EERC MM21036.JPG


OCT 25 2002

Figure 23. The EERC-2 sludge dispersion nozzle – end view.

Containment System for Sludge Dispersion Testing

Two separate systems were initially designed for containment of the sludge during dispersion testing. The first system, shown in Figure 24, was intended to allow injection of the dispersed sludge into an entrainment column. The entrainment column would be fed at the bottom with air from a blower. Although operated at atmospheric pressure and ambient temperature, the flowing conditions of the entrainment tower would produce particle drag and lift essentially equivalent to those achieved in the Wabash River gasifier. The entrainment tower would be ported to allow attachment of a pneumatic dispersion device such as the shotcrete nozzle (or other) or a twin-screw conveyor.

The second system was designed principally for evaluation of the shotcrete nozzle. This system consisted of a 2.7-m (9-ft)-long, 483-mm (19-inch)-diameter carbon steel pipe with several ports along its length. The sludge pump was positioned with the attached shotcrete nozzle at or near the entrance of the horizontally oriented pipe. Sludge impacting on the end panel was to fall through the lower port. The side ports located within 0.76 m (2.5 ft) and 1.7 m (5.5 ft) of the entrance were covered with plexiglass to allow observation of the nozzle spray. The first shakedown tests with the shotcrete nozzle indicated this vessel to be unwieldy with respect to recovery of the sludge for subsequent tests. Consequently, a new system was developed that was used throughout all remaining atmospheric pressure dispersion tests.

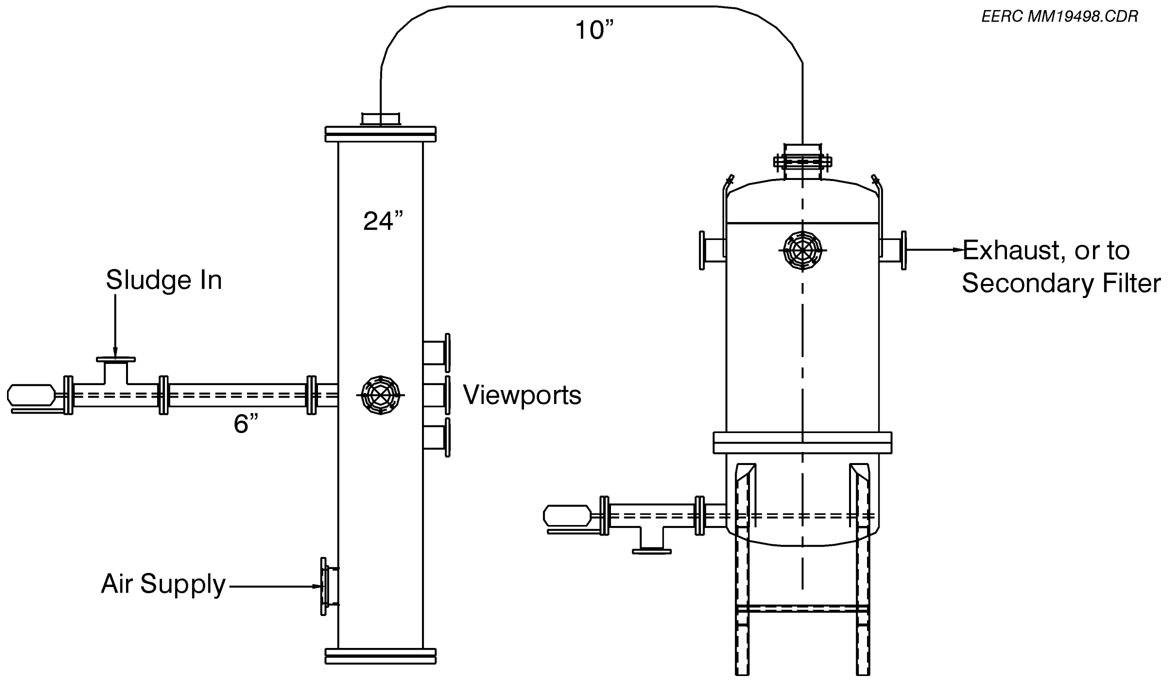

Figure 24. Sludge dispersion and entrainment column.

