The Schwing pump system was connected to the 100-mm (4-inch) Jamesbury valve on the pressure vessel. Only the lower pipe section with support legs and pedestal was used for the pressure pumping test. Connections were made using 63.5-mm (2.5-inch) heavy-duty snap-type closures with a maximum pressure rating of 13.8 MPa (2000 psig). Photos of the pump system and pressure vessel configured for pressurized pumping testing are shown in Figures 12 and 13. The flexible hose was originally selected over a rigid pipe and flange connection system to minimize the requirement for field-fitting and to hasten initiation of testing. Further, the flexible hose and heavy duty connectors made it easier to reposition and clean process equipment.

Once the Schwing pump was connected to the pressure vessel, the back-pressure control valve was reset to a relief pressure of 2.2 MPa (320 psig); the safety relief valve was set at 3.1 MPa (450 psig). With the 100-mm (4-inch) ball valve in the closed position and the flexible hose full of sludge, the pressure vessel was brought up to 2.2 MPa (320 psig) with nitrogen. The screw feeder and sludge pump were then started, and almost immediately, the opening of the ball valve was initiated. Simultaneously, the back-pressure control valve started to relief, indicating positive flow of sludge against pressure into the vessel. The pump was allowed to feed for approximately 5 minutes during which time no evidence of backflow of sludge or nitrogen was detected. Even after shutting off the pump but before closing the ball valve, there was no backflow. The pumping test was considered a success, and it was felt that doing the same at 2.83 MPa (410 psig) would not present any problems.

Dispersion/Injection of Sewage Sludge

After breaching the pressure boundary, it was envisioned that the sludge would need to be dispersed at a sufficiently small particle size to ensure entrainment. These values were previously

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Figure 12. Pump system configured for pumping sludge into pressurized vessel – side view.

Figure 13. Pump system configured for pumping sludge into pressurized vessel – top view.

estimated to be in the range of 2.5 to 5.0 mm (0.1 to 0.2 inches). Three methods of injection/dispersion of sewage sludge into the Wabash River entrained-flow gasifier were considered: 1) mechanical dispersion, 2) screw-feeding with pneumatic dispersion, and 3) injection through a dual-fluid nozzle.

Mechanical Dispersion

Concepts considered for mechanical dispersion included 1) extrusion through a die followed by cutting the sludge extrudate with a high-speed rotational knife and 2) injection using a modified agricultural manure/sludge spreader. The spreader uses high-rotational-speed hammers (similar to a hammermill) or impellers to "project" the sludge, often at distances over 30 meters (100 ft). Screw augers are used to force feed the impellers or hammers. The spreader concept has a parallel in the sludge-drying industry. Fluid-bed systems used for producing thermally dried, pelletized (i.e., sphered: to form into a sphere) sludge as soil amendment use a "flinger" type feeder to propel small chunks of sludge into the dryer.

The principal drawbacks perceived to be associated with these systems included a short operating life and low reliability for rotating parts exposed to the high-temperature (approximately 1370°C [2500°F]) and potentially slagging atmosphere at the proposed injection point. Further, preliminary estimates indicate that rotational speeds for an impeller or hammers in a spreader-type system would be very high (several thousand rpm) again providing an equipment-reliability challenge, especially if thousands of continuous on-line hours for the feeder are required. The mechanical feeding/dispersion concept was not pursued further.

Screw Feeding with Pneumatic Dispersion

Principally because of the potential for sludge flow pulsation when a piston pump is used, screw feeding was considered as an option for leveling out sludge flow. Further, it was envisioned that the auger flights would provide an initial means of delumping the pumped sludge prior to using a directed stream of high-pressure gas from a dispersion nozzle to further size-reduce and convey the sludge into the flowing gas stream of the gasifier.

As part of proposed demonstrations, a design was developed for a twin-screw auger that would be coupled with a pump system. The twin-screw auger was sized based on an estimated maximum pumping rate of 0.76 L/sec (12 gpm). The proposed system consisted of twin overlapping screw flights, both with inward rotation. The overlapping flights would theoretically function to provide self-cleaning and inhibit buildup of sticky sludge. Pressure containment would be attained by housing the twin screws in a pipe/flange system rated for a minimum pressure of 410 psig.

