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COMMERCIALIZATION OF THE POLYETHYLENE MACROENCAPSULATION PROCESS*

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ABSTRACT

With support from the U.S. Department of Energy Office of Science and Technology (DOE OST) and assistance from Brookhaven National Laboratory (BNL), Envirocare of Utah, Inc. (Envirocare) is commercializing the polyethylene macroencapsulation process. Envirocare, currently the only commercially licensed mixed waste disposal facility in the U.S., will initially demonstrate the process by treating and disposing up to 227,000 kg (500,000 lbs) of radioactively contaminated lead. This waste, considered mixed due to both radioactive and hazardous constituents, is currently being stored at various sites throughout the DOE complex. Following this initial work for DOE, the process will be available for the treatment of other applicable wastes. Throughout commercialization of this process, BNL has provided Envirocare with technical support for engineering and permitting.

INTRODUCTION

Polyethylene encapsulation technologies have been developed by the U.S. Department of Energy (DOE) for solidification and stabilization of hazardous, radioactive and mixed wastes. Through 12 years of development at Brookhaven National Laboratory (BNL), polyethylene encapsulation has progressed from proof-of-principle through bench-scale development and full-scale demonstration[1]. Polyethylene has been shown to be a durable and stable encapsulant for the required treatment and disposal of both DOE and commercial wastes.[2-7] BNL early development efforts focused on microencapsulation of wastes where waste particles are interspersed in a polyethylene matrix. Alternatively, macroencapsulation which has recently received increased attention can be utilized for encapsulating large solids and debris by surrounding waste within an outer layer/coating of polymer.

The Environmental Protection Agency (EPA) has identified polymer macroencapsulation in 40 CFR 268.40 as the Best Demonstrated Available Technology (BDAT) for D008 radioactive lead solids, e.g., all lead shielding and other elemental forms of lead. In addition, macroencapsulation, abbreviated as MACRO by the EPA, has been designated in 40 CFR 268.45 as an Immobilization Technology under Alternative Treatment Standards for Hazardous Debris (defined as waste with dimensions greater than or equal to 60 mm). In 40 CFR 268.42, MACRO is defined as applying surface coating materials such as polymer organics (e.g., resins and plastics) or a jacket of inert inorganic materials to substantially reduce surface exposure to potential leaching media.

Envirocare of Utah, Inc., currently the only commercially licensed radioactive and mixed waste disposal facility in the U.S., has installed a polyethylene macroencapsulation process for the treatment of applicable wastes. Under an agreement with and support from the DOE, Envirocare will demonstrate the first commercial polyethylene macroencapsulation process by treating and disposing of up to 227,000 kg (500,000 lbs) of radioactively contaminated lead (D008). The lead, considered a mixed waste due to both radioactive and hazardous constituents, is currently stored throughout the DOE complex. BNL has provided Envirocare with support for process engineering and regulatory licensing to facilitate the successful commercial application of polyethylene macroencapsulation. Following a successful test demonstration of this process using both non-radioactive and radioactive lead samples in November 1995, Envirocare recently received

*This work was performed under the auspices of the U.S. Department of Energy.

permit modification approval by the State of Utah, Department of Environmental Quality, Division of Solid and Hazardous Waste, to include macroencapsulation as a waste treatment alternative at its South Clive facility.

POLYETHYLENE ENCAPSULATION

Polyethylene is an inert, low permeability, thermoplastic material that is highly resistant to chemical attack, microbial degradation and radiation damage. The combination of these properties makes polyethylene an ideal encapsulant and produces extremely durable and stable final encapsulated waste forms. BNL identified polyethylene over 12 years ago as a leading solidification candidate during a survey of potential binder agents with selection criteria based on considerations such as compatibility with waste, material properties, solidification efficiency, ease of processibility and economic feasibility. This work was conducted as part of the Waste Form Development/Test Program sponsored by the DOE Low-Level Waste Management Program.[8-9] Early development efforts focused on microencapsulation of wastes, in which wastes are combined with molten plastic in an extruder to form a homogeneous mixture which is then cooled to form a monolithic solid final waste form. In microencapsulation, individual waste particles are surrounded by a polyethylene layer. Since polyethylene is inert and no chemical reactions are required for solidification, a broad range of waste types have been shown to be amenable to encapsulation with polyethylene. These include aqueous concentrates such as nitrate, chloride, sulfate and borate salts, off-gas scrubber salts, incinerator fly and bottom ash, ion exchange resins, and spent molten salt oxidation residuals.

Polyethylene encapsulation has also been applied to the solidification of larger pieces of waste (e.g., lead, debris) that are not suitable for extrusion processing and microencapsulation. For polyethylene macroencapsulation, wastes are surrounded by a layer of clean, molten polyethylene that upon cooling forms a solid monolithic waste form. The EPA has deemed polymer macroencapsulation as the BDAT for D008 radioactive lead solids and debris waste. Since macroencapsulation is an EPA alternative treatment technology for certain wastes, Envirocare has developed a full-scale commercial macroencapsulation process.

