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SAFETY CONSIDERATIONS FOR LOW PRESSURE CLEANING APPLICATIONS

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ABSTRACT

Low pressure cleaning is commonly conducted on industrial sites by contractors utilizing "Pressure Washer" pumps and tooling such as guns or wands designed for the pressure washer cleaning market. Site Personal Protective Equipment (PPE) requirements for use while operating this equipment often consist of safety glasses, face shield, gloves, rubber boots and rain suits, as compared to the minimum requirements of metatarsal and shin protection for hand-held waterblast cleaning. Operating pressures up to 27.5 MPa (4000 psi) and flow rates up to 76 liters/minute (20 gallons per minute) are possible within the pressure washer realm. The purpose of this study was to determine the level of jet impact protection provided by typical rubber boots and rain suits, as well as tests on simulated skin to demonstrate the effect of jet impact with various combinations of pressure and flow within the pressure washer cleaning range.

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1. INTRODUCTION

Contractors and industrial sites frequently use pressure washers for low pressure cleaning applications, such as light foulant removal from valves and flanges. These machines are less expensive to purchase and operate than a typical waterblast pump unit when the jetting power of a larger pump is not necessary. The PPE requirements and gun design requirements for these units are below those of typical waterblast industry requirements that are in place to prevent waterjet injuries to operators. With the higher flow capabilities now available in pressure washer pumps, the combination of a higher flow, even at a lower pressure, can generate substantial jet impact, approaching that of the lower end of what would otherwise be considered waterblast power.

Waterblast handheld shot guns have a required minimum barrel length of 122 cm (48 inches) and an overall length requirement of 168 cm (66 inches) from the nozzle to the shoulder rest. This design physically prevents the operator of the gun from passing the jets across the feet or legs when properly held, preventing accidental jet contact with the body. Guns or wands used within the pressure washer industry are typically much shorter for ease of use.

Minimum PPE requirements for handheld waterblast shotgun work include metatarsal and shin protection for the gun operator, and face shields for protection from debris as well as rain suits for chemical and splash protection. PPE for pressure washing may be as minimal as steel toe rubber boots, rain suits and goggles or face shields.

One potential difference in pressure washer applications is the common use of a fan jet, as compared to a round jet, although round jets may still be used with a pressure washer for difficult, harder deposits. A fan jet quickly dissipates in impact energy with distance compared to a round jet; however, a fan jet at a very close distance can have an impact energy nearly equivalent to a round jet. Rotating “turbo” nozzles are also commonly used, and when rotating properly, they would be expected to have an impact effect similar to a traversing round jet orifice, although with the effect of multiple passes if held in one place on a surface.

2. TEST ARRANGEMENT

Tests were conducted by traversing a jet across samples at a rate of 150 mm/second (6 in/second) at pressures and flow rates of 3.4 to 27.6 MPa and 3.8 to 76 lpm (500 to 4000 psi and 1 to 20 gpm). At the center of the sample, the traversing motion was stopped, and the time required for the stationary, or static, jet to penetrate the sample was recorded. Both round and 15 degree fan jets were compared at several standoff distances from the samples.

The test samples were held in place by an assembly that allowed them to be tensioned, keeping the surface of the samples from being deflected by the jet impact. The simulated skin samples were tanned cowhide, 1 mm thickness, smooth finished on one side, as suggested by the paper titled “Ballistic Skin Simulant”[1] for research in forensic science. Samples of fresh pig skin with a thickness of 4 mm were used for comparison, since this material has also been used in evaluations of jet impact. The rubber boot samples were taken from the upper and ankle section of new steel toe rubber work boots commonly worn in industry. These samples consisted of both single layer and double layer rubber coating on a fabric backing, with combined thicknesses of 1.63 and 2.54 mm (.064 and .100 in). The rain suit samples came from lightweight fire resistant PVC/Polyester rain suit pants with a thickness of 0.38 mm (.015 in). The sample holder and traversing lance with nozzle are shown in Figure 1, and the boots and rain suit types tested are shown in Figure 2.

