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Paper

JET IMPACT AT CONSTANT POWER WITH THE VARIATION OF PRESSURE AND FLOW AT LARGE STANDOFF DISTANCES

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ABSTRACT

In a waterblast system, power is directly proportional to pressure and flow rate; if the pressure is doubled the flow rate is halved for the same power. There is a general knowledge in the industry that the combination of a lower pressure and higher flow can be more effective than the equivalent higher pressure and lower flow combination when applied at the large jet standoff distances typical of vessel cleaning. The purpose of this research was to determine and express in practical terms the effect of the combination of pressure and flow on creating the greatest impact with large standoff distances.

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1. INTRODUCTION

Standoff distances of 2 meters and greater can be experienced in large vessel cleaning such as reactors, boilers, and storage tanks, where access is limited to a few openings and waterblast systems must be quickly and easily put in place through manways or nozzle openings in the vessel without confined space entry whenever possible. There is a general assumption based on practical experience that effective cleaning at these large jet standoff distances is best accomplished with the combination of lower pressure and higher flow than the equivalent combination of higher pressure and lower flow for the same pump power.

Jet power is directly proportional to pressure and flow; this means that a 450 kW (600 hp) pump could be used to provide 340 lpm (90 gpm) at 69 MPa (10,000 psi) or 170 lpm (45 gpm) at 138 MPa (20,000 psi) as an example. The higher pressure produces a higher jet velocity which is often necessary for cutting into a material to be removed. The higher pressure also requires a smaller orifice size to pass the lower flow at the higher pressure, while a lower pressure requires a larger orifice size to pass the higher flow for the same power. The rate at which a jet deteriorates with distance traveled through air or water is inversely proportional to the orifice size; a jet produced by a smaller orifice will have deteriorated more than a jet produced by a larger orifice at the same distance traveled through the air. This rate of deterioration is assumed to be based only on orifice size, independent of pressure. However, the jets produced by higher pressure are traveling at a higher velocity, meaning a greater relative velocity to the surrounding static air and potentially resulting in faster disruption of the jet, particularly at these larger standoff distances. The jet produced by at 138 MPa is traveling 1.4 times faster than a jet produced by 69 MPa, and a jet produced by 276 MPa (40,000 psi) is traveling twice as fast.

The jet impact force is directly proportional to the mass flow rate of the water, and to the square root of the pressure. Therefore, the lower pressure and higher flow combination will always have more impact force for the same power than a higher pressure at a lower flow combination, although impact force alone does not directly represent material removal capability as velocity is necessary as well. The required jet impact force and jet velocity for successful cleaning varies widely based on the material to be removed and how well bonded it may be to the vessel or structure. In hard materials, such as refractory that is anchored to the vessel wall, higher jet velocities are needed to successfully remove the material, and the standoff distance must be kept to a minimum to maintain the effective velocity. Softer or not well bonded materials may be removed at much greater distances as a different combination of jet impact force and jet velocity are ideal.

The goal of this testing was to determine if a quantifiable difference exists in the rate of jet deterioration at large standoff distances when comparing jets produced by equal power at pressures of 69, 138 and 276 MPa (10,000, 20,000 and 40,000 psi) that would support the assumption that effective cleaning at these large distances can be more effectively accomplished with a lower pressure and higher flow system.

2. TEST ARRANGEMENT

The two types of data collected in this testing consisted of measuring jet impact force on a steel plate with a load cell behind, and depths of cut in a medium-strength, fine grained sandstone block produced by a jet traversed across the face in a single pass to produce a relative measurement of effective remaining jet velocity, as a jet will erode sandstone as the mechanism of cutting. Measurements were taken at standoff distances of 1, 2 and 3 meters from the nozzle exit. Carbide nozzle assemblies were used for the 69 and 138 MPa tests, and large sapphire nozzle assemblies were used for the 276 MPa tests. All nozzles were placed on the end of a .9 m straight feeder pipe to provide good upstream conditions to the nozzle. The tests were performed at powers of 60, 130 and 242 kW (80, 175 and 325 hp) through a single nozzle orifice at each pressure.