PROCESS DESCRIPTION

The polyethylene macroencapsulation process utilizes a single-screw plastics extruder to melt, convey and pump molten polyethylene through a die and into a container. This technology has been used routinely in the plastics industry for many years to process thermoplastic polymers for various end-uses including pipe profiles, blow molding, and plastic sheeting. For application to macroencapsulation, the extruder requires little or no modification and is used to produce a continuous flow of molten polymer. The molten polymer is then poured around the waste which has been consolidated and placed within a suitable container or mold.

The encapsulation system installed at Envirocare uses a 114 mm dia. (4.5 in.) production-scale single-screw extruder capable of processing approximately 900 kg/hr (2000 lbs/hr) of polyethylene. Figure 1 is a schematic diagram of an extruder and is similar to the units installed at BNL and Envirocare. A photograph of the plastics extruder installed at Envirocare's macroencapsulation process facility is shown in Figure 2. An extruder consists of an auger-type screw enclosed in a barrel to which polyethylene, typically in the form of beads, is gravimetrically fed from a feed hopper resting above the feed throat. The polyethylene is gradually heated and melted by electric resistance band heaters on the outside of the barrel and by frictional heat generated by the mechanical action of the screw. Various screw designs are available that can enhance mixing and venting of volatiles. For macroencapsulation, a simple metering screw is employed. The plastic is masticated and conveyed through the barrel between screw flights with gradually decreasing channel depth. The decreasing screw channel volume results in an increase in pressure and shear. Temperatures are set to achieve a uniform molten output flow and are maintained by independently controlled zone heaters and

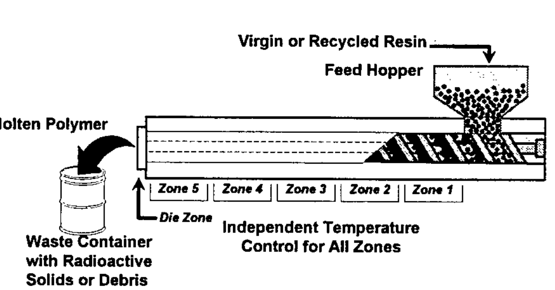

Figure 1. Schematic of Single-Screw Extruder for Polyethylene Macroencapsulation.

coolers. The molten polyethylene exiting the extruder die (extrudate) is poured into a waste container in which waste materials have either been suspended or supported. Cooling and subsequent solidification of the polyethylene results in the final waste form for disposal although some final modifications of the waste form are typically required. Techniques for generating uniform macroencapsulated waste forms depend on desired waste form geometry, extruder/die configuration, processing conditions, and type of resin used. The development of an acceptable waste form

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geometry and generation procedure requires considerable attention and testing.

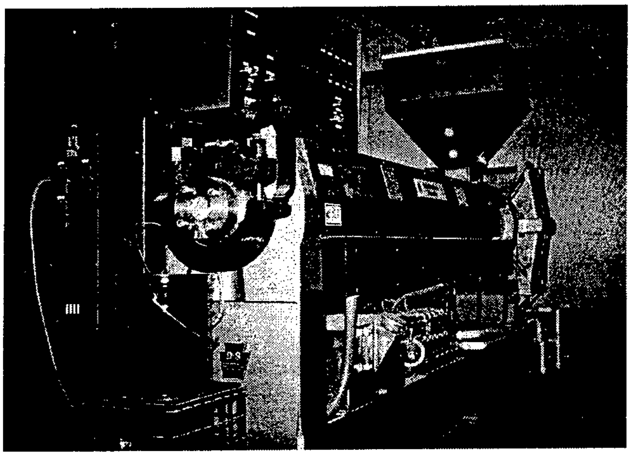

Figure 2. Single-Screw Extruder Installed at Envirocare's Macroencapsulation Process Facility

PROCESS OPERATION DEVELOPMENT

During process setup and testing, BNL provided technical support for identification and specification of key processing parameters, development of an operating procedure, and development of a practical waste form geometry. These items have been specified and integrated within the Envirocare macroencapsulation permit modification. Processing parameters (e.g., melt profile, die temperature, screw speed), set to achieve a desirable melt flow, vary with the type and grade of resin and desired waste form geometry. Although virgin resin has been utilized throughout process development, recycled resins may have application in this process, thereby providing a valuable and new end-use for industrial and post-consumer solid waste plastic. However, recycled resins present an increased processing challenge due to difficulties predicting flow behavior since they are often comingled mixtures of many resins and grades and are not well characterized. Once routine processing has been established, Envirocare plans to incorporate recycled resins in this process.