3. TEST RESULTS

3.1 Round Jets and Skin Simulant

3.1.1 Standoff Distance

Initial tests on the skin simulant were conducted using a 0.8 mm diameter (.031 in) round carbide orifice to determine the effect of standoff distance, with the intention of conducting testing within the range that would be the most likely to result in damage. It was found that within the standoff distance range of 10 to 76 mm (0.38 to 3 in) there was not a significant difference in result for penetration of the simulant, although with increasing standoff distance the width of cut did increase.

3.1.2 Static Jet Penetration

The time required for the static jet to completely penetrate the skin simulant was measured for several pressures, flows from 2.3 to 38 lpm (.6 to 10 gpm) and standoff distances of 10 to 76 mm, but there were no significant differences among these variables other than the slight change in pressure. Using a 0.8 mm (.031 in) round orifice at 3.4 MPa (500 psi) and 2.3 lpm (.6 gpm), the sample was penetrated in 5 seconds, while at 4.8 MPa (700 psi) and 2.6 lpm (.7 gpm), the sample was penetrated in less than 1 second, both tests conducted with a 76 mm (3 in) standoff distance. Essentially, once the threshold pressure of the material was reached, combined with the 1 mm thickness of the material, the penetration time was very short for all flow rates tested.

Tests were conducted on the 4 mm fresh pig skin using the 0.8 mm (.031 in) orifice at the 76 mm (3 in) standoff distance, with the result that at 6.9 MPa (1000 psi), it required 6 seconds to achieve full penetration through the sample by the jet.

3.1.3 Traversing Jet Penetration

The traversing jet tests were conducted with three orifice sizes, 0.8, 2.0 and 3.0 mm (.031, .078 and .118 in) and a higher pressure was used in each individual pass over fresh material surface until the skin simulant was cut through along the traverse, using a standoff distance of 76 mm (3 in). The results of this testing showed a decrease in the pressure required to achieve the cut as the flow rate was increased from 4.5 lpm (1.2 gpm) to 25 lpm (6.5 gpm). The 0.8 mm (.031 in) orifice achieved a cut through along the traverse at 13.8 MPa (2000 psi) with a corresponding flow rate of 4.5 lpm (1.2 gpm) while the 2.0 mm (.078 in) orifice achieved a cut at 11 MPa and 25 lpm (1600 psi and 6.5 gpm). Increasing to the 3.0 mm (.118 in) orifice resulted in a smaller decrease in pressure, requiring 10.3 MPa while flowing 55 lpm (1500 psi and 14.5 gpm). This result is plotted in Figure 3. The higher flow rates at lower pressures produced tearing of the simulant along with

a wider jet impact. Figures 4 and 5 show the resulting cuts produced with the 0.8 mm orifice compared to the 3.0 mm orifice.
Traversing jet tests were also conducted on the pig skin samples with the 0.8 mm (.031 in) orifice at a standoff distance of 76 mm (3 in). A pressure of 20.7 MPa (3000 psi) with a flow rate of 5.3 lpm (1.4 gpm) was reached before penetration began to occur along the jet path.

3.2 Round Jets and PPE Resistance

3.2.1 Rubber Boot Static Jet Penetration

The 0.8 mm (.031 in) orifice was used for a static jet penetration test on a sample from the rubber boot. At a pressure of 6.9 MPa (1000 psi) producing a flow rate of 3 lpm (.8 gpm), the jet penetrated the material in less than 2 seconds at a standoff distance of 38 mm (1.5 in). Essentially, the rubber boot material would not offer protection at close range from a static round jet with pressures at or above 6.9 MPa (1000 psi), well within the range of the smallest pressure washers.

