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The Use of Ultra High Pressure Water for Installation of Instrumentation in "Assumed" Leaker Tanks

G. T. Dukelow
N. A. Hertelendy

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Westinghouse
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THE USE OF ULTRA HIGH PRESSURE WATER FOR INSTALLATION OF INSTRUMENTATION IN "ASSUMED" LEAKER TANKS

G. T. Dukelow, N. A. Hertelendy

ABSTRACT

In most cases, inserting instrumentation or other equipment into waste storage tanks at the Hanford Site usually requires the penetration of a hard saltcake, which can be 6.10 meters (20 feet) thick. For the Hanford Site tanks containing ferrocyanide, additional thermocouple trees were required to enhance safety. Historically instrumentation was installed in Hanford Site tanks using the water sluicing technique, which requires large volumes of water. Because some of the ferrocyanide tanks had leaked in the past, there was concern over the volume of water normally used to install the thermocouple trees. Any technique used to install instrumentation must be successful, because retrieving instruments is very difficult. The instruments would require decontamination, placement into a shielded container, and handling as radioactive mixed waste.

Until now, high volume water lancing has been the only method used by the Westinghouse Hanford Company to install instrumentation and other equipment into a saltcake type of waste. Water lancing uses 38 to 82°C (100 to 180°F) water at 620 to 1,034 kPa (gage) (90 to 150 psig) to bore the installation hole. Water lancing actually dissolves and erodes, rather than cuts, the saltcake. Dissolution/erosion is simple and effective but very inefficient, using 750 to 5,680 liters (200 to 1,500 gallons) of water per installation (depending on the hardness and solubility of the saltcake). The water becomes additional waste; and, when added to tanks that have leaked in the past, increases the quantity of liquid waste that could potentially leak to the ground. Of the 24 ferrocyanide tanks, 13 tanks have leaked in the past (these are assumed leakers).

To reduce the amount of water added to the suspected leaker tanks, a technique using ultra high pressure water, using pressures up to 259,000 kPa (gage) (37,500 psig), was developed to install thermocouple trees. The technique will enable the use of water to be decreased by up to a factor of 30, thereby reducing the potential for leaks. Although the final design is specifically to install thermocouple trees, this concept also can be used for installation of many other types of equipment into waste storage tanks.

DESIGN

Ultra High pressure Water Supply

Ultra High pressure Water (UHPW) is generated by a high pressure intensifier. An intensifier unit that was onsite was used for testing, and will be refurbished before use for installing thermocouple (TC) trees into tanks. This unit is powered by a 50-horsepower air-cooled diesel engine driving a large volume hydraulic pump. The hydraulic pump in turn drives the low pressure side (large volume side) of the intensifier. The high pressure side (low volume side) is the water side, which is fed by a low pressure feed pump. The water pressure is amplified by the ratio of the low pressure piston's surface area to the high pressure piston's surface area, which is roughly 12.5:1 for the unit used. The two intensifiers on this unit operate 180° out of phase (i.e., when one is in the intake cycle, the other is in the discharge cycle). The output is fed to a large high pressure accumulator to smooth the pulsating flow. The water pump's output is large enough to cool the hydraulic fluid, which is heated by operation of the pump. This extra water, normally dumped on the ground, will be returned to a tank located on the bottom of the intensifier trailer. The coolant flow rate is regulated by a temperature controlled bypass flow regulator, which senses the oil discharge temperature from the heat exchanger and varies the intensifier feed pressure by varying the back pressure. If the hydraulic system temperature rises too high due to some off normal condition, the flow regulator can open high enough to drop the intensifier feed pressure to the "insufficient water flow" cutoff point, thus shutting the system down. (A planned intensifier upgrade includes the replacement of the heat exchanger with a larger capacity unit to eliminate this problem.)

The diesel engine, once started, is operated by a "governor" which maintains a constant, preselected engine speed. Pump output water is normally pumped through the bypass valve back to the hydraulic tank. When the bypass valve is wide open, the output pressure is sufficient to drive the intensifier at an output pressure of 38,000 kPa (gage) (5,500 psig). Once the engine is warmed up, the operator throttles the hydraulic bypass flow which in turn increases the hydraulic output pressure. The maximum intensifier pressure, which is 259,000 kPa (gage) (37,500 psig) for this unit, is obtained when the bypass is completely closed.

