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Paper

REFRACTORY REMOVAL BY HIGH PRESSURE WATERJET

D. Wright
StoneAge, Inc.
Durango, Colorado, U.S.A.

ABSTRACT

The removal of refractory from lines and vessels in the petrochemical industry is necessary for inspection, repair, maintenance, and replacement. The small spaces and difficulty of access have otherwise limited the methods of removal to manual labor with handheld chipping hammers. This allows only the limited power and force that an individual can support, while exposing these workers to the hazards of silica dust, extreme noise, vibration, and physically exhausting labor in a confined space.

Refractory materials can be safely removed through the proper application of high pressure waterjets and mechanization, from localized repairs to complete vessel cleaning. The use of high pressure water allows the transmission of hundreds of times the power of handheld chippers, with resulting refractory removal rates on the order of days to weeks faster than manual methods. This paper presents the results of multiple tests to define the key operating parameters for the successful removal of several refractory types with high pressure water, the possible rates of removal, and other considerations necessary for the successful execution of field work.

1. INTRODUCTION

Refractory materials are installed in vessels, boilers and process lines to provide insulation and erosion resistance. The primary components are alumina and silica, and the lining may be cast in place, gunned or manually applied. Some refractory also contains steel needles. The refractory is held in place by welded anchors or a steel hex mesh welded to the vessel wall. Dual layer installations consist of a thick layer cast in place, topped by a layer of hex mesh refractory. The analysis and results presented in this paper were obtained by testing a Type 1 cast refractory with needles, RS-17E cast refractory with needles, and AA-22 refractory in hex mesh.

Refractory linings may need to be removed for replacement, inspection or repair. Manual chipping is still commonly practiced, with the only other alternative being replacement of the entire vessel or line. The removal of refractory by high pressure waterjet has been proven to be more than ten times faster than manual chipping, resulting in the elimination of over 500 hours of worker exposure to silica dust, noise, and vibration within a confined space on a typical refractory replacement. The mechanical properties of refractory materials lend themselves to penetration by high pressure waterjets, even more so after being in service, due to fractures and weaknesses that develop in the material. In every case, the sample refractory materials provided for testing were more difficult to remove than the actual in-situ refractory.

The application of water for the suppression of silica is a well known control, dating to the early use of pneumatic rock drills in underground mining. These drilling operations were performed dry, with operators breathing the dust produced. This resulted in an average life expectancy of 4 years for the miners due to silicosis, leading to the “widow maker” name for these first drills. The addition of water through the drill steel to the bit completely eliminated the dust, and saved many lives going forward.

The waterjet equipment employed is relatively lightweight, permitting use in small spaces, yet capable of applying 750 kW (1000 hp) of water power. Confined space entry is often required to install the equipment, but once installed the operation can be controlled from outside of the vessel.

This paper presents the important operating parameters for refractory removal, including effective pressures, flow rates and standoff distances. Based on the results presented, estimated rates of removal can be derived for planning purposes.

2. COMPARISON OF MANUAL CHIPPING TO WATERJET REMOVAL

A demonstration of manual chipping with a 7 kg (15 lb) pneumatic hammer was conducted in Type 1 refractory, 127 mm (5 in) thickness, installed within a 1020 mm (40 in) diameter section. The operator of the hammer worked for 1 hour, within a square of 305 mm (1 ft^2). The result was an estimated removal rate of .003 m^3 (.1 ft^3) per hour, illustrated in Figure 1.

Figure 2 shows the effect of 1 hour with high pressure water, operating at 124 MPa (18,000 psi) and 276 lpm (73 gpm), resulting in a removal rate of .27 m^3 (9.5 ft^3) per hour. The waterjet removal rate was 100 times faster than manual chipping in this application.

3. SELECTION OF OPERATING PRESSURE AND FLOW RATE

The selections of operating pressure and flow rate are dependent on the refractory type, the expected standoff distance from the surface that can be achieved, the refractory thickness, the rate of production desired, and the type of equipment to be used.