3.2.2 Rubber Boot Traversing Jet Penetration

The traversing jet tests were conducted with four orifice sizes to test for the effect of increasing flow rate on the minimum pressure to produce a penetration completely through the material. All tests were conducted at a standoff distance of 38 mm (1.5 in). The results showed the trend that increasing flow resulted in a lower pressure required to achieve penetration completely through the material. The smallest orifice, 0.8 mm (.031 in), with a flow of 5.7 lpm (1.5 gpm), was able to reach a pressure of 24.1 MPa (3500 psi) before the jet began to penetrate the rubber boot material along the traverse as pinholes. This test was repeated with a sample of skin simulant underneath the boot material to determine if the material was absorbing any of the jet energy; the traversing jet penetrated both the boot and skin simulant, as shown in Figure 6.

When the orifice size was increased to 1.6 mm (.062 in), the boot material was cut completely through on the traverse with 20.7 MPa (3000 psi) at the accompanying flow rate of 21.6 lpm (5.7 gpm); with the 2.0 mm (.078 in) orifice, the necessary pressure to cut reduced to 17.2 MPa (2500 psi) with a flow rate of 31 lpm (8.2 gpm). A 2.5 mm (.100 in) orifice cut through on traverse at a pressure of 13.8 MPa (2000 psi) and a flow rate of 45.4 lpm (12 gpm). These results are shown in the chart in Figure 7. The 0.8 mm and 2.5 mm (.031 and .100 in) orifice tests were repeated at the same pressures on the dual layer boot material, and the increased stiffness of the thicker material resulted in more defined traversing cut results.

3.2.3 Rain Suit Resistance to Round Jets

The static and traversing round jet tests on the plastic coated rain suit material were conducted at a standoff distance of 38 mm (1.5 in). The 0.8 mm (.031 in) orifice required less than 1 second to penetrate at 6.9 MPa (1000 psi) with a flow rate of 3 lpm (.8 gpm) in the static jet test. With this same orifice size, the pressure required an increase to 10.3 MPa (1500 psi) with 3.8 lpm (1 gpm) to produce a continuous cut through this material when traversing. A 1.6 mm (.062 in) round orifice achieved a traversing cut through the rain suit at a pressure of 6.9 MPa (1000 psi) and a flow rate of 12.5 lpm (3.3 gpm). This rain suit material was less resistant to the jet impact than the skin simulant and should not be considered as protection from any jet.

3.3 Fan Jets and Skin Simulant

3.3.1 Static Jet Penetration and Standoff Distance

Fan jets are commonly used with pressure washer systems, and similar tests were conducted with 15 degree fan jets in equivalent orifice sizes to the round jet tests. The effect of increasing standoff distance of the orifice from the material showed a significant influence on the pressure required to penetrate the skin simulant with a stationary or static jet due to the rapid dissipation of jet energy. At the closest standoff distance of 6.4 mm (.25 in), the minimum pressure required for static jet penetration was similar to the round jet results in all except the smallest orifice size (0.9 mm or .036 in), which required a pressure of 10.3 MPa (1500 psi) at 5.3 lpm (1.4) gpm to achieve penetration in 2 seconds or less. The 1.6 and 2.0 mm (.064 and .080 in) fan jets penetrated the skin simulant at 5.5 MPa (800 psi) with flow rates of 11.7 and 18.5 lpm (3.1 and 4.9 gpm) respectively.

The same fan jet orifice sizes were tested at standoff distances of 38 and 76 mm (1.5 and 3.0 in) for complete static jet penetration of the skin simulant in 2 seconds or less. These results are shown in Figure 8 along with the 0.8 mm (.031 in) round jet results. All points plotted would cause significant injury and are well within the range of commonly available pressure washers; this plot does show that a round jet can carry impact energy further than a fan jet.

3.4 Fan Jets and PPE Resistance

3.3.2 Rubber Boot Static Fan Jet Penetration

The results of the static fan jet tests on the rubber boot material showed that with the 0.9 mm (.036 in) equivalent orifice size at a standoff distance of 6.4 mm (.25 in), penetration occurred at 13.8 MPa (2000 psi) with a flow rate of 6 lpm (1.6 gpm). A 2.6 mm (.103 inch) equivalent fan jet orifice penetrated the material at 6.9 MPa (1000 psi) in less than 1 second, with a flow rate of 34 lpm (9 gpm), again showing that this material would not offer protection at close range from static round or fan jet penetration.