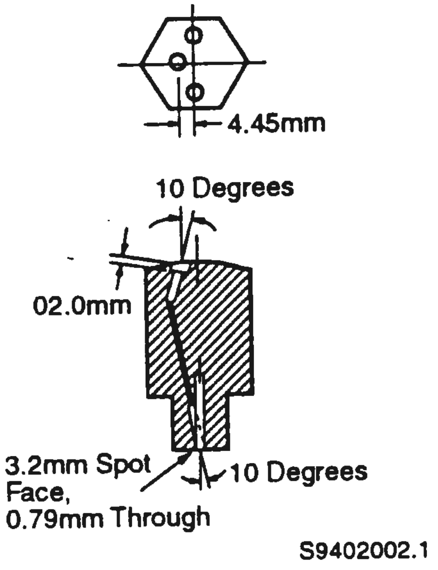
Design Operating Principle

The UHPW is discharged through a very small orifice, typically 0.10 to 0.46 millimeters (0.004 to 0.018 inches) in diameter, at supersonic velocity. At impact, the water causes the material to spall, fracturing the material, and the solids are blown out of the stream's way. A very small fraction of the material is dissolved as the kerf (cuttings) is carried away by the water. A stationary stream of water bores a hole slightly larger in diameter than the ejecting orifice diameter (roughly 0.25 to 0.30 millimeters [0.010 to 0.012 inches] for a 0.20-millimeter- [0.008-inch-] diameter orifice), because the water tends to "crater," i.e., "cone." (The splash-back creates the cone-shaped crater in hard/tough material.) If the stream is moved linearly, a narrow cut (roughly 0.25 to 0.30 millimeters [0.010 to 0.012 inches] for a 0.20-millimeter- [0.008-inch-] diameter orifice) is made. The depth of the cut depends on the material being cut, and the depth is directly proportional to the speed at which the stream is being moved relative to the material being cut. Because of this, the steel tank bottom is not damaged as long as the bore head is rotated (i.e., moved), although the tank waste (being softer) is being cut (a hole is being bored). It is impossible to define a "linear cutting rate" without comprehensive testing in the particular media. The bore head cuts slices of waste in circular but slanted paths that intersect, thus chopping up the sliced waste into kerf of manageable size.

Design Configurations

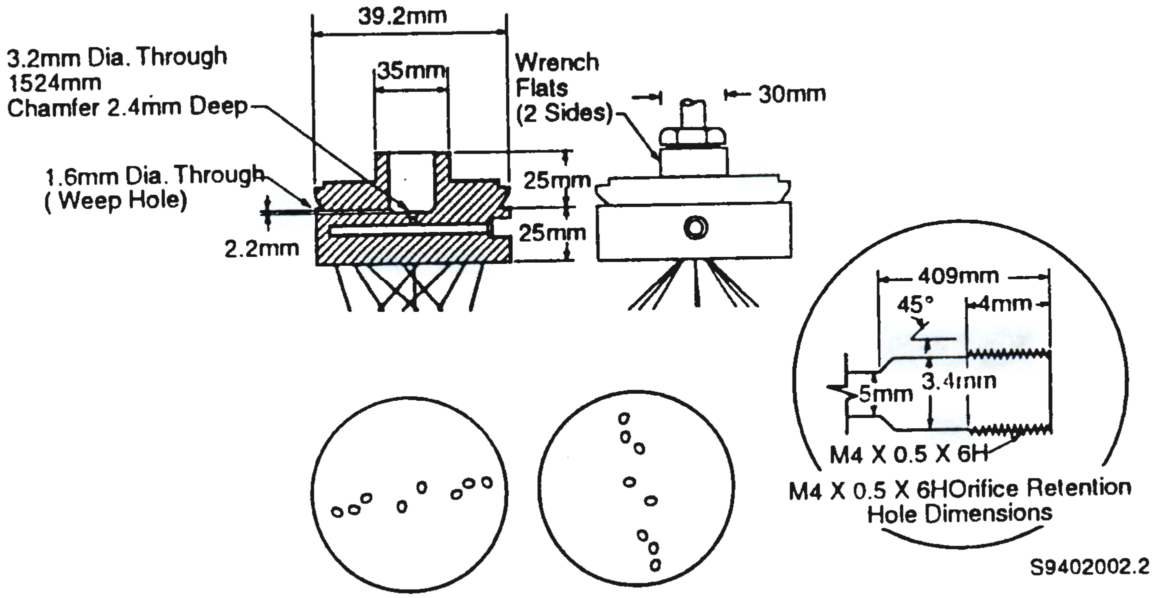
For the evaluation of the basic bore head concept, a commercially available "45° two orifice scarifying" head was modified. The UHPW 45° scarifying head is a 38-millimeter (1½-inch) hex shaped device equipped with two orifice receptacles on 25-millimeter (1-inch) centers that are canted outward from the center at 45½°, diametrically opposite from one another. This head attached to the scarifying rotator provides a "45° cone-shaped" spray. The head was generally rotated by a hydraulically driven motor at about 30 r/min (30 rpm.) This head was modified by the addition of a third orifice 90° from the existing orifices and canted inward at 10° (Fig. 1). The 10° and the exact location of the third orifice were dictated by the room available in the existing manifold in the bore head. Thus it was not considered an optimum layout. Each orifice was a 0.33-millimeter (0.013-inch) sapphire which was "reverse oriented." The sapphire orifices are precision machined to have a sharp edge inlet and at half thickness there is a 45° diverging section. This causes the stream to start diverging shortly past the nozzle. According to the manufacturer, Quest Integrated, this orientation gives better results for the simulated saltcake material in this application.

