POLYMER SOLIDIFICATION TECHNOLOGY - Technical Issues and Challenges

CHARLES JENSEN, JUYOUL KIM*
Diversified Technologies Services, Inc., 2680 Westcott Blvd., Knoxville, TN 37931
*FNC Technology Co., Bldg.#135, Seoul National University, Gwanak-gu, Seoul
cjensen@dts9000.com

1. Introduction

Since 1992, Diversified Technologies has worked to improve and expand polymer solidification technology for processing of radioactive wastes to a stable waste form. The path to achieving an approved NRC 10CFR61.56 Branch Technical Position (BTP) waste form (or equivalent) is a long and arduous one. Many factors come into play, most of which are discovered and resolved only during full-scale solidification testing of each of the media commonly used in nuclear power plants (including anion, cation and mixed bed resins; activated carbon; zeolites; and specialty wastes such as dried concentrate from evaporators or reverse osmosis systems). Each waste stream is unique, and must be addressed accordingly. This testing process is so difficult that Diversified's Vinyl Ester Styrene (VES^{TM}) and Advanced Polymer Solidification (APS ^{TM}) are the only two approved processes in the United States today. This paper summarizes a few of the key obstacles that must be overcome to achieve a reliable, repeatable process for producing an approved Stable Class B&C waste form.

2. Methods and Results

Several key factors come into play in producing a compliant NRC 10CFR61.56 Branch Technical Position (BTP) waste form. Each of the following is discussed in detail below.

A key parameter of the binder formulation is viscosity. If the binder is too viscous, it cannot be pulled through the waste beds. The problem of viscosity is not evident in small containers such as test cups or small drums, but is more evident in 60-, 80- or 100-cubic foot liners. When binder is introduced to large liners, it penetrates the top 1'-2' very rapidly, and then slows sharply. Some momentum can be maintained by increasing the vacuum on the liner, but the vacuum must be limited if the bed is organic resin. Wetting characteristics of the binder also play a role: it's important that the binder has very good wet-out behavior. If the binder does not wet-out, each bead or granule that it passes will create a small amount of resistance - much like what we feel when we try to push the same poles of two magnets together - as they get close, they repel each other. This creates "resistance" in the bed, which impedes binder flow through the bed, and increases the challenge posed in solidifying large liners with viscous binder in cooler temperatures. Diversified devoted the better part of two years to running multiple full-scale tests until we developed a reliable combination of viscosity, wetting, vacuum pressures and liner internals. There simply are no shortcuts to full-scale testing to bound these parameters.

An important factor in repeated successful solidification is the type and configuration of the dewatering/solidification internals. If the internals are not properly configured and spaced, areas can be left unimpregnated with binder as the binder, drawn by the vacuum, advances toward the solidification internals, overrunning gaps between them, or not reaching the lower outside shoulder of the liner's perimeter. If the media being solidified is wet resin, unwanted pockets of water can be left. The configuration of the internals is less critical in smaller containers (e.g., drums) than in large liners, where there are greater gaps between internals and the advancing binder face can vary greatly over the area in the bottom of the liner. Once the appropriate internal configurations were determined, DTS conducted full-scale tests in 55-gallon drums and 15-, 60-, 80-, 120- and 200-cubic foot liners. The NRC required demonstration of these capabilities before the final qualifying solidification was allowed to go forward in the 200 cubic foot liner. NRC personnel observed that solidification, and it was the basis for our formal Topical Report submittal to the NRC.

During early testing, waste interference was a chronic problem. When one of the three resin types was not fully depleted or when carbon was present, one of the binder formulation components would be stripped from the binder as the binder passed down through the bed. This resulted in good solidification at the top of the liner, but partial or no solidification at the bottom. This behavior is not evident in cup or small drum testing, as the binder travels only a few inches or feet through the waste media. In larger liners, the binder has to slowly travel through as much as 4' of the waste bed, and is exposed to stripping for 1 to 1.25 hours. The NRC required full-scale testing of each of these media to demonstrate that there was not waste interference: anion, cation, mixed bed, cation, fine activated carbon and inorganic zeolitic media (used for cesium removal). Based on successful demonstration that these media (in their undepleted form, which would be more reactive with the binder) did not interfere with proper gelation and solidification, the final 200- cubic foot qualification test was conducted with the required layers of each of these media in the liner.