3.3.3 Rubber Boot Traversing Fan Jet Penetration

The traversing fan jet tests were conducted at standoff distances of 6.4 to 76 mm (.25 to 3.0 in) with equivalent orifice sizes from 0.9 to 2.6 mm (.036 to .103 in) and the plane formed by the 15 degree fan pattern oriented parallel to the traversing axis to represent a worst case condition. The results at the 6.4 mm (.25 in) standoff distance are shown versus flow rate in Figure 9 and compared to the similar test with round jets; the smallest orifice size produced a cut through on traverse at 24.1 MPa (3500 psi) while the largest orifice cut through at 16.5 MPa (2400 psi). The fan jet results at a 6.4 mm (.25 in) standoff distance are comparable to the round jet results at 38 mm (1.5 inches) standoff distance. The largest fan jet orifice size (2.6 mm or .103 in) was tested with a standoff distance of 76 mm (3.0 in) with traverse at a pressure of 27.6 MPa (4000 psi); this did not produce a cut through the rubber boot material, but once the traverse was stopped, full penetration occurred in less than 1 second.

3.3.4 Rain Suit Resistance to Fan Jets

The static and traversing fan jet tests on the plastic coated rain suit material were conducted at a standoff distance of 6.4 mm (.25 in). The 0.9 mm (.036 in) equivalent fan jet orifice required less than 1 second to penetrate at 6.9 MPa (1000 psi) with a flow rate of 4.2 lpm (1.1 gpm) in the static jet test. With this same orifice size, the pressure required an increase to 11 MPa (1600 psi) with 5.3 lpm (1.4 gpm) to begin to produce a cut through this material when traversing, similar to the round jet tests and again demonstrating that this material does not offer protection from a round or fan jet impact.

4. CONCLUSIONS

The purpose of these tests was to demonstrate the potential risks of jet impact produced in the pressure and flow range of what is commonly considered to be pressure washing and determine the level of jet impact protection provided by common protective wear used in the industry. A significant difference in pressure required to penetrate all samples did exist depending on whether the jet was stationary or traversing the sample. Using larger orifice sizes to increase flow rate resulted in a decrease in the pressure required to produce traversing cuts through the samples. The results also illustrated the greater risk of round jets due to the ability to carry concentrated energy much further than fan jets, although both were capable of penetrating a human skin simulant at close range with pressures as low as 3.4 MPa (500 psi).

The protective equipment tested consisted of rubber boot and plastic coated rain suit samples. The results showed that the rain suit material should not be considered as any level of protection from jet impact, being slightly less resistant than the skin simulant samples. The rubber boot material was able to be penetrated by a stationary jet at 6.9 MPa (1000 psi), and only showed resistance up to 13.8 MPa (2000 psi) with a traversing round jet. This material did show resistance to the traversing fan jet test but only with increased standoff distance; it did not resist close range fan jet impact for either the stationary or traversing jet within the range of what is commonly available in pressure washer systems. At a minimum, operators of these systems should be instructed of the risk of significant injury that can be caused by the jets produced by common pressure washer machines.

REFERENCES

1. Jussila J, Leppaniemi A, Paronen M, Kulomaki E. “Ballistic Skin Simulant”. *Forensic Science International*. 2005, Volume 50(1), pages 63-71.