To facilitate more efficient utilization of the sludge and to minimize manual recovery of sludge from containers, a dispersion barricade or shroud (Figure 25) was placed above the opening to the twin-screw feeder. This four-and-a-half-sided shroud was constructed of steel plate and was clamped to the flange of the screw-feeder opening. The purpose of the shroud was to allow continual dispersion of sludge through a nozzle with the sludge impinging on the walls of the hood and then falling back to the screw feeder to be reused. Only periodic recharging of fresh sludge was required. The top side of the hood was equipped with a plexiglass-covered 0.30-m (12-inch)-diameter hole above which a halogen lamp was used to provide lighting within the hood. The dispersion nozzle was supported by a vice on a roller stand. The vice and stand could be moved to allow proper positioning of the dispersion nozzle over the twin-screw feeder hopper. The half-length side allowed simultaneous containment of the sludge and filming of the dispersed sludge spray. The distance between the nozzle tip and hood walls was about 0.61 m (2 ft).

Nozzle Testing

Excluding several shakedown tests, a total of 41 dual-fluid nozzle sludge dispersion tests were conducted at the EERC. Tests 1 to 29 were conducted in December of 2001, and Tests 30 to 41 were conducted in June of 2002. The first 20 tests were conducted with the shotcrete nozzle, while the latter tests were conducted with two different versions of the annular nozzle type as previously described.

EERC MM21078.PCX

Figure 25. Containment shroud on twin-screw feeder hopper.

As indicated in Table 17, the controlled variables included sludge rate, dispersion air rate, and nozzle configuration. Measured variables included the dispersion gas pressure at the nozzle and the hydraulic pressure for the pump.

Control of the sludge pump stroke rate was achieved through a manual rheostat located on the power pack. An analog gauge indicated the percentage of maximum pump stroke rate for the respective rheostat setting. The pump could be field-adjusted to increase the low-end and high-end pump stroke rates up to a maximum rate of about 24 strokes per minute to achieve a theoretical 6.9 L/sec (110 gpm). Control of the twin-screw auger speed (or feed rate) was similarly achieved with adjustments to low- and high-end speed made concurrently to changes in the pump stroke rate range. Maintaining a twin-screw auger speed at or 20% higher than the pump stroke rate setting was sufficient to achieve good pump filling. A few instances of poor filling, as evidenced by excessive pulsations in the sludge spray, were due to letting the feed hopper get too low on sludge.

The sludge-pumping rate was determined by measuring the mass of sludge pumped into a half-barrel over a specified period as recorded by a stop watch. Several calibrations were performed at each pump stroke setting and were found to differ by no more than a few percentages. Because the pump stroke rate is not affected by back pressure and filling efficiency is determined by the twin-screw auger, the sludge mass rate was presumed to be unaffected by changes in back pressure on the pump. Changes in back pressure at a constant pump rate would come from changing the gap size, for example, on the dispersion nozzles.

Table 17. Sludge Nozzle Test Conditions and Results

Test No.	Nozzle	Nozzle Configuration	Sludge Rate, lb/min	Air Rate, acfh	Velocity, ft/sec	Gauge Pressure, psig	Comments
1	Shotcrete	1.50" tip ID, Insert 1	225	4400	100	<10	Poor spray. large chunks
2	Shotcrete	1.50" tip ID, Insert 1	225	6600	150	<10	Better spray. smaller chunks
3	Shotcrete	1.50" tip ID, Insert 1	225	8800	200	<10	Improved spray. particles too large
4	Shotcrete	1.50" tip ID, Insert 2	225	8800	200	<10	No improvement from modified insert
5	Shotcrete	1.50" tip ID, Insert 2	225	11000	250	13	Wider spray angle. smaller particles
6	Shotcrete	1.50" tip ID, Insert 2	225	13300	300	17	
7	Shotcrete	1.50" tip ID, Insert 2	225	15500	350	20	Better distribution within spray cone
8	Shotcrete	1.50" tip ID, Insert 1	225	15500	350	20	Slight reduction in spray angle
9	Shotcrete	1.50" tip ID, Insert 1	120	15500	350		Less dense spray cone, wider angle
10	Shotcrete	0.96" tip ID, Insert 2	250	6300	350	45	Narrower spray cone, particles < 1/4"

Continued. . .