Bid specifications for constructing a pilot-scale twin-screw auger were forwarded to six conveyor manufacturers. Five of the six vendors declined to participate. The remaining vendor, Unico Services (53), claimed experience in producing screw augers used for the controlled removal of high-temperature ash from two demonstration-scale gasifiers. The system quoted by Unico was $45,000, which was deemed excessive. Subsequent to the bid process, attention has focused on possibly building a system in-house with purchased components. Critical to the development of the pressurized-screw feeder was a shaft seal that can seal at 410 psig. Discussions with eight shaft seal vendors indicated that nothing was available off-the-shelf. The seal manufacturers would require significant engineering time to develop new or modify existing designs. Most vendors declined further involvement, knowing the request was for no more than two seals. One vendor offered a quote of $3000 per seal.

Dual-Fluid Nozzle Injection

After considering and rejecting mechanical dispersion and screw feeding with pneumatic dispersion, injection using a dual-fluid nozzle became the primary focus of sludge-feeding/dispersing options. Initial design options focused principally on the application of a shotcrete nozzle, a tool used for wet concrete "gunning." Shotcrete nozzles intimately mix compressed air with concrete in a converging pipe, resulting in a high-velocity stream (100 to 200 ft/sec) of concrete that can be deposited on vertical services at distances up to approximately 6 meters (20 feet) or more from the nozzle. A photo of an application of a shotcrete nozzle is shown in Figure 14 (54). These nozzles can feed concrete with aggregate up to 19 mm (0.75 inch) in diameter. It was presumed that recycle syngas available at Wabash River could replace air as the pneumatic transport fluid. Preliminary estimations show that the sludge:syngas volume ratio available for the Wabash River gasifier is similar to the concrete:compressed air ratios normally achieved with the nozzle.

Several shotcrete nozzle manufacturers were identified. A 6.35-mm (2.5-inch) nozzle with a rated capacity of approximately 18.4 m^3/hr (24 yd3/hr) concrete was purchased from Shotcrete Technologies (55). A schematic of the nozzle is shown in Figure 15, and a photo of the nozzle is

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Figure 14. Shotcrete Technologies nozzle being used for concrete gunning.

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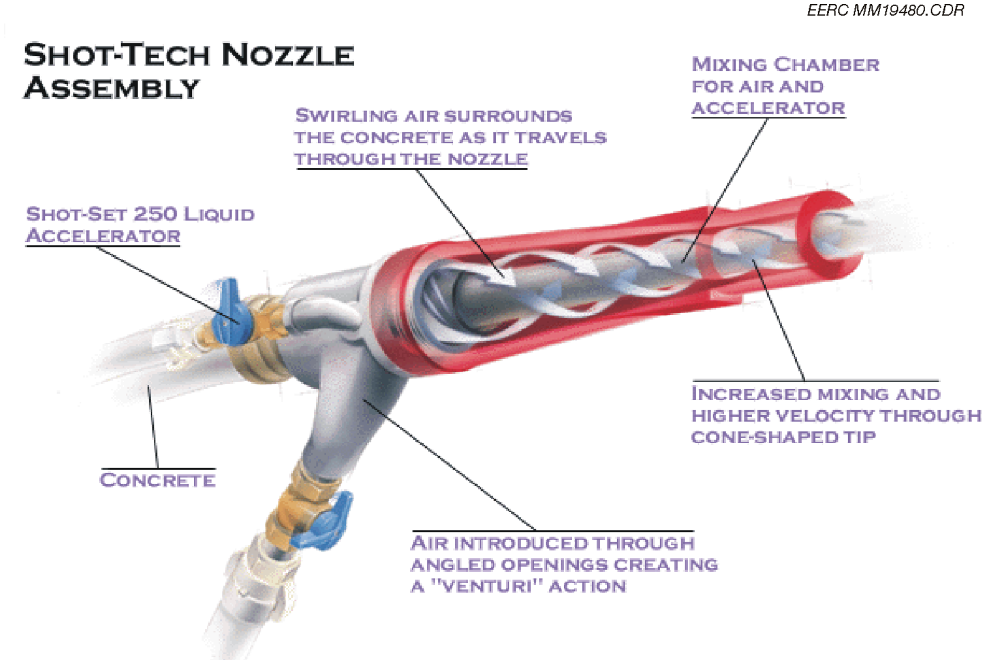