The power of a waterjet is directly proportional to the pressure and the flow rate. For example, 138 MPa (20,000 psi) at 136 lpm (36 gpm) is the same power as 276 MPa (40,000 psi) at 68 lpm (18 gpm). However, the efficiency of removal is dependent on the material to be removed and the standoff distance of the jet orifice to the surface.

3.1 Optimization of Pressure

The operating pressure must meet the minimum effective pressure to remove the refractory. As with most other materials, the most efficient pressure is around 2 to 3 times the minimum effective pressure. Efficiency then begins to drop as pressure is increased above the optimum pressure. Therefore, to increase the removal rate, it is most effective to operate at the optimum pressure and increase the flow rate to apply more power.

For the pressure efficiency tests, the minimum effective pressure and optimum pressure varied with the refractory type. For the refractory types tested, the optimum pressure occurred between 103 and 138 MPa (15,000 and 20,000 psi). All tests were conducted with a single jet orifice, traversed across the refractory sample at a standoff distance between 76 and 102 mm (3 and 4 in.)

Figure 3 shows the results for pressure versus volume removed in Type 1 refractory, at two different powers. The next curve, for RS-17E refractory in Figure 4, is an average of results at three powers, 19, 38, and 75 kW (25, 50, 100 hp) and plotted as power unit per volume removed versus pressure. This was the lightest weight refractory tested, and the results show that the optimum pressure was accordingly lower. In related work performed with this refractory type present, it has been found that operating at a pressure below 55 MPa (8000 psi) reduced risk of damage to this refractory. Figure 5 presents the curve for AA-22 refractory in hex mesh, tested and expressed in the same fashion as the RS-17E material. Comparing AA-22 to RS-17E, the optimum pressure increased by about 35 MPa (5000 psi), but the power required to remove the same volume of material tripled.

Operating at a higher pressure than the optimum does allow a lower flow rate for the same power if water volume is an issue for work nearby, but removal rate will decrease for the same power, and standoff distances must be more tightly controlled, as the orifice sizes are smaller.

3.2 Standoff Distance

In addition to maintaining effective pressure, the other important parameter is keeping the waterjet orifice within an effective standoff distance range. This can be the most difficult and limiting factor to maintain, due to the complex geometries and access limitations in some vessels. The effective standoff distance is proportional to the orifice size, which determines the flow rate at a given pressure. If the conditions require a larger standoff distance or variations of standoff distance, a larger orifice size, and therefore more flow, is necessary. Even within a range that is effective, the rate of removal decreases rapidly with increasing standoff distance. The thickness of the refractory must also be accounted for within the effective standoff distance to achieve complete removal. To calculate the effective standoff distance with a given orifice size, multiply the orifice diameter by the effective standoff distance ratio.

In Type 1 refractory, the maximum effective standoff distance ratio was found to be 130 times the orifice size, when operating at 124 MPa (18,000 psi). However, when at a closer standoff distance ratio of 84 times the orifice size, the removal rate was more than two times faster. The efficiencies versus standoff distance are shown in Figure 6.

The maximum effective standoff distance ratio for AA-22 refractory was found to be 120 times the orifice size, operating at 124 MPa (18,000 psi). When the standoff distance was reduced to 90 times the orifice size, the efficiency of removal doubled.

Another test conducted in AA-22 refractory was the comparison of a 2-D rotating head to a 3-D rotating head, both operating at the same pressure and flow. The 2-D head maintained the jets perpendicular to the surface and at a constant standoff distance, while the 3-D head pattern spent only 30% of the time within the effective standoff distance range. The angle of impingement of the jets to the surface resulted in shadowing by the hex mesh, preventing complete removal of the refractory. In repair work, this 3-D shadowing results in partial removal in many cells as compared to a clean line of removal with a 2-D pattern, as illustrated in Figures 7 and 8. The 2-D tool was six times more efficient than the 3-D in refractory removal.

4. ESTIMATIONS OF REMOVAL RATE

The tests performed allow a calculation of specific energy required to remove a refractory, and this value can be used to estimate the time it will take to remove a given volume or surface area of material. These values assume operating near the optimum pressure and standoff distance; as was shown in Figure 6, the specific energy more than doubled with an increase in standoff distance.