Table 17. Sludge Nozzle Test Conditions and Results (continued)

Test No.	Nozzle	Nozzle Configuration	Sludge Rate, lb/min	Air Rate, acfh	Velocity, ft/sec	Gauge Pressure, psig	Comments
12	Shotcrete	0.96" tip ID, Insert 2	250	8100	450	45	Poor camera view
13	Shotcrete	0.96" tip ID, Insert 2	250	3600	200	30	Sludge initially out as stream
14	Shotcrete	0.96" tip ID, Insert 2	250	3600	200		
15	Shotcrete	0.96" tip ID, Insert 2	250	1800	100		Same as 13, poor particle dispersion
16	Shotcrete	0.96" tip ID, Insert 2	250	5400	300	35	Similar to test 10
17	Shotcrete	0.96" tip ID, Insert 2	340	5400	300	50	Spray concentrated in middle of cone
18	Shotcrete	0.96" tip ID, Insert 2	340	7200	400		Good dispersion, better than 17
19	Shotcrete	0.96" tip ID, Insert 2	340	9000	500	65	Best spray cone, smallest particles
20	Shotcrete	0.96" tip ID, Insert 2	280	5400	300	35	Spray concentrated in middle of cone

Continued. . .

Table 17. Sludge Nozzle Test Conditions and Results (continued)

Test No.	Nozzle	Nozzle Configuration	Sludge Rate, lb/min	Air Rate, acfh	Velocity, ft/sec	Gauge Pressure, psig	Comments
21	EERC-1	0.18" annular gap	340	4400	130	25	Better dispersion, smaller particles than most shotcrete tests, ~ 0.20" particles
22	EERC-1	0.18" annular gap	340	6600	195	35	Finer particles (<0.20"), even distribution
23	EERC-1	0.25" annular gap	340	4400	95	10	Coarser spray, >0.25"
24	EERC-1	0.25" annular gap	340	6600	140	20	Slight reduction in particle size, worse than 21
25	EERC-1	0.18" annular gap	490	6600	195	45	Slightly better than 21
26	EERC-1	0.18" annular gap	490	4400	130		Coarser spray, comparable to 21
27	EERC-1	0.18" annular gap	575	6600	195	50	Slightly better than 21
28	EERC-1	0.18" annular gap	575	4400	130	40	Coarser spray, nozzle obstructions
29	EERC-1	0.18" annular gap	575	8800	255		Finest spray of first 29 tests, approaching 0.10"
30	EERC-2	0.125" annular gap	700	4400		100	Out as streams at start of stroke, smallest particles of first 30 tests, ~0.10"

Continued. . .

Table 17. Sludge Nozzle Test Conditions and Results (continued)

Test No.	Nozzle	Nozzle Configuration	Sludge Rate, lb/min	Air Rate, acfh	Velocity, ft/sec	Gauge Pressure, psig	Comments
31	EERC-2	0.125" annular gap	700	5200		85	Better spray, equally small particles
32	EERC-2	0.125" annular gap	700	5100		100	Comparable to previous two tests
33	EERC-2	0.18" annular gap	695	4400	130	45	Finer particles than 21, 26 and 28; 0.20" and less
34	EERC-2	0.18" annular gap	790	4400	130	56	Distinctly finer particles than 33; 0.10" to 0.20"
35	EERC-2	0.18" annular gap	850	4400	130	60	Comparable to 34
36	EERC-2	0.18" annular gap	850	2200	65	43	Poor distribution; starts as stream; not enough gas
37	EERC-2	0.18" annular gap	850	3300	98	45	Comparable to better than 33
38	EERC-2	0.22" annular gap	695	4400	123	35	Coarser particles, 0.20"
39	EERC-2	0.22" annular gap	850	4400	123	35	Comparable to 38
40	EERC-2	0.22" annular gap	695	3300	92	29	Poorer distribution, coarser particles than 38
41	EERC-2	0.22" annular gap	850	3300	92	29	Slightly better distribution but similar particle size to 40, 0.20 to 0.25"

The control and volume rate measurement of dispersion gas, for all tests air was used, was achieved by utilizing equipment from the TRDU gasifier at the EERC. A Baumann valve provided flow rate control with volume rate measurement provided by a Roots positive-displacement meter. The master computer for the TRDU was utilized to monitor flow rate and allow setpoint changes to the dispersion gas flow rate. The dispersion gas pressure at the nozzle was monitored using an analog gauge.

To perform a test, the tip of the respective sludge dispersion nozzle was positioned, as previously described, with respect to the containment shroud and the twin-screw feeder hopper. The dispersion gas flow rate was started and a setpoint entered into the control computer. The twin-screw feeder was started first and then the sludge pump. All tests were recorded using a Hi8 camcorder to allow comparative review of the tests. As the learning curve progressed, an attempt was made to capture images of the nozzle spray patterns at different angles.