3. TEST RESULTS AND ANALYSIS

3.1 Impact Force

The results of the jet impact force tests are shown in Figures 1-3 for the three powers tested at each pressure versus the actual standoff distance. The 69 MPa curves show the least degradation with standoff distance, while the 138 and 276 MPa curves show progressively more loss in impact. The displacement of the power curves on the vertical axis is likely a function of the individual jet quality, depending on the nozzle orifice used in the test, as it would be expected that the curves would otherwise be equally spaced. Figure 4 shows the average impact at each pressure as a percentage of the maximum force measurement for these tests. The greatest impact forces occur at the lower pressure, as should happen for the same power since the impact force is a function of the mass flow rate times the velocity, and velocity is proportional to the square root of the pressure. The 69 MPa result shows a loss of only 8 percent from 1 to 3 meters, while the 138 MPa result show a 20 percent decrease, and the 276 MPa result has a 35 percent loss, showing a pattern of deteriorating impact force with increasing pressure over these standoff distances.

3.2 Depth of Cut

The comparative depth of cut tests in the sandstone block were conducted to reflect the jet velocity, although the mass flow rate increase at each pressure with increasing power also affected the cut depth. In these tests, the maximum depth of cut was achieved at 138 MPa at the 1 meter standoff distance, although the performance of the 138 MPa jet was surpassed at the 2 meter standoff distance and beyond by the 69 MPa pressure at each power tested. The 276 MPa test at the maximum power had a very small erosion of the surface at 2 meters. Figure 5 shows the average depth of cut for the powers tested at each pressure as a percentage of the maximum occurring with 138 MPa at the 1 meter standoff distance, which on average outperformed the 69 MPa tests by 14 percent. However, at the 3 meter standoff distance, the 69 MPa tests exceeded the 138 MPa depths by 10 percent, showing more remaining jet energy.

Figure 6 compares the 69 MPa to the 138 MPa results at the lower test power of 60 kW; the higher pressure being 8% better at 1 meter standoff and the lower pressure better by 9 percent at 2 meters. At 3 meters, the 69 MPa still showed 4 percent of the relative maximum, while the 138 MPa had no effect. Figure 7 shows the relative performance between these pressures at the higher power of

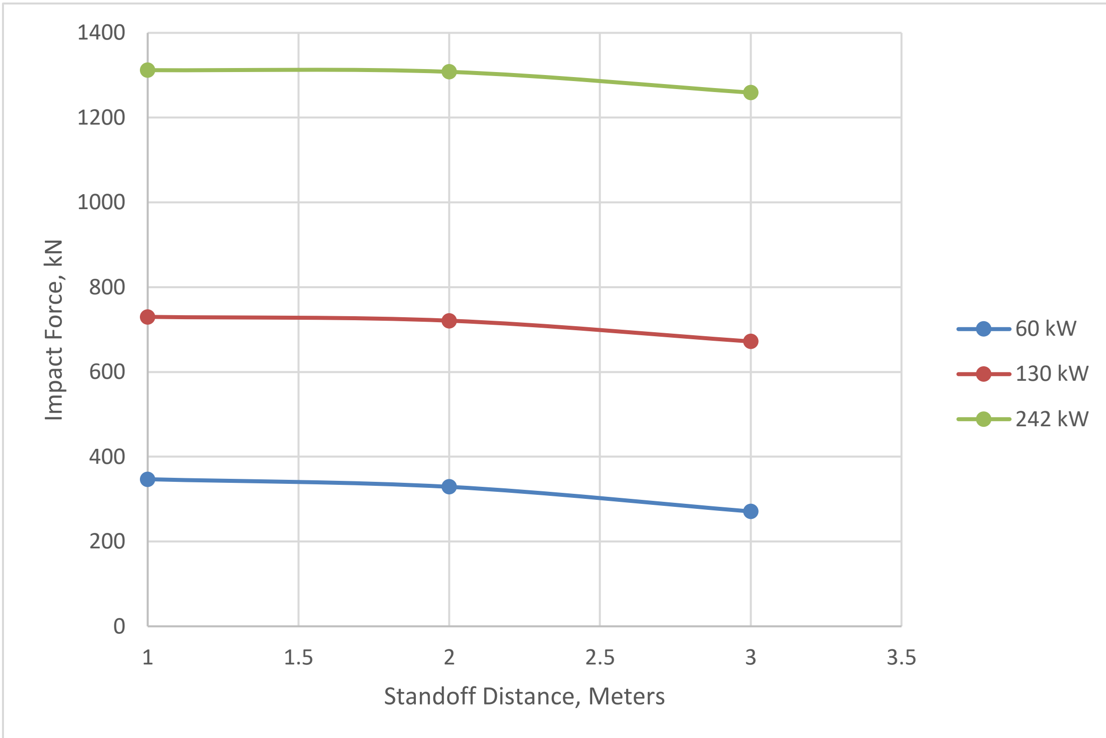
242 kW, where the 138 MPa again outperformed the 69 MPa by 9 percent at the 1 meter standoff, while at 3 meters the 69 MPa result was 21 percent greater than the 138 MPa result. The increasing performance of the lower pressure over the higher pressure at standoff distances of 2 and 3 meters with increasing power shown in comparing these two graphs would indicate that the trend would continue to further benefit the lower pressure with increasing powers at larger standoff distances.