Figure 1. Standard Scarifying Head.



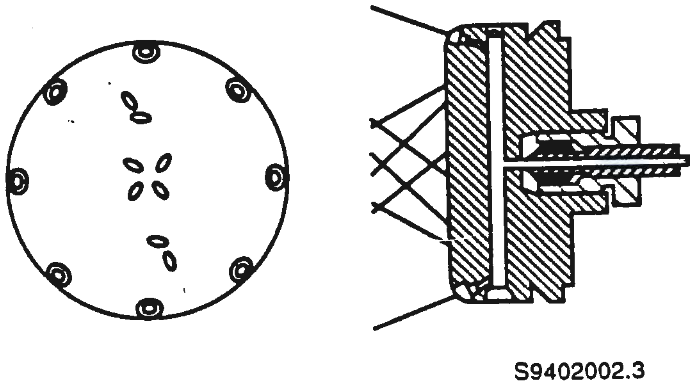
Based on the data and experience gained from the three orifice bore head tests, an eight orifice bore head was designed to bore a 88-millimeter- (3½-inch-) diameter hole. Several eight nozzle pattern designs were tested to find an efficient pattern that would cut a relatively small kerf with minimum rotation. The nozzles must be oriented in some pattern to ensure that all material contained within the desired diameter is cut loose or the bore head will bottom out on uncut waste. The small kerf is necessary so it can readily pass by the bore head body without jamming. The eight orifice pattern design with 0.2-millimeter- (0.008-inch-) orifice diameters was selected for testing (Fig. 2). This design was used throughout the evaluation program. Hand rotation was used throughout the testing in lieu of the hydraulically driven system. Hand rotation was necessary because a rotating shaft on the TC tree would have added unnecessary complexity to the design.

Figure 2. High Pressure Water Bore Head.



The final design was derived from this pattern and was optimized by the vendor, Quest Integrated, who tested two 16 orifice designs as well. The final design is a 16 orifice pattern comprising eight 0.20-millimeter- (0.008-inch-) diametrical orifices and eight 0.15-millimeter- (0.006-inch-) peripheral orifices (Fig. 3) (Appendix A, pages A-1 and A-2). A problem in the initial design was that the head had to be lowered very slowly through the simulant or ledges would form causing the head to divert off at an angle, and the instrument would not be installed vertically. The addition of the eight peripheral orifices eliminated the vertical feed rate sensitivity of the original bore head.

Figure 3. Nozzle Body.



TESTING

Vendor Supplied Single Orifice Head

For the initial tests, a small vendor-supplied single orifice cutting head attached to a hand-held rotating wand was tested using KMAG™[1], a commercial fertilizer that is widely used at the Hanford Site as a waste simulant. It immediately became obvious that UHPW does not work on the same principle as sluicing. The UHPW jet stream, when left stationary, bored a deep hole slightly larger in diameter than the stream diameter; traditional sluicing dissolves the material and creates a hole diameter that is several times greater than the stream diameter (seven to eight times greater during TC installation). A slowly moving UHPW stream cut, like a very sharp knife, a narrow (estimated 0.33 to 0.51 millimeters [0.012 to 0.020 inches]) slit in the KMAG simulant.

