZ is initiated at the top, upstream end of the solids column and allowed to traverse to the bottom, completely consuming all combustible matter and leaving an ash residue, produces a combustible gas product consisting of 51.9 percent carbon dioxide. This gasification mode can be used to convert spent char used for sludge treatment to an ash product that can be safely disposed.

The curve showing drying of a mixture of one part wet sludge to two parts char by mass is illustrated in Figure 2. This was found to be the maximum ratio of sludge to char that could be used and still maintain air flow through a porous sludge/char mixture. It was observed that under the conditions used, drying is complete within 12 hours, reaching 89 percent of the level of drying attained by an additional two hours of drying at 150° C. The dried sludge/char mixture gasifies easily, with production of significant quantities of combustible gas and a char residue that can be recirculated through the drying process. It also was observed that the dried sludge/char mixture without gasification functioned equally well as a drying agent for additional sludge through at least two more cycles of drying. This provides a means of loading the mixture with additional gasifiable matter if needed for gasification to proceed.

With repeated cycles of drying, eventually ash will build up in the char product, requiring its disposal. When this occurs,

Figure 2: Drying Curve
(One part by mass of sewage sludge and two parts by mass of char from the gasification sludge.)



the char can be subjected to a final gasification in the forward mode. This step produces an ash product with minimum volume and reclaims all fuel in the char.

Summary

A system has been described based on the gasification of sewage sludge that enables facile drying of the sludge and ultimately the reduction of the sludge to its ash content. The process requires no materials or supplemental fuel other than those obtained from the sludge itself and oxygen from air. A combustible gas product is generated that can serve as fuel in a gas turbine, thus providing the energy needed to extract oxygen from air.

It is anticipated that commercial membrane processes can be used to extract oxygen, which does not need to be in a highly purified form. The ash residue, free of organics and pathogens with heavy metals sequestered in it, can be safely disposed.

REFERENCES

1. Garcia-Bacaicoa, Pedro, Rafael Bilbao, and Cristina Uson, "Sewage Sludge Gasification: First Studies," Proceedings of the Second Biomass Conference: Energy, Environment, and Agricultural Industry, pp. 685–694, 1995.

2. Whiting, Kevin J., "Gasification of Sewage Sludge—A Sustainable Option," Proceedings of the International Conference on Incineration and Thermal Treatment Technology, University of California, Irvine, CA, pp. 153–156 (1997).

3. Jaeger, M. and M. Mayer, "The Noell Conversion Process—A Gasification Process for the Pollutant-Free Disposal of Sewage Sludge and the Recovery of Energy and Materials," *Water Science and Technology,* 41, pp. 37–44 (2000).

4. Stanley E. Manahan and David W. Larsen, "Proceso 'ChemChar' para la Gasificació n de Residuos Peligrosos y Mezclas de Residuos Radioactivos y Peligrosos," *Tecnologia Ciencia Educacion,* 14, pp. 51–58 (1999).

5. Laura L. Kinner, Audrey McGowin, Stanley E. Manahan, David W. Larsen, "Reverse-Burn Gasification for Treatment of Hazardous Wastes: Contaminated Soil, Mixed Wastes, and Spent Activated Carbon Regeneration," *Environmental Science and Technology,* 27, pp. 482–488 (1993).

6. Laura L. Kinner, David W. Larsen and Stanley E. Manahan, "Gasification of Waste-Contaminated Soil by the ChemChar Process," *Journal of Environmental Science and Health,* A28, pp. 697–727 (1993) .

7. R. Scott Martin, Stanley E. Manahan, J. Steven Morris, and David W Larsen, "The Destruction of Chemical Warfare Surrogates and Subsequent Phosphorus Distribution during Gasification," *Journal of Environmental Science and Health.*

8. "The Destruction of Chlorofluorocarbons during ChemChar Gasification," R. Scott Martin, Kenneth E. Garrison, Stanley E. Manahan, J. Steven Morris, and David W Larsen, *Journal of Environmental Science and Health,* A34(4), pp. 767–793 (1999).

9. Bradley D. Medcalf, David W Larsen, and Stanley E. Manahan, "Gasification as an Alternative Method for the Destruction of Sulfur Containing Waste (ChemChar Process," *Waste Management,* 18, pp. 197–201 (1998).

10. Bradley D. Medcalf, David W Larsen, and Stanley E. Manahan, "Fate of Nitrogen in Nitrogen-Containing Compounds during Cocurrent Flow Gasification (ChemChar Process)" *Environmental Science and Technology ,* 31, January 1997, pp. 194–197.

11. James W. Colbert, R. Scott Martin, Stanley E. Manahan, and J. Steven Morris, "The Study of the Distribution of Arsenic, Mercury, Uranium, Thorium, Neptunium, and Protactinium Under the ChemChar Gasification Process Using Radioactive Tracers," *Journal of Radioanalytical and Nuclear Chemistry,* 230 (1998) pp. 61–70.

About the Authors:
Stanley E. Manahan is a professor in the Department of Chemistry at the University of Missouri in Columbia.

Brendan McAuley and Julie Kunkel are students at the University of Missouri.

For more information on this subject, circle 867 on the reader service card.