Table 1 lists the values of specific energy by refractory type. The dual layer type was composed of AA-22 in hex mesh on top of Stellit FS70, shown in Figure 9. The steel hex mesh interferes with the jet, increasing the specific energy to remove the Stellit beneath.

To calculate the time it would take to remove a known volume of refractory, a flow rate must be selected. Using this flow rate and the operating pressure, the power of the system can be calculated. To calculate the estimated time for removal, multiply the known volume of refractory by the specific energy of the refractory type and divide by the power to be used. This shows that removal rate is directly proportional to power applied; it is possible to double the removal rate by doubling the power applied. An important practical consideration is minimizing pressure losses through the high pressure system with increasing flow rates.

5. PLANNING AND EXECUTION CONSIDERATIONS

There are other important considerations when planning refractory removal in field applications. The complex geometry of some internal structures may require a support system for the waterjet tooling to maintain effective standoff distances. Access locations and size of openings for tool installation, along with a means to hold the tooling in place, are necessary information. A plan of high pressure water pump location and hose rigging is needed to manage pressure loss, particularly with higher flow rates over long hose run distances.

The execution planning should allow for the time to obtain access and install the equipment; it is typical for the total time to take over twice the actual time the pumps are operating and refractory is being removed. If the hex mesh is sufficiently welded to the vessel wall, the waterjet will not damage it and it can be repacked. However, V-anchors typically get flattened against the wall by the impact of the jets. A plan should be in place for capturing and managing the spent water and refractory material as it is removed.

6. CONCLUSIONS

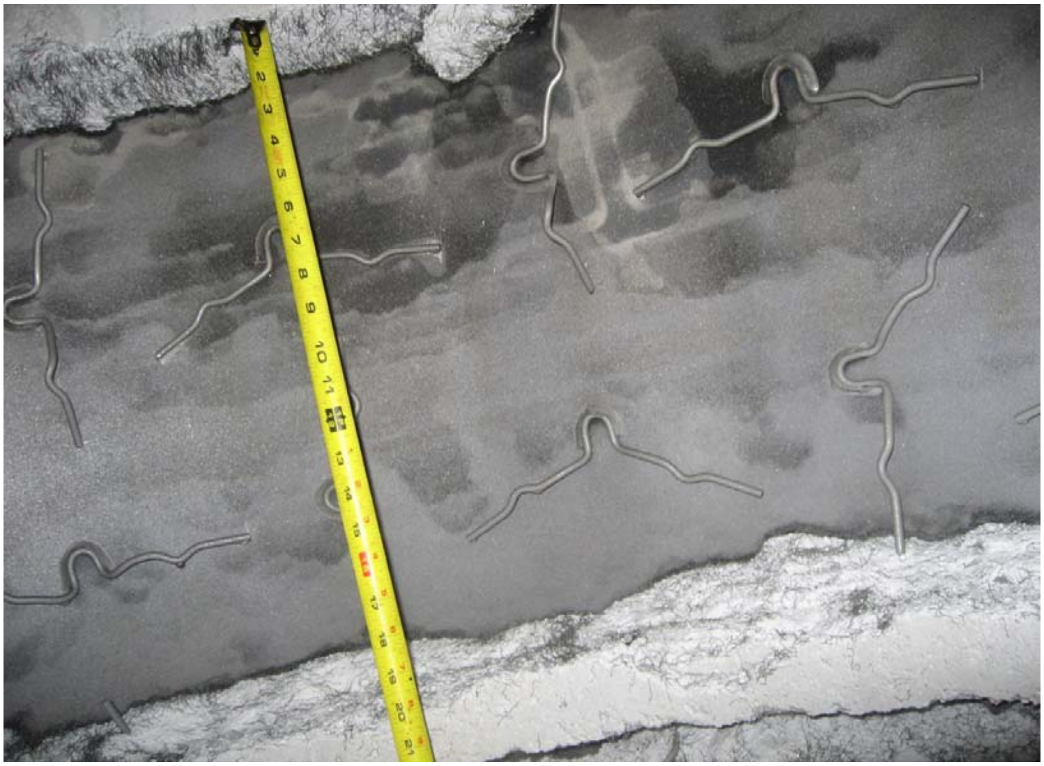
High pressure waterjetting, when properly applied, has proven to be an effective method of removing refractory. The use of high pressure water allows the transmission of hundreds of times the power of handheld chippers, with resulting refractory removal rates on the order of days to weeks faster, while removing these workers from exposure to the hazards of silica dust, extreme noise, vibration, and physically exhausting labor in a confined space.