Vendor Supplied Two Orifice Head

A 28-millimeter- (1 1/8-inch-) diameter scarifying head with two 0.38-millimeter- (0.013-inch-) diameter orifices was attached to a hand-held wand and tested. This configuration basically carved out a cone shaped groove; tilting and moving the head did not produce a concentric hole.

This head was modified by the addition of a third orifice 90° from the existing orifices and canted inward at 10°. Water pressure of 37,000 psig, producing an exit velocity of 3,100 ft/s (3,100 fps) at 2.4 gal/min (2.4 gpm), produced a 50.8-millimeter- (2-inch-) diameter hole. Gravity caused the bore head to drift downward in the initial horizontal tests causing some binding. The binding was later corrected by vertical boring, and bore rates also increased. Even these horizontal tests demonstrated that cutting is much faster and uses less water than sluicing. The water temperature is of no real significance, although the water exit temperature of 71°C (160°F) is created by the high pressure. A penetration rate of 8 ft/min at a flow rate of 2.2 gal/min. (2.2 gpm) was experienced. This resulted in approximately 0.95 liters (0.25 gallons) of water per foot of penetration or a volume of about 5 gallons of water to penetrate 6.10 meters (20 feet) of simulated waste (KMAG) with a 50.8-millimeter (2-inch) bore.

During these tests the intensifier output pressure was calculated from the hydraulic pressure gauge on the operating panel. This hydraulic gauge on the oil side is a 50.8-millimeter (2-inch), 0 to 21,000 kPa (gage) (0 to 3,000 psi) gauge that has not been calibrated. A ± 15% error is feasible. As proven later in the test series, a pressure variation of ± 28,000 kPa (gage) (4,000 psi) above 138,000 kPa (gage) (20,000 psig) output pressure does little to the bore head's performance.

Multiple Orifice Bore Head Tests

Three full-scale boring heads have been tested. Before these tests, an uncalibrated 0 to 345,000 kPa (gage) (0 to 50,000 psig) range pressure gauge was installed downstream of the UHP accumulator. During the first test with

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[1] KMAG is a trademark of Duval.

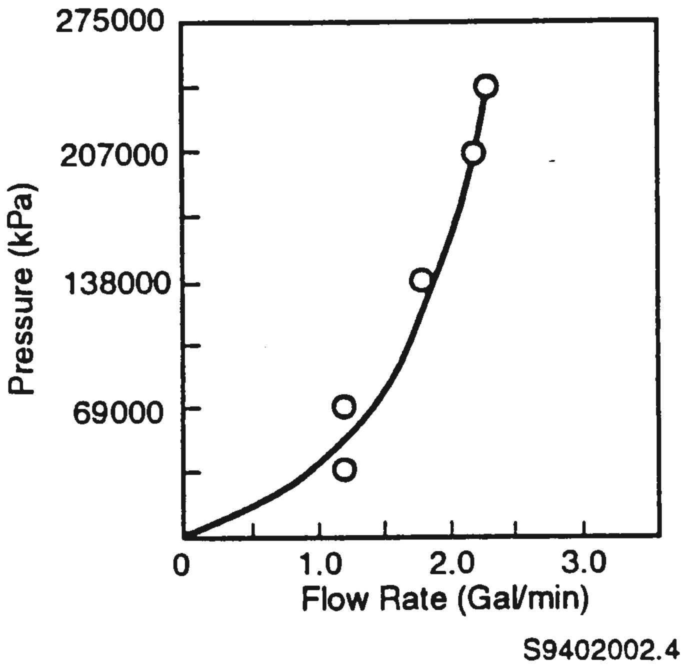
this gauge, a spot check verified the pressure reading against the calculated one. The pressure calculated from the hydraulic side matched the indicated pressure within 3.5 to 4.5 percent.

Testing of the first two heads proved the eight nozzle pattern to be very efficient with the exception of the 13-millimeter- (½-inch-) thick ring at the periphery. The bore head would hang up on the ledge if the bore head were allowed to come in contact with the waste. To avoid hanging up on the ledge, it was necessary to control the vertical feed rate very carefully.