Though the vacuum pressure applied can be varied across a small band, it's important that the vacuum be matched to the binder viscosity and temperature. The optimum band of vacuum pressures must be determined based on polymer formulation. If the vacuum is too low, the binder will be drawn too slowly through the liner, and the advancing binder face will start to gel before the liner is completely impregnated. If the vacuum is too high, the binder will advance too fast, resulting in a non-uniform binder face. This non-uniform advancement can create voids or holidays in the monolith as the polymer or overruns some regions of the liner, arriving at the solidification internals before other regions have been fully impregnated with polymer. An initial vacuum that is too high can cause bed compression, primarily an issue with organic resins. This compression can reduce the flow paths through the resin, slowing or stopping the flow of binder through the bed. While a higher viscosity formulation requires higher vacuum pressures, they cannot be so high as to compress the resin bed. Diversified developed it's optimum vacuum band for the three variations of the APS™ formulation, when used in ambient temperature range. Extensive testing and multiple full-scale solidifications were necessary to develop this banding.

To meet our testing needs and the preliminary requirements of the NRC, all of the full-scale liners had their skin removed and were cut into halves or quarters with a diamond wire saw to expose all regions of the interior for inspection for voids or water pockets. For the final 200- cubic foot test liner, the NRC required Diversified to bore 13 holes completely through the monolith from top to bottom in a pattern provided by the NRC. All the borings were then inspected for voids or areas not fully impregnated. Any suspect areas had to be cut out and compressive tested. That monolith has been retained and is to be inspected at intervals of every few years to confirm that the monolith is intact, even after going through rain, snow and numerous freeze-thaw cycles. Other full-scale monoliths or sections thereof have been saved for future inspection.

Though it was not a requirement of the NRC, Diversified was required by U.S. nuclear plant that we had the ability to recover from an upset condition that prevented all the polymer from being introduced before the polymer started to gel. This would leave a partially solidified liner with the top of the waste bed solidified and the bottom of the bed unsolidified with accumulated water (if wet resins are being solidified). A partially solidified liner cannot be buried as it does not meet the Class B&C Stable requirement, so Diversified was required, by U.S. nuclear power plants, to demonstrate a means of recovery from this upset condition before the APS™ solidification process could be used. To meet this requirement, Diversified conducted a demonstration test in a 120 cubic foot liner of ion exchange resins. Polymer was introduced in accordance with normal solidification procedure until approximately 2/3rds of the top region of the waste bed will impregnated with binder, and then polymer transfer was secured, and the polymer was allowed to cure for two days. On the third day, Diversified changed its solidification equipment to the new configuration to apply the proprietary corrective action process. As can be seen in Fig. 1, the upset recovery was completely successful. There were no voids or unsolidified regions at the interface between the two polymer introductions campaigns and all resin in the lower region of bed, approximately 18"-24" above the bottom of the liner, were fully involved with binder. Though infrequent, eventually the loss of air, electrical power, emergency evacuation or accelerated gelation because of temperature or error in formula mixing, will result in a partially solidified liner. The solidification process supplier must be able to demonstrate, full scale, that they have a method of recovering from such upset conditions.

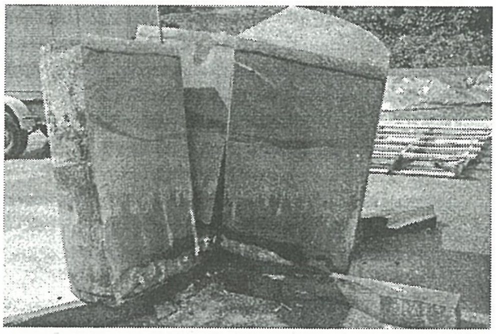

Fig. 1. Upset Recovery Test monolith after sectioning with a diamond wire saw.

3. Conclusions

Before other solidification and encapsulation technologies can be considered compliant with the requirements of a Stable waste form, the tests, calculations and reporting discussed above must be conducted for both the waste form and solidification process used to produce the waste form. Diversified's VERI™ and APS™ processes have gained acceptance in the UK. These processes have also been approved and gained acceptance in the U.S. because we have consistently overcome technical hurdles to produce a complaint product. Diversified Technologies' processes are protected intellectual property. In specific instances, we have patents pending on key parts of our process technology.