The key considerations for the effective removal of refractory as presented in this paper include operating at the optimum pressure for a given refractory type, maintaining the standoff distance within an effective range relative to the orifice size, and the estimation of removal rate based on power applied through the high pressure waterjet system.

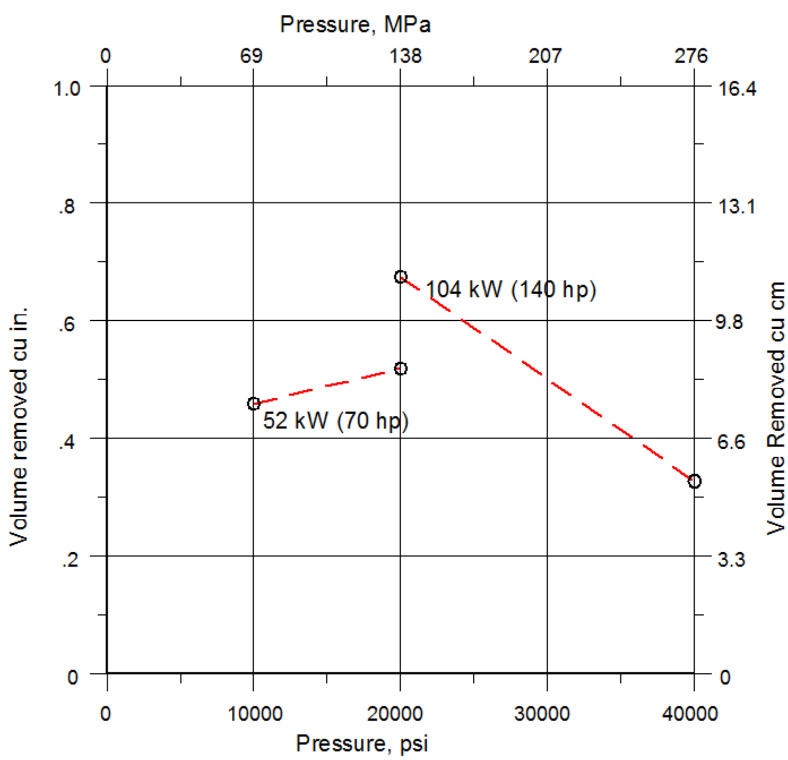
Type 1	RS-17E	AA-22	Stellit FS70	Dual Layer
2.5 hp-min/in^3	1.8 hp-min/in^3	6.2 hp-min/in^3	1.2 hp-min/in^3	3.7 hp-min/in^3
114 W-min/cm^3	82 W-min/cm^3	282 W-min/cm^3	55 W-min/cm^3	168 W-min/cm^3

Specific Energy by Refractory Type
Table 1.