The design was further modified by the vendor, QUEST Integrated, by adding eight 0.15-millimeter (0.006-inch) orifices around the bore head's periphery (Fig. 3). The addition of the peripheral orifices eliminated the 'ledge' and its associated problems. Holes up to 4.6 meters (15 feet) deep were bored in extremely hard simulated waste (KMAG). The bore head worked very well and, unlike the bore head without peripheral orifices, careful vertical feed was not required. A 4.6-meter (15-foot) deep, 114-millimeter- (4½-inch-) diameter hole was bored into very hard KMAG to demonstrate the abilities of this bore head configuration.

During the test program, the flow rates were calculated using charts supplied by the vendor (Quest Integrated). However, as part of the performance evaluation tests of the final 16 orifice bore head, the bore head was flow calibrated. The results are shown in Fig. 4.

Figure 4. Calibrated Flow Rate of 16 Orifice Bore Head.



Potential Damage to Tank Bottom

To address concerns of the possible effects of the high pressure water damaging the carbon steel bottom of the tank, the effects of UHPW on steel plate were evaluated. This test series was designed to demonstrate that safe operation is feasible inside a waste tank by using proper procedures and controls to avoid any damage to the tank.

Data from the test setup shown in Fig. 5 and 6 are plotted in Fig. 7 through 9. These three graphs summarize the test series. Each test was conducted using eight 0.20-millimeter- (0.008-inch-) diameter orifices aimed at the test specimen at 45°. Each data point represents the maximum (worst) penetration damage. None of the tests created eight uniform damage depths; they all varied widely. The variation can be caused by many local and variable phenomenon such as partial local plugging of the orifice or test specimen rotation caused by the water stream. In each case, the deepest (worst) hole was used as the representative damage to create these plots. These data are representative of the damage caused by the actual temperature tree bore head, without the peripheral orifices.

Figure 5. Damage Potential Test Set Up (Tests 1 Through 5).

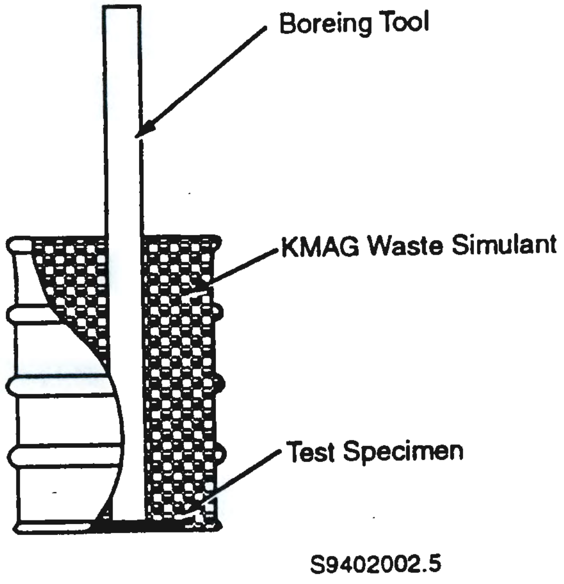


Figure 6. Damage Potential Test Set Up (Tests 6 Through 22).

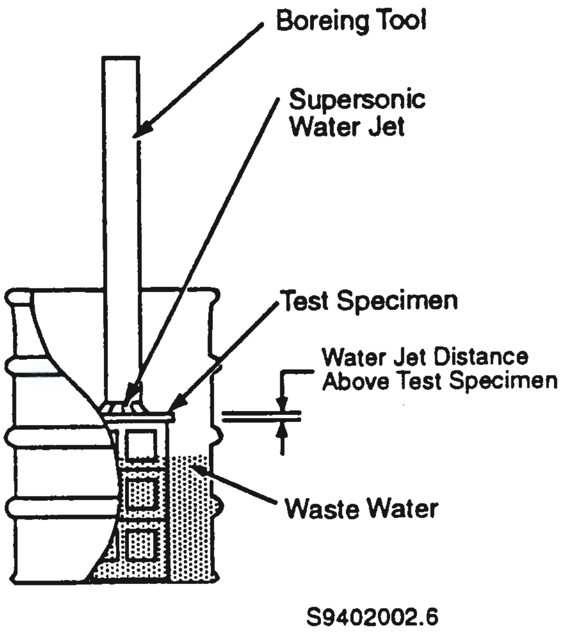


Figure 7. Damage Versus Time of Exposure.