Figure 15. Cutaway diagram of Shotcrete Technologies shotcrete nozzle.

shown in Figure 16. This nozzle was equipped with 63.5-mm (2.5-inch) heavy-duty connection to allow easy mating to existing piping.

In addition to the shotcrete nozzle, a nozzle design was advanced that was based on a mechanical sludge dispersion system used by the Western Lake Superior Sanitary District (Duluth, Minnesota) (56) for feeding 16 wt% solids sludge to an, now inoperable, atmospheric-pressure fluid-bed incinerator. A schematic of this dispersion system, informally called a lance, is shown in Figure 17. The lance consisted of a solid rod with a solid metal cone attached at one end. The pipe and lance were suspended vertically with the sludge being forced through the annulus created by the cone and the 152-mm (6-inch) pipe. The thinning of the sludge allowed it to be more effectively dispersed and consumed within the fluid bed. The supported end of the rod was attached to a spring mechanism that allowed the lance to move downward, increasing the annular space in the event that a rag or similar potential obstruction was passed with the sludge.

As the requirements for sludge dispersion within the Wabash River gasifier were presumed to be much more severe, a dispersion nozzle with a lance-type insert was designed and constructed, with the principal design upgrade being the addition of perforations to the angled face of the cone. The perforations would allow the introduction of high-velocity jets of recycle syngas that would ideally disintegrate the sludge and carry the sludge into the gasifier. A shop construction drawing of the nozzle insert is shown in Figure 18, and a photo is shown in Figure 19. Initially, the confidence level in this design was less than that of the shotcrete nozzle, and consequently, the first nozzle system (EERC-1) was quite unrefined. The first nozzle insert consisted of two back-to-back concentric 25.4-mm × 50.8-mm (1-inch × 2-inch) reducers with one end sealed by a 25.4-mm (1-inch) cap. The opposite end was connected to a 25.4-mm (1-inch) pipe which supplied the

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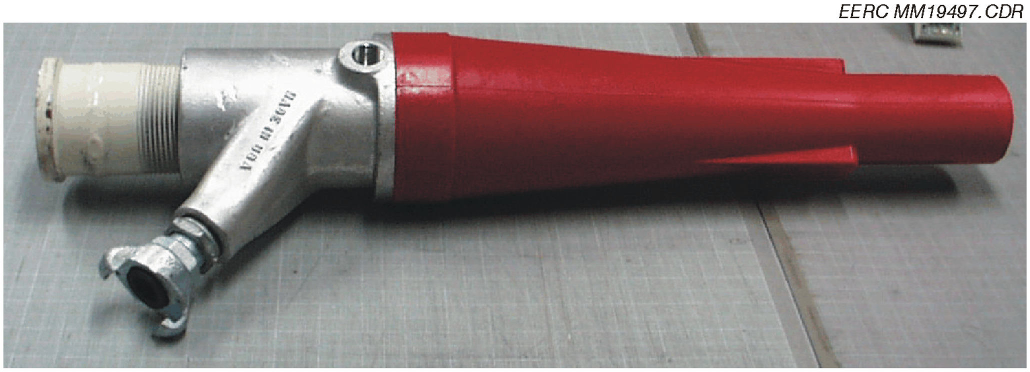

Figure 16. Shotcrete Technologies 2½-inch shotcrete nozzle.