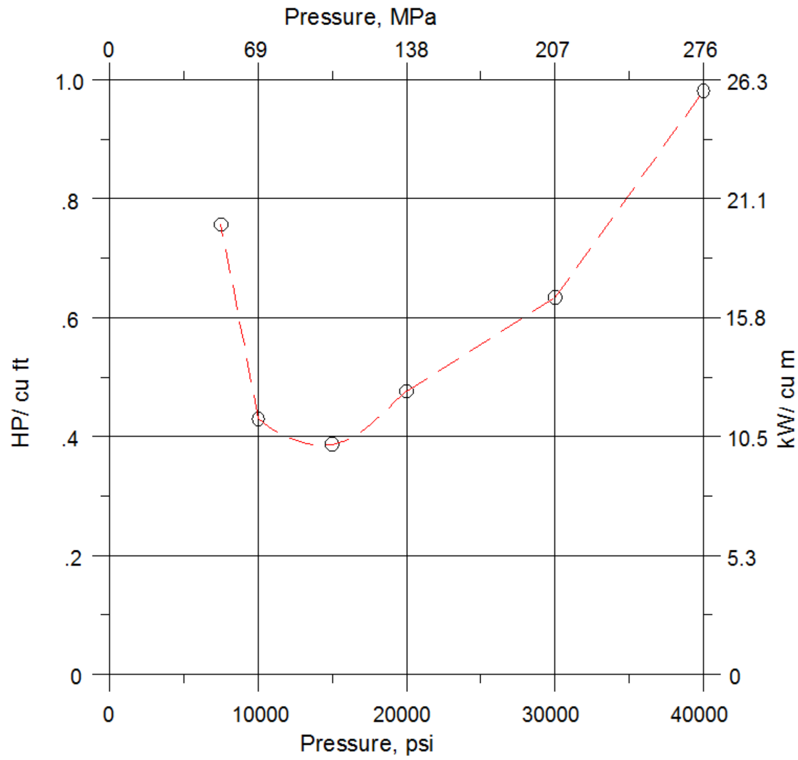
Results of Manual Chipping in Type 1 Refractory, 1 Hour Duration
Figure 1.



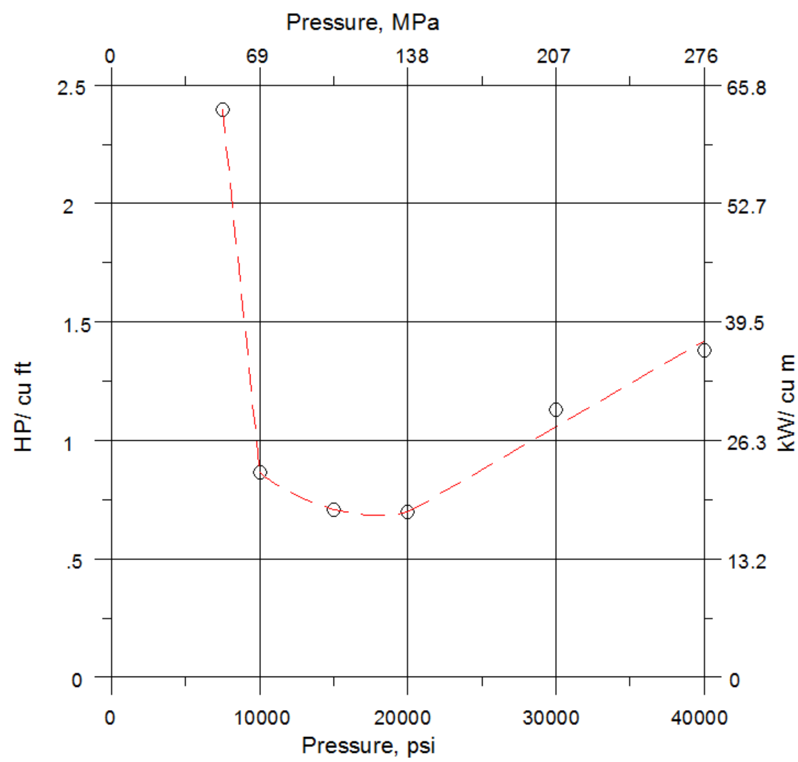
Results of Waterjet Removal in Type 1 Refractory, 1 Hour Duration
Figure 2.