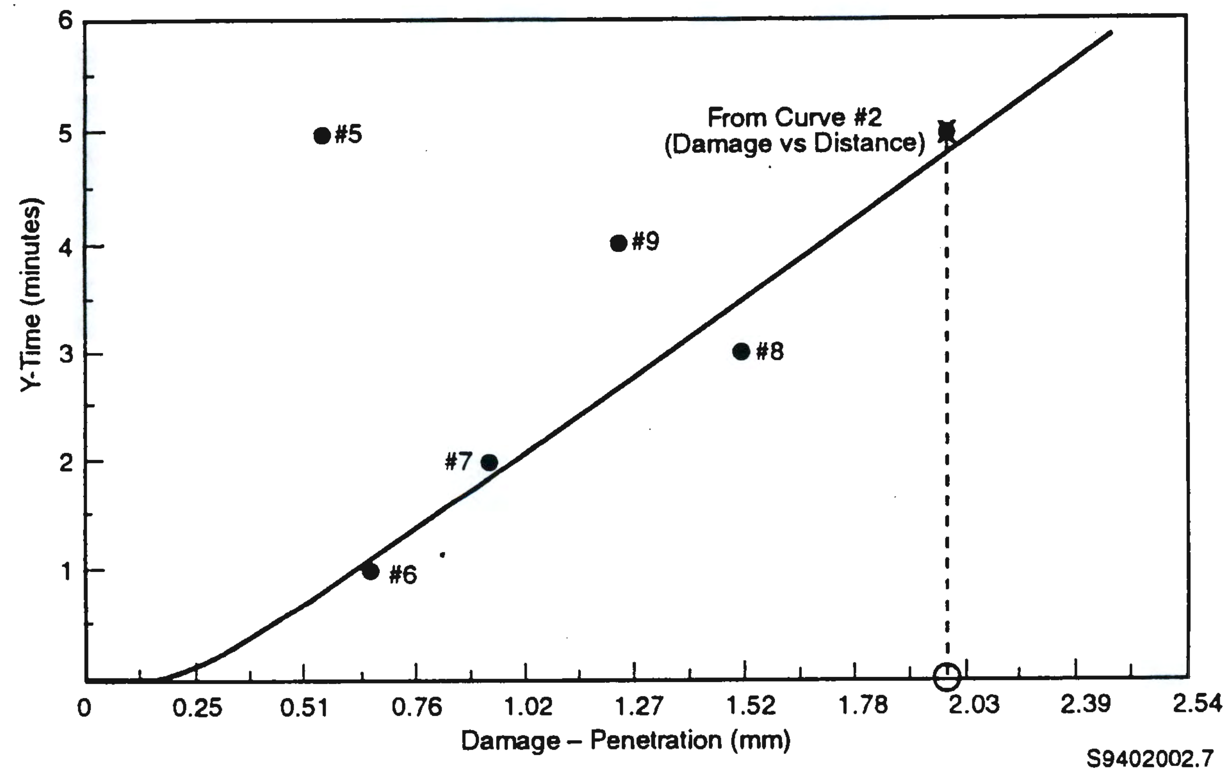


Figure 8. Damage Versus Distance of Jet.