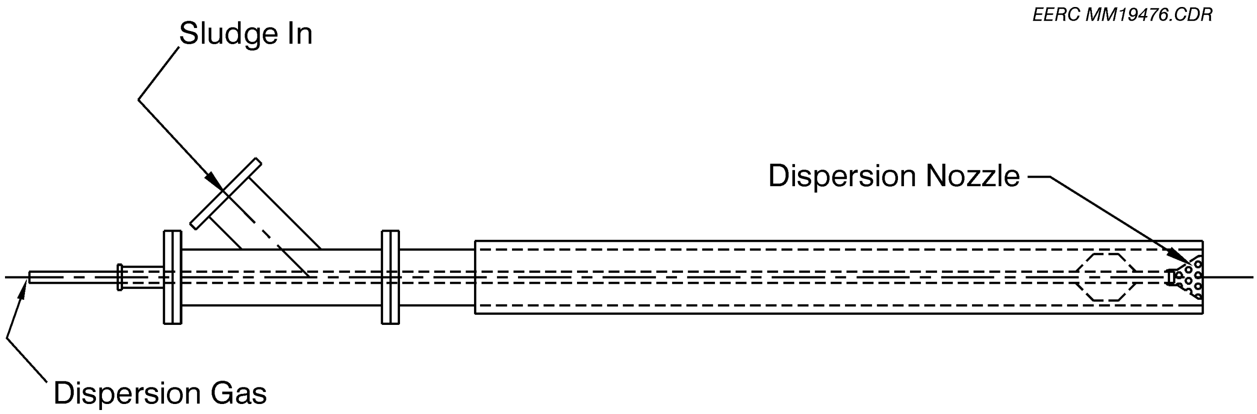

Figure 17. Sludge dispersion lance used in fluid-bed incinerator.

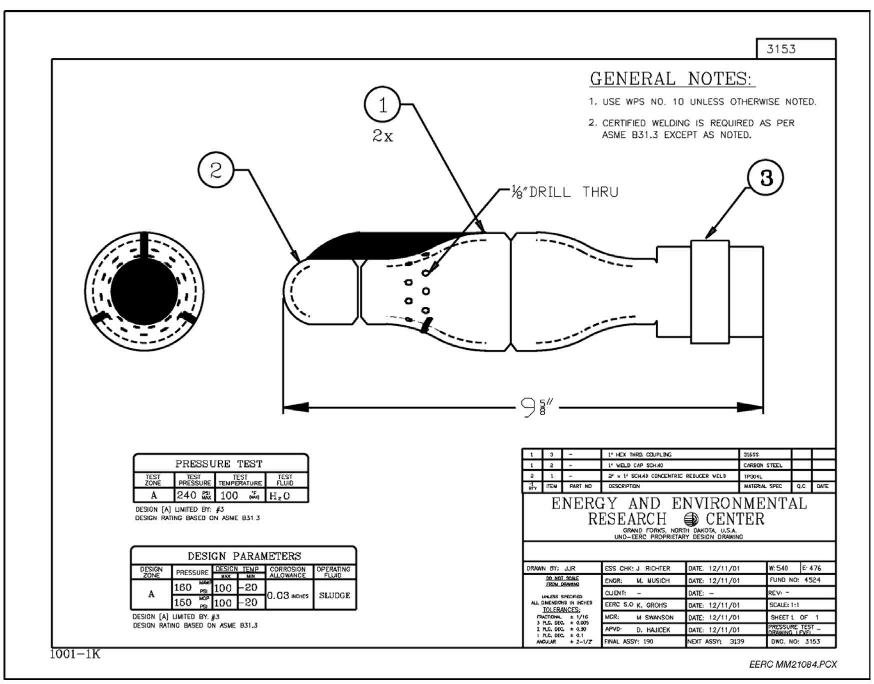

Figure 18. Shop drawing of the EERC-1 sludge dispersion nozzle.