3.3 Combined Effect of Impact Force and Velocity

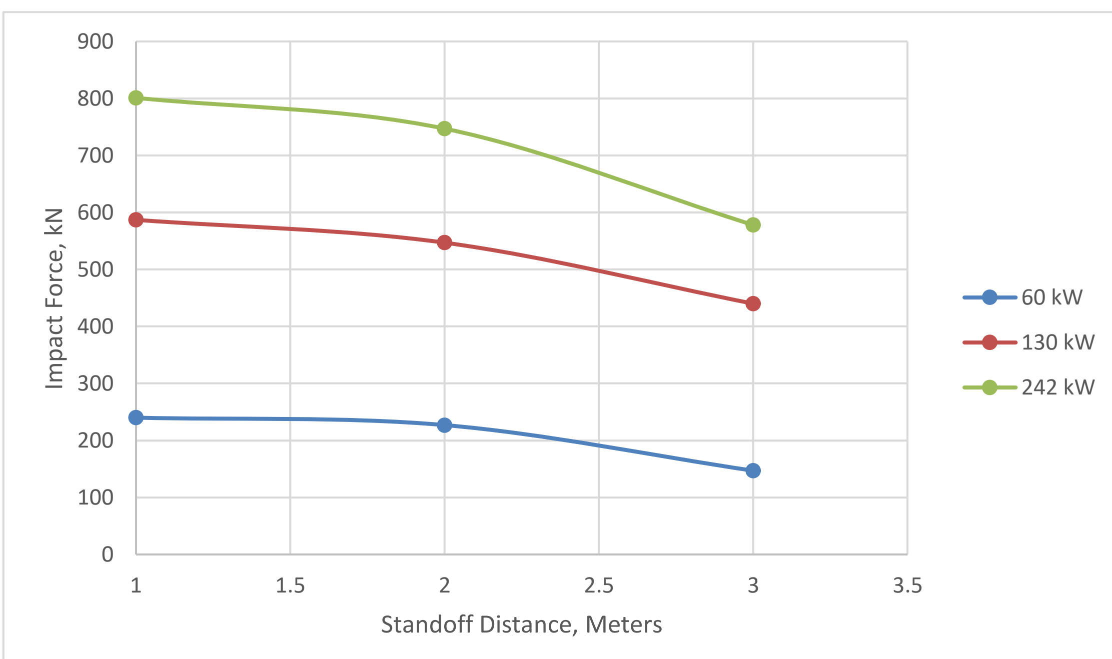
When waterblast cleaning in vessels and tanks with material deposits such as petroleum coke that may be hard but fractured and not well bonded to the steel structure, it is likely that a combined effect of the impact force of the water combined with sufficient velocity is responsible for removing these materials at a much greater standoff than when the same material is well bonded to a refractory lined surface. This would also likely apply to much softer deposits that are easily removed. To illustrate the effect this would have, the impact force and the depth of cut were multiplied, and the results shown in Figure 8 as a relative percentage. This would emphasize the lower pressure of 69 MPa by 35 to 45 percent over the 138 MPa pressure.