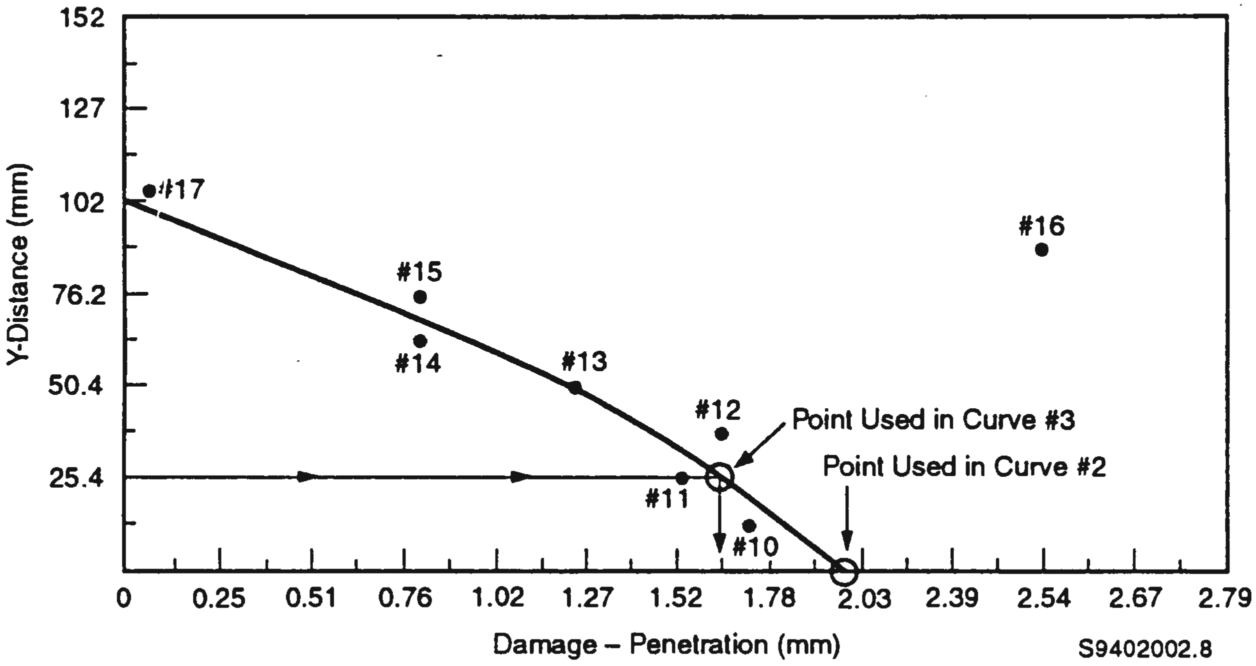


Figure 9. Damage Versus Nozzle Discharge Pressure.

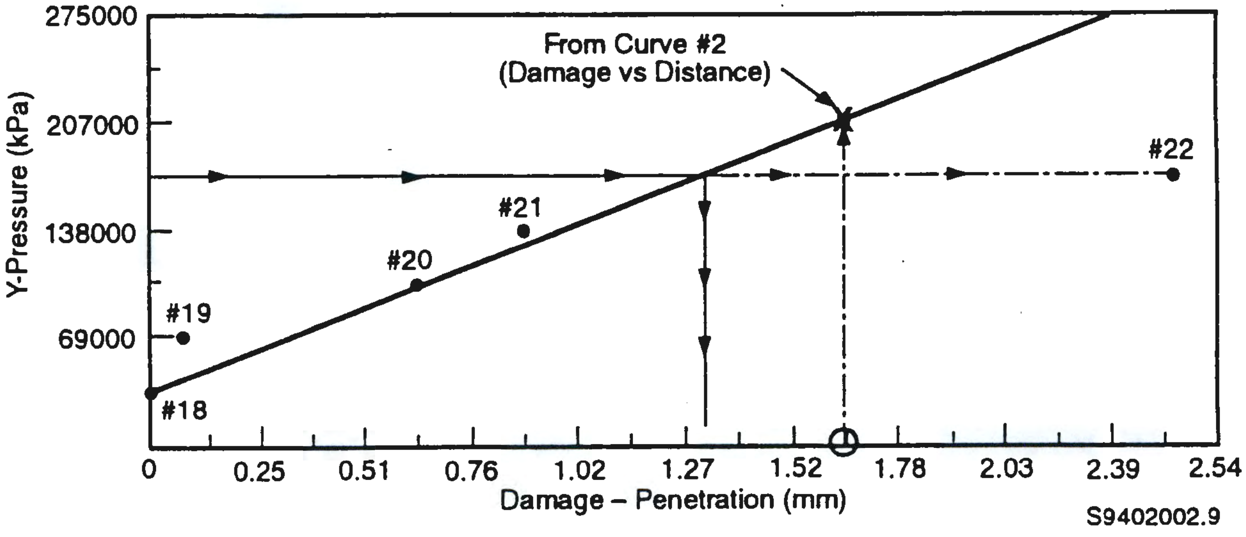


Figure 7 represents the damage caused by the water jet while the bore head is stationary and in full contact with the test specimen for various durations; hence, "Time vs. Damage" in Fig. 7. Four of the five data points were used to generate this curve, while the fifth was thrown out as a "bad point." The curve (and thus the data) was checked by a common point with Fig. 8 (Distance of Jet vs. Damage), and found to be in agreement. As the curve shows, the damage rate is very high during the first 5 to 6 seconds, tapering off to a constant rate. The explanation is that at initial contact, all the jet's energy is expanded to dislodge the metal. As the hole (damage) grows, some of the water back-scatters and interferes with the free jet, thereby reducing its effectiveness, i.e., damage rate. After a certain penetration, the energy loss caused by back-scatter becomes constant; thus, the damage rate versus time becomes linear.