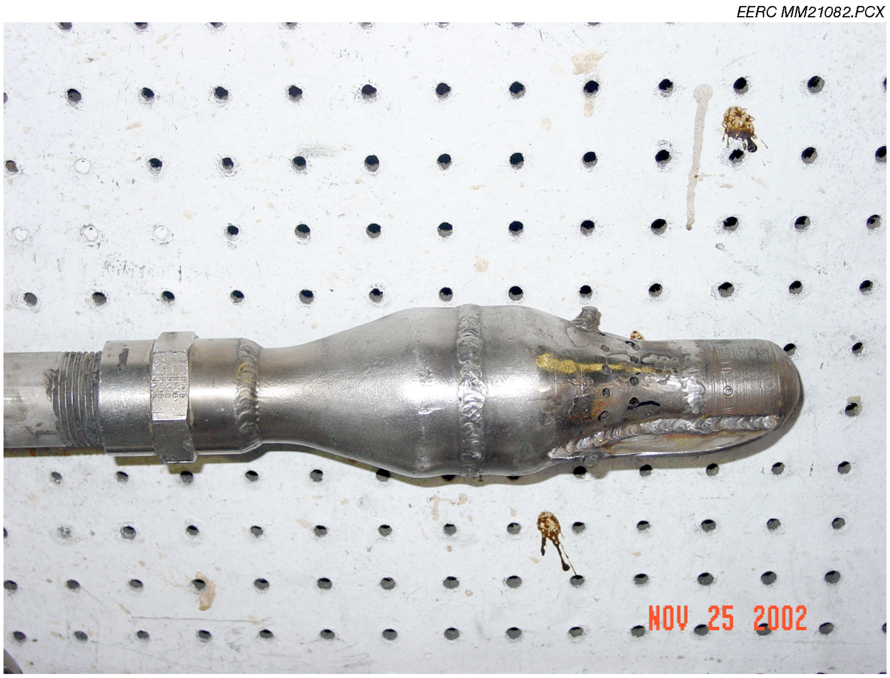

Figure 19. The EERC-1 sludge dispersion nozzle.

dispersion gas. Three alignment fins were attached approximately 120 degrees apart on the sloped face of the nozzle to help provide a uniform annular space around the circumference. A support system was constructed that allowed the EERC-1 nozzle to be held securely within the end of the 63.5-mm (2.5-inch), 7.6-m (25-ft)-long high-pressure, flexible hose. The support system allowed the nozzle to be moved in or out of the hose to change the width of the annular gap. The number of holes on the face of the upstream reducer was determined based on a desired velocity of 30 m/sec (100 ft/sec) through each hole at a total flow rate of 4400 scfh.

Subsequent to the evaluation of the shotcrete nozzle and the EERC-1 nozzle, a more refined version of the latter nozzle was designed, constructed, and tested. A shop drawing of the EERC-2 nozzle is shown in Figure 20, and photos of the nozzle are shown in Figures 21–23. The principal improvements in this nozzle were that the dispersion gas pipe ran down the center of the nozzle and that the pipe and cone were a singular, integral unit. A compression fitting with a Teflon ferrule was utilized to allow the 19.1-mm (0.75-inch)-OD dispersion gas pipe (with dispersion cone) to be moved in and out to change the width of the annular gap. A threaded-rod locking assembly was used to prevent the unwanted movement of the dispersion pipe. Initially, it was hoped that the rigidity of the heavy wall 19.1-mm (0.75-inch)-OD dispersion gas pipe would inhibit flexing and, consequently, nonuniformity of the annular gap width. The first shakedown tests indicated otherwise, and as with the EERC-1 nozzle, three alignment fins were added to help maintain proper gap. The end of the nozzle pipe was machined to a taper with an angle equivalent to that of the dispersion cone angle. The dispersion cone was machined from a piece of round stock and then sealed on the large end with flat stock. The number of holes on the dispersion cone was similar to that of the EERC-1 nozzle.