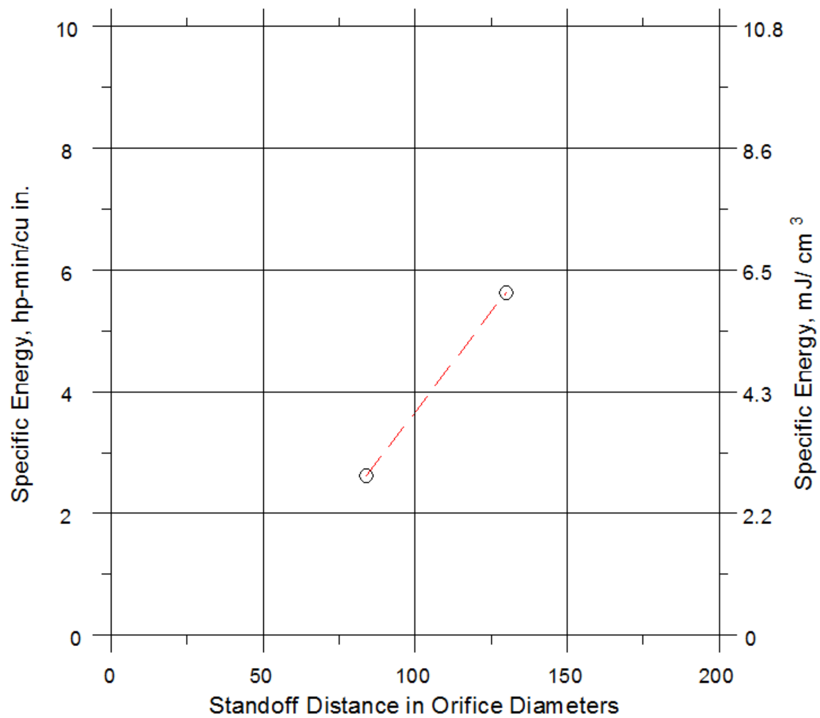
Efficiency of Pressure in Type 1 Refractory Removal
Figure 3.



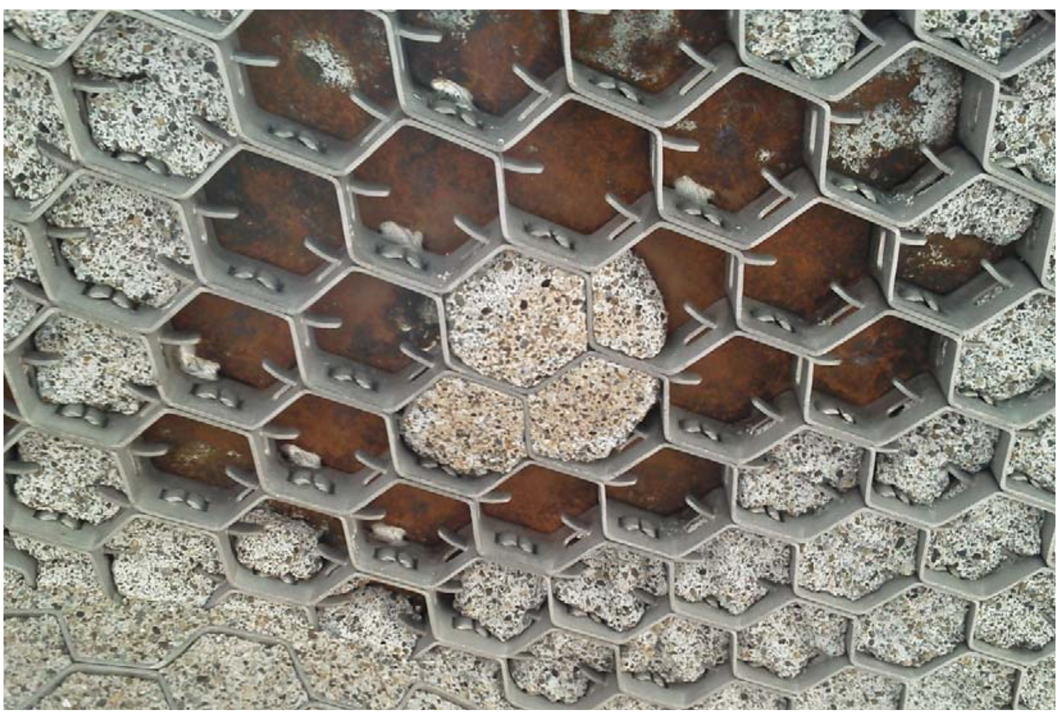
Efficiency of Pressure in RS-17E Refractory Removal
Figure 4.



Efficiency of Pressure in AA-22 Refractory Removal
Figure 5.



Efficiency Versus Standoff Distance in Type 1 Refractory
Figure 6.



Partial Removal by 3-D Due to Mesh Shadow in AA-22 Refractory
Figure 7.

Complete Removal by 2-D in AA-22 Refractory
Figure 8.

Dual Layer Refractory
Figure 9.