Fig. 8 was generated from data obtained by operating the stationary bore head at 207,000 kPa (gage) (30,000 psig) pressure for five minutes at different jet distances from the test specimens. The specimens were in air (as opposed to being underwater) for the worst case, because the energy of the jet is not as quickly dissipated in air as underwater. Again, below the jet,a distance of 50.8 millimeters (2 inches) from the surface, the graph has a slight curvature, non-linearly decreasing the effective rate. This is also due to the water back-scatter.

Fig. 9 is a study of the effect of nozzle feed pressure on the damage. During these tests the water jet was held 2.5 millimeters (1 inch) from the surface for a 5-minute duration (exposure) at each of the pressures. Pressures from 38,000 (the minimum attainable with the intensifier) to 207,000 kPa (gage) (5,500 to 30,000 psig) were explored. The 207,000 kPa (gage) (30,000 psig) data were thrown out because the plate became submerged during the test. Test specimen #22 (at 172,000 kPa [gage] [25,000 psig]) was also discounted as a "bad data point," because it also does not agree with the rest of the data. Again, a point at 207,000 kPa (gage) (30,000 psig) was taken from Fig. 9, and it is in complete agreement with the other data when cross-plotting the results. At 38,000 kPa (gage) (5,500 psig), the test specimen was cleaned of dirt and grease, but the mill-scale was not removed, and **no damage occurred.**

Five tests were conducted with the bore head in contact with the test specimens. The bore head was rotated ± 45°; the nozzle inlet pressure was 255,000 kPa (gage) (37,000 psig); and the exposure rate varied in 1-minute intervals from 1 to 5 minutes. **None produced any damage**, other than scratching caused by the bore head rubbing against the specimen.

Based on these tests, and as a conservative operation, the bore pressure will be reduced to 34,000 kPa (gage) (5,000 psig), ± 4,100 kPa (gage) (± 600 psig), when the bore head reaches the distance of 305 millimeters (12 inches) above the calculated bottom. This will ensure that no damage will occur to the tank. The 305-millimeter (12-inch) distance is based on the assumption that the maximum error in the tank depth due to buckling of the bottom does not exceed 152 millimeters (6 inches), and the tests show that at 102 millimeters (4 inches) the stationary 241,000 kPa (gage) (35,000 psig) water jets cause no damage to steel. This leaves an additional 50.8 millimeters (2 inches) as a safety buffer. To provide additional assurance, bore head rotation will be maintained as long as there is water flow.

SAFETY

A safety analysis of a sudden shearing of the UHP hose was conducted and concluded that for a worker to receive an injury from the sudden release of stored energy, the worker's exposed body part must be no further than 15 millimeters (0.6 inches) from the severed hose. Because water is not compressible, the UHP would be relieved in 4.76 microseconds. Thereafter, water would flow out the open end at 35 ft/min and would not injure a properly attired person. Further, the rotation of the TC tree will be translated to a slight bending of the hose as it hangs in a loop, and will pose no threat from fatigue failure. The hose is rated for 5,000,000 flexes into a 0.9-meter- (3-foot-) diameter. The maximum flexing expected from TC tree insertion is about 600 bends into a 3-meter (10-foot) diameter.

CONCLUSIONS

Based on the test results, the UHPW installation method is found to be an effective, efficient, and safe instrumentation installation method that will result in less than 946 liters (250 gallons) of water being added to assumed leaker tanks. This method can be implemented with relatively minor changes to the TC tree design. This method will provide an additional benefit in that the bottom TC can be placed within approximately 6 millimeters (¼ inch) of the bottom of the TC tree.

The results indicate that penetration rates of 0.40 ft/min to 1.33 ft/min, using water at a rate of 8.71 to 22.0 liters (2.3 to 5.8 gallons) of water per foot of penetration, can be achieved. This in turn equates to a total of about 174 to 439 liters (46 to 116 gallons) of water for penetrating

6 meters (20 feet) of even the hardest solidified waste that normally would require 3,800 liters (1,000 gallons) or more. Based on the results of these tests, the operating procedure will require that as the TC tree approaches 30.5 meters (12 inches) of the calculated tank bottom, the intensifier pressure will be reduced to 38,000 kPa (gage) (5,500 psig) (by opening the hydraulic bypass valve), and rotation will continue until the UHPW is turned off after reaching the bottom of the tank or the desired vertical position.

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