Figure 1. Sample Holder and Traversing Nozzle Lance Test Arrangement

Figure 2. Rubber Boots and Rain Suit of the Types Tested

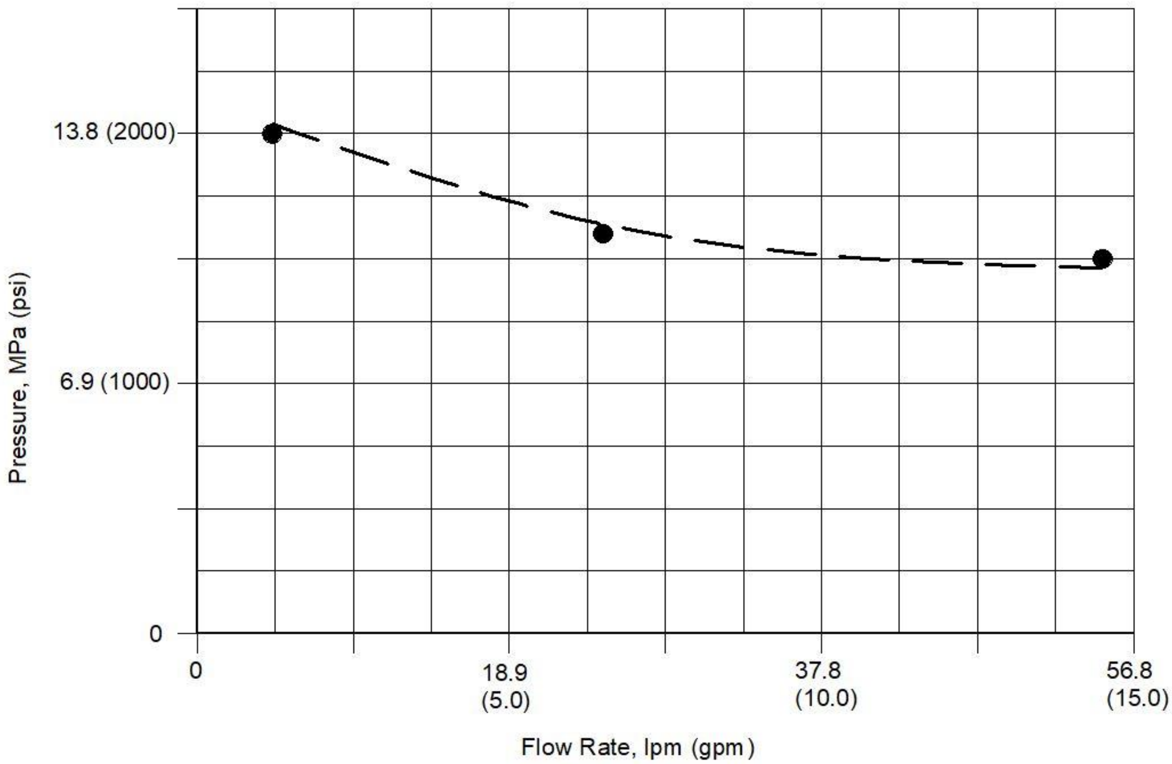

Figure 3. Pressure and Flow Rate to Result in Cut from a Traverse of Skin Simulant

Figure 4. Cut from a Traverse of Skin Simulant by 0.8 mm (.031 in) Orifice at 13.8 MPa and 4.5 lpm (2000 psi and 1.2 gpm)

Figure 5. Cut from a Traverse of Skin Simulant by 3.0 mm (.118 in) Orifice at 10.3 MPa and 55 lpm (1500 psi and 14.5 gpm)