4. CONCLUSIONS

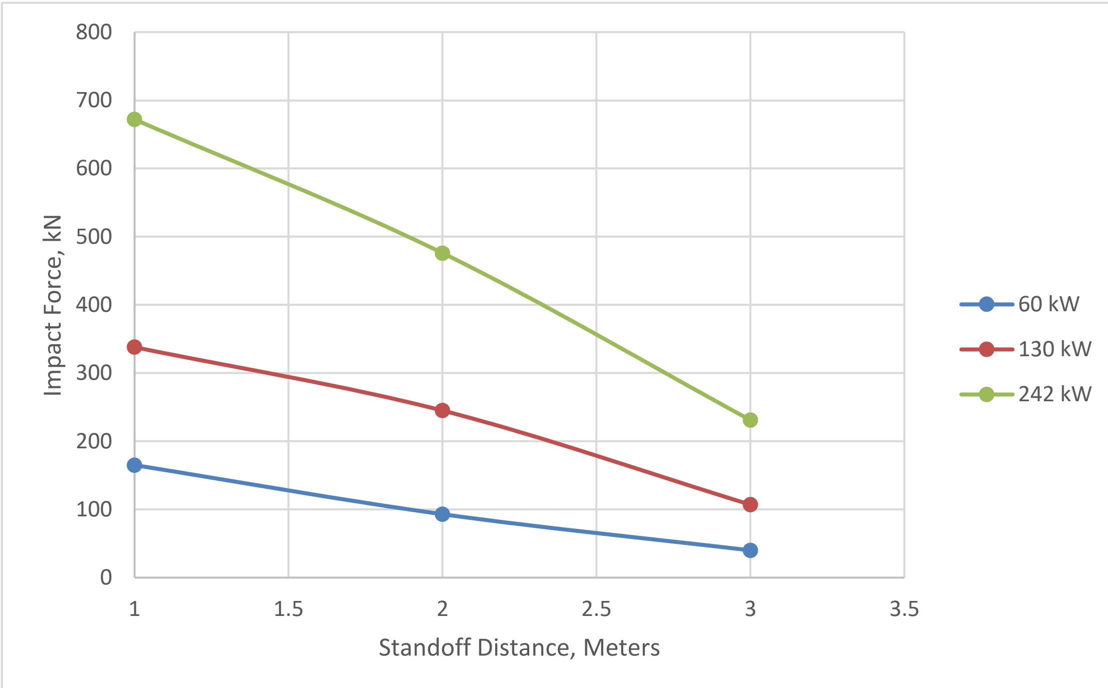
The hypothesis exists that for the same power, the most effective cleaning at large standoff distances in tanks and vessels occurs when utilizing a lower pressure and higher flow combination. This testing illustrated that the impact force will always be greater with the lower pressure, and with increasing standoff distance the velocity of the jet at lower pressure surpasses that of the jet at higher pressure by not losing energy as quickly. The impact force of a 69 MPa (10,000 psi) jet will be 30 to 50 percent greater than the impact force of a 138 MPa (20,000 psi) jet in the standoff distance range of 1 to 3 meters, and the percentage of loss over this distance is greater with the higher pressure. The velocity as based on depth of cut in the sandstone sample showed that the 138 MPa jet would outperform the 69 MPa jet at distances of 1 meter and less but fall below the performance of the lower pressure jet beyond this distance by 10 to 20 percent. If a combined effect of velocity and impact force is compared, the 69 MPa jet could potentially show 35 to 45 percent benefit over the 138 MPa jet at these large standoff distances, where softer or not well bonded brittle materials are being removed. The more rapid loss in relative energy of the higher pressure jet also illustrates why it is important to maintain close standoff distances when using the higher pressures required to remove harder materials such as refractory linings.



