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Paper

THE EFFECT OF UPSTREAM FEEDER TUBE DIAMETER AND LENGTH ON WATERJET PERFORMANCE IN CLEANING APPLICATIONS

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ABSTRACT

The use of tubing to support and feed a waterjet nozzle is a common and easily achieved method of bringing the nozzle closer to the surfaces to be cleaned in large tanks, vessels and pipe lines. The use of such extensions brings the added benefit of improving the upstream conditions and producing a higher quality and further carrying jet stream. In a 1972 publication Hydrodynamics of High Pressure Fine Continuous Jets, Shavlovsky stated that the ideal inner diameter of this upstream tubing would be 8 to 10 times the diameter of the waterjet orifice, and the optimum length would be 40 to 50 times the inner diameter of the tubing. In today's waterjet cleaning, with high flow rates, there are practical limitations that make it difficult to achieve upstream diameter ratios only as great