Figure 6. Penetration of Skin Simulant Placed Behind Rubber Boot Material

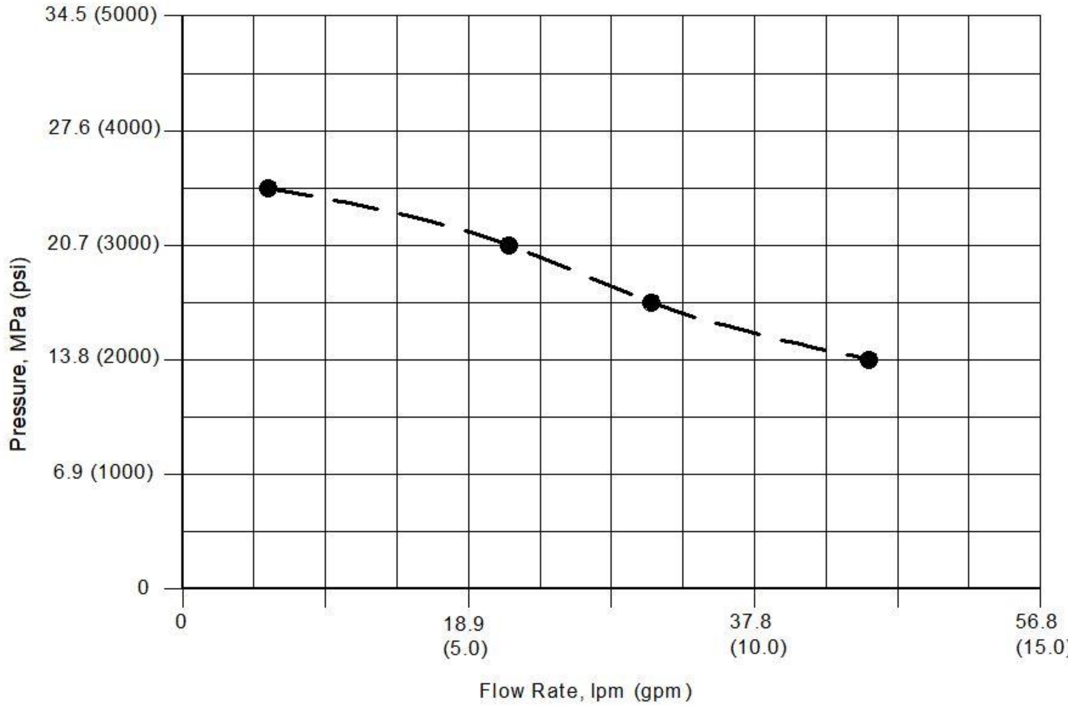

Figure 7. Pressure and Flow Rate to Result in Cut from a Traverse of Rubber Boot Material