Tests 1 to 20 were conducted with the Shotcrete Technologies nozzle. Tests with this system were less than encouraging. This nozzle produced a narrow, concentrated spray with a diverging cone angle estimated at about 12°. The first nine tests utilized the unmodified nozzle with a tip opening of 38.1 mm (1.5 inch) and the original gas–sludge mixing insert (Insert 1) as shown in Figure 26. The insert formed an annular region within the nozzle body. All gas entering the nozzle passed through holes located on the exterior ring of the insert. The holes were machined into the ring at an angle to impart a swirling action during contact with the sludge as it entered the nozzle through the center of the insert. Tests 4 to 7 were performed with a modified insert (Insert 2) as shown in Figure 27. This insert was modified by adding a number of holes along the insert wall and by adding a ring at the end of the insert to force the gas through the holes. The presumption was that this would allow earlier and more intense mixing of the dispersion gas with the sludge to produce smaller particles. There was no observed improvement to the sludge particle size or spray pattern. These initial tests with the shotcrete nozzle indicated that the dispersion gas- to-sludge ratios would be significantly above that available at Wabash River.

A more productive improvement to the shotcrete nozzle included the insertion of a cylindrical plug with a 24.4-mm (0.96-inch)-ID, shown in Figure 28, into the end of the nozzle. This plug resulted in a nearly 60% reduction of the cross-sectional area of the tip. The plug, while producing a narrower spray pattern, was effective at producing particles with sizes even better than those achieved with the 38.1-mm (1.5-inch) opening. This was accomplished at lower dispersion gas-to-sludge ratios. However, the dispersion gas-to-sludge ratios were still too high. There was no attempt to test an tip insert with a even smaller ID.

Tests 21 to 29 with the EERC-1 nozzle immediately followed the shotcrete nozzle testing. Based on the first test, this nozzle concept immediately appeared to be a better approach than the shotcrete nozzle. This improvement (reduction in particle size) was presumed to result from the more efficient degradation of the sludge stream as it was essentially extruded through the annulus around the dispersion cone. This was accomplished even though the cross-sectional area of the EERC-1 nozzle opening at 4.57 mm (0.18 inch) was almost 80% larger than the shotcrete nozzle using the 24.4-mm (0.96-inch) tip insert. Tests 23 and 24 showed that increasing the gap size to 6.35 mm (0.25 inch) resulted in an increase in particle size. Test 28, conducted at a dispersion gas-to-sludge

EERC MM21079.PCX

Figure 26. Mixing-Insert 1 for shotcrete nozzle body.

EERC MM21080.PCX

Figure 27. Mixing-Insert 2 for shotcrete nozzle body.

EERC MM21081.PCX


NOV 25 2002

Figure 28. Plug inserted into tip of shotcrete nozzle.

ratio 21% higher than desired, produced particles around 5.1 mm (0.20 inch) with significant reduction in particle size down to about 2.5 mm (0.10 inch) after doubling the dispersion gas rate in Test 29. Although the results of the last few tests of the series showed significant promise and would be achievable with recycle syngas resources available at Wabash River, the dispersion gas-to-sludge ratios were still higher than desired by Global Energy.

Consequently, the Schwing sludge pump system was leased for a second time after producing the, hopefully, more improved EERC-2 nozzle. The purpose of the last round of tests (30 to 41) were to evaluate the new nozzle at dispersion gas-to-sludge ratios near the maximum desired by Global Energy. In this round of tests, the highest sludge pumping rates were achieved, with rates ranging from 316 to 386 kg/min (695 to 850 lb/min), the latter value essentially being a maximum for the leased pump. As with tests with the EERC-1 nozzle, reductions in sludge particle size were attained by decreasing annular gap size and by increasing dispersion gas rate. It also appeared that, for a fixed dispersion gas rate, increasing sludge mass rate (over a small range) also decreased particle size.

In the first three tests with the EERC-2 nozzle, with a nozzle gap of 3.2 mm (0.125 inches), the smallest particles (approximately 2.5 mm [0.10 inch]) of all tests were produced. However, the concurrent effect was an increase in sludge dispersion gas pressure to 0.69 MPa (100 psig), the highest of all tests. Another positive development observed in tests with the EERC-2 nozzle was that at equivalent gap sizes (e.g., 4.6 mm [0.18 inches]) relative to tests with the EERC-1 nozzle, particle sizes achieved with the improved nozzle were comparable even at sludge mass rates twice these previously tested. For example, in Test 33 with the EERC-2 nozzle, the observed particle sizes were smaller than those achieved in Test 21 with the EERC-1 nozzle. Also, in Test 37, again conducted