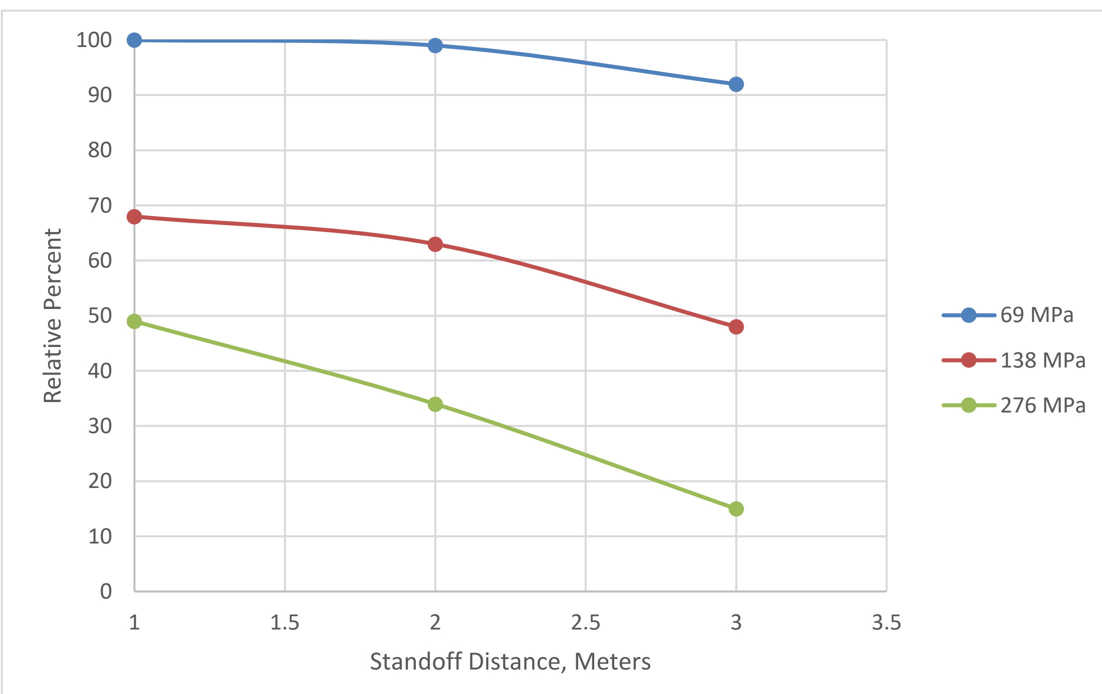
Impact Force by 69 MPa (10,000 psi) at Three Different Powers
Figure 1.



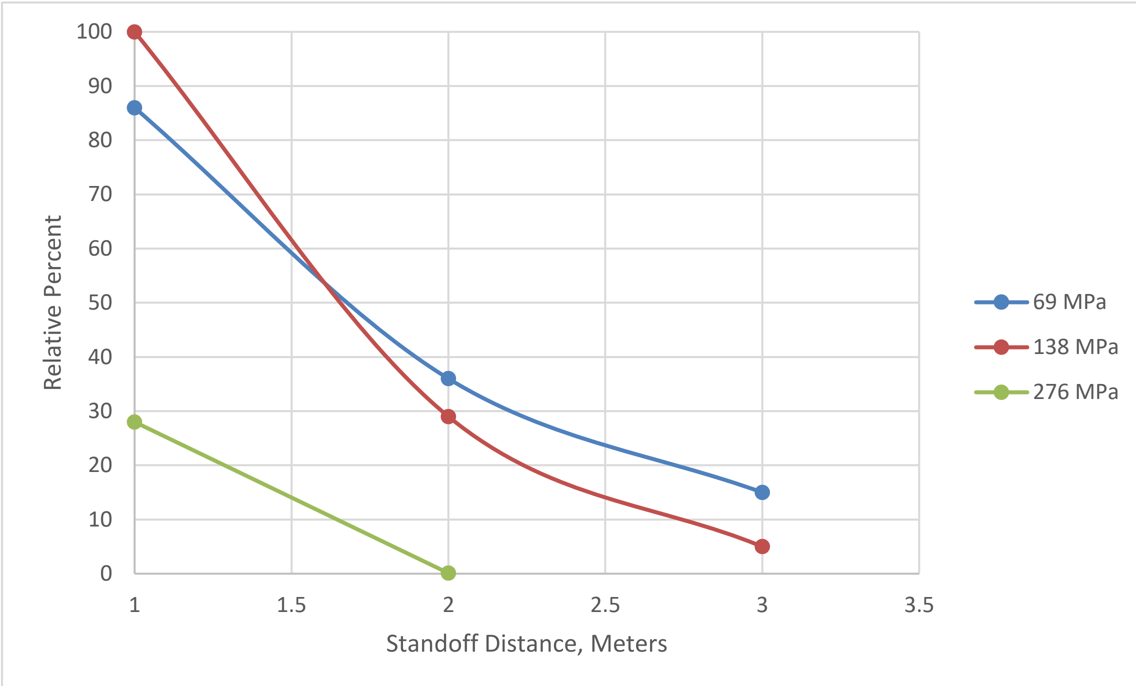
Impact Force by 138 MPa (20,000 psi) at Three Different Powers
Figure 2.