During process development at Envirocare numerous waste form designs and filling techniques were tested. Initially, scrap metal debris and non-radioactive lead bricks were used as simulated wastes during optimization studies of waste form geometry. Later, radioactive lead bricks from Idaho National Engineering Laboratory (INEL) were substituted for the simulated wastes. A schematic representation of a macroencapsulated waste form is shown in Figure 3. This shows a circular waste form encasing two individual rectangular solids (bricks) that are supported within an interior cage. A polyethylene layer completely surrounds the waste solids and provides an insulation buffer between the waste and the environment. Geometries like the one represented in Figure 3 were successfully tested by Envirocare and BNL but alternative geometries have also been investigated in an effort to provide improvements in packaging and loading efficiencies. In fact, for lead bricks a rectangular geometry has been developed that meets the treatment requirements in the Envirocare operational permit. Approval for changes and adjustments to the currently accepted waste form may be obtained from the State of Utah.

Several macroencapsulated waste forms from initial trial runs were sectioned to observe effectiveness of the encapsulation. These waste forms were generated in circular 19 liter (5 gal.) steel containers. After cooling to ambient temperature, the encapsulated waste form underwent a slight degree of shrinkage and thus was easily removed from the container. Sectioning revealed that the bricks were well encapsulated with no significant interior voids. In addition, the bricks were completely covered by a layer of polyethylene. However, in some cases the top of the waste form contained an air bubble(s) that formed as a result of the trapping of displaced air by the polyethylene. Entrapped air has a tendency to rise through the polyethylene due to the heat of the waste form and create a bubble or void below the top surface. This is more significant during encapsulation of debris due to the increased void space and, therefore, increased amount of entrapped air. Bubbles or near surface voids can be remedied while the waste form is cooling or later, by reheating the waste form surface and refilling with additional resin. This technique is also employed to repair macroencapsulated waste forms where the waste supports have protruded through the outer surface.

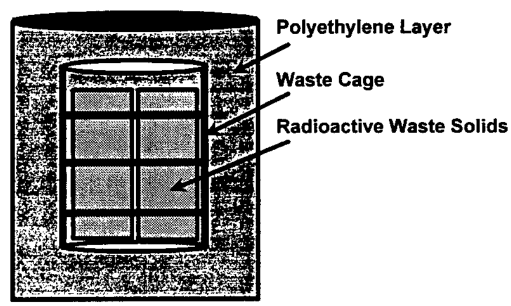

Figure 3. Macroencapsulated Waste Form

Under current federal regulations, macroencapsulated waste does not require performance testing for mechanical integrity or leachability as specified by the Nuclear Regulatory Commission (NRC)[10-11] and the EPA[12] for microencapsulated waste. At the request of the State of

Utah, Envirocare conducted a practical integrity experiment to demonstrate the mechanical durability of macroencapsulated waste forms. Several waste forms were buried in a disposal cell, leaving only their tops exposed. The forms were then subjected to the force of a 16,200 kg (35,700 lbs) track hoe which was driven over the tops of the waste forms. The forms were then exhumed from the cell and examined with no significant mechanical degradation observed.

The design, geometry, and dimensions of macroencapsulated waste forms are not specified under current federal regulations. The optimal design thickness of the outer polyethylene layer also has not been determined but throughout process development the goal was to provide a uniform layer approximately 50 mm (2 in.) thick. BNL has conservatively estimated that with a wall thickness of 50 mm (2 in.), for example, the leaching of soluble lead would not exceed 0.34 g/100 years or 0.76 g/100 years for a 25 mm (1 in.) wall thickness. This calculation assumes that the waste form integrity is intact but that the lead has already been mobilized by permeation of water into the waste form. Leachability and mechanical integrity need to be considered in determining the ultimate design thickness. The State of Utah in the current operating permit has very conservatively specified 50 mm (2 in.) as the minimum thickness requirement. Consequently, this is also the minimum wall thickness requirement in the acceptance criteria for disposal of macroencapsulated waste forms at Envirocare.

CURRENT STATUS

A successful demonstration of the process using non-radioactive and radioactive lead samples was conducted in November 1995. In attendance were representatives from DOE Headquarters, DOE-Idaho, Idaho National Engineering Laboratory, BNL, the DOE Mixed Waste Focus Area, the State of Utah, communities in which wastes are currently stored, and local media. The campaign for a commercial macroencapsulation process has been established with the operational permit approval by the State of Utah Division of Solid and Hazardous Waste. Envirocare has received approval for receipt of DOE mixed waste lead and has recently initiated the treatment of lead bricks and lead debris from INEL.

Following the treatment and disposal of 227,000 kg (500,000 lbs) of DOE radioactively contaminated lead, Envirocare's macroencapsulation facility will be available to treat hazardous, radioactive and mixed waste solids and debris from both commercial and DOE facilities. This new process provides cost-effective, durable final waste forms for many types of debris for which alternative treatment technologies are limited.

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