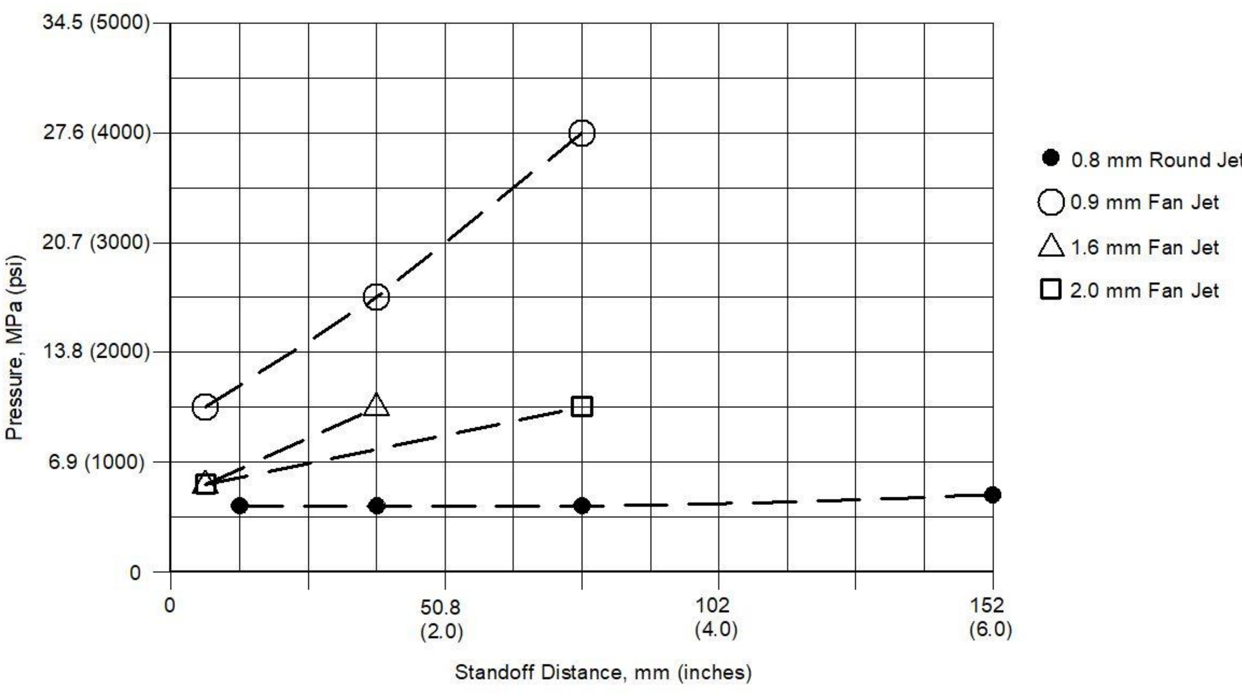

Figure 8. Static Jet Penetration of Skin Simulant with Standoff Distance

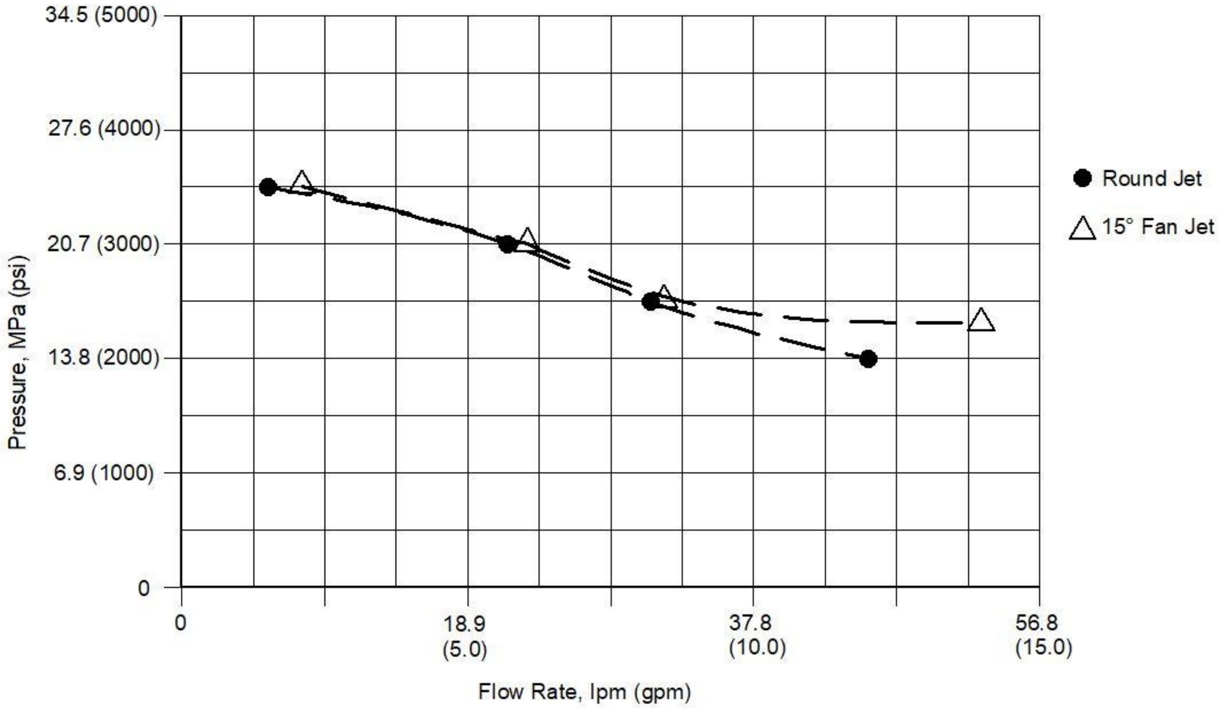

Figure 9. Pressure and Flow Rate to Result in a Cut from a Traverse of Rubber Boot Material