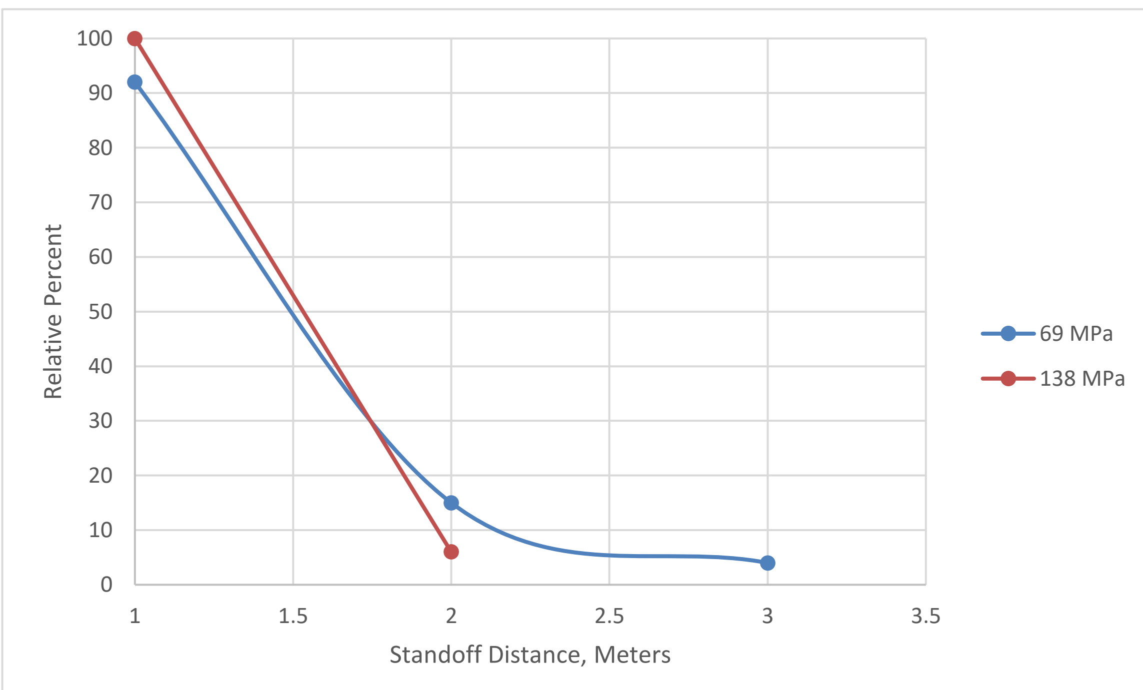
Impact Force by 276 MPa (40,000 psi) at Three Different Powers
Figure 3.