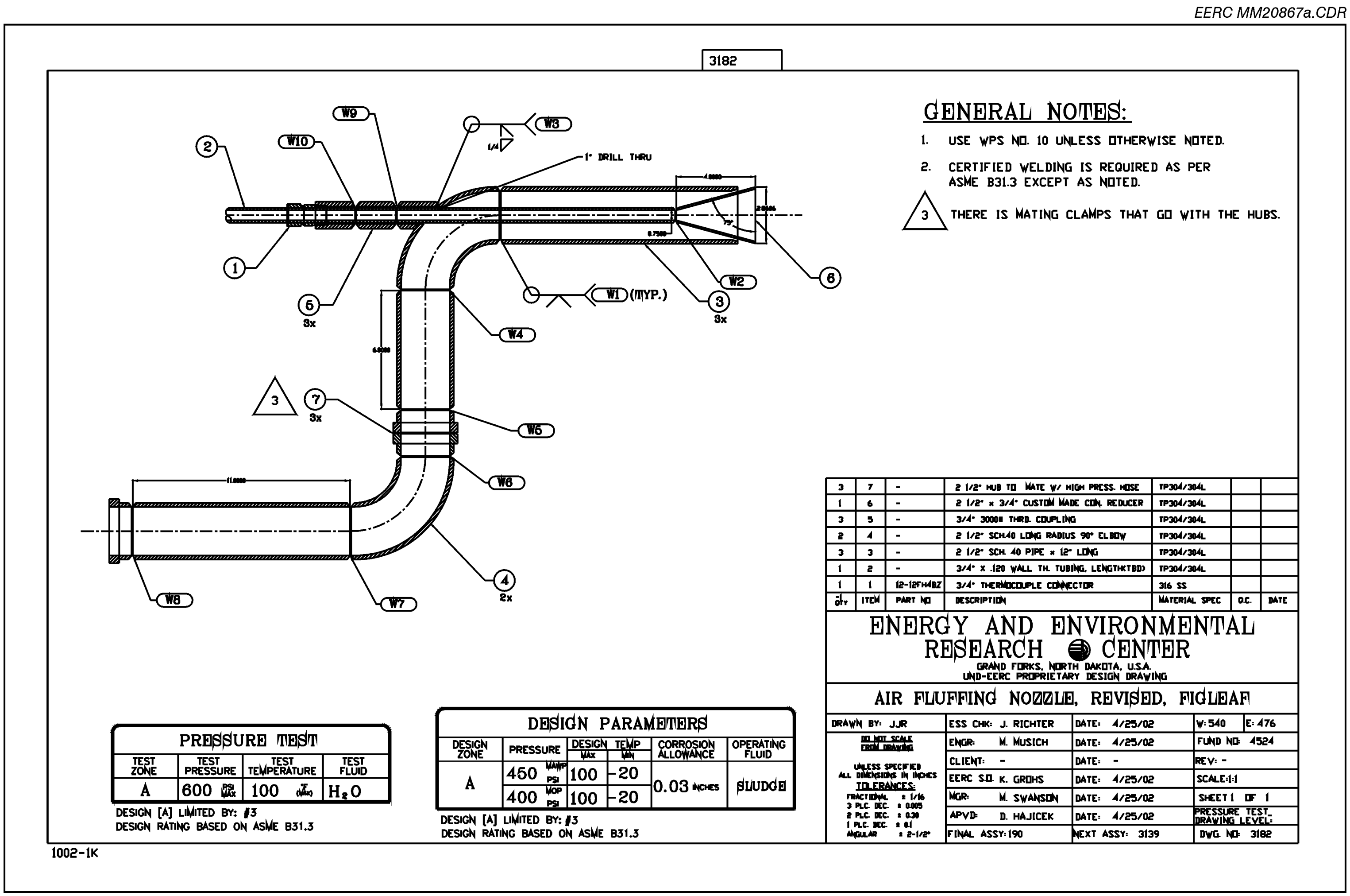

Figure 20. Shop drawing of the EERC-2 sludge dispersion nozzle.

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Figure 21. The EERC-2 sludge dispersion nozzle.

EERC MM21035.JPG

Figure 22. The EERC-2 sludge dispersion nozzle – end view.