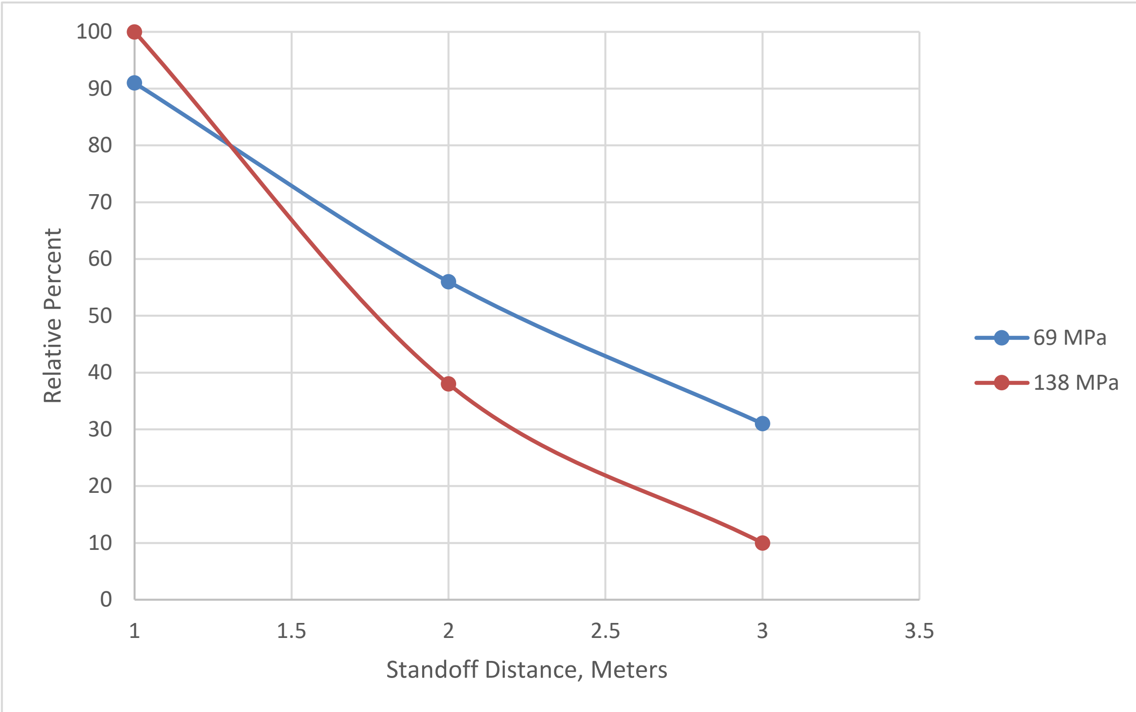
Average Relative Jet Impact Force by Pressure
Figure 4.



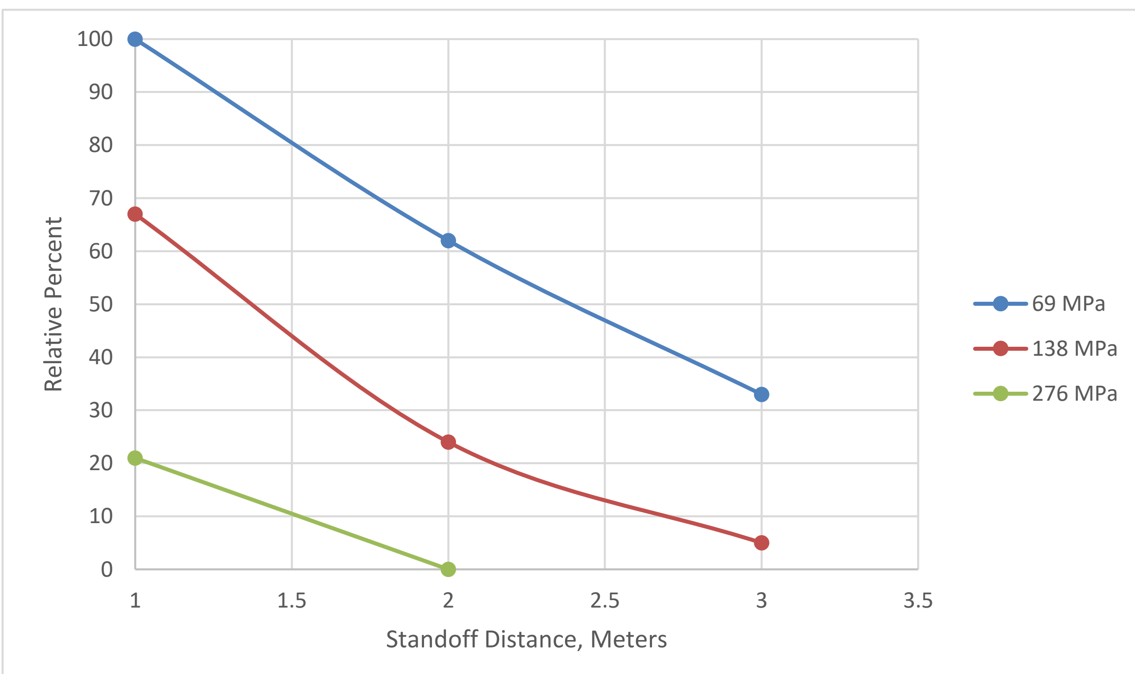
Average Relative Depth of Cut by Pressure
Figure 5.



Relative Depth of Cut by Pressure at 60 kW
Figure 6.



Relative Depth of Cut by Pressure at 242 kW
Figure 7.



Impact Force Multiplied by Depth of Cut at 242 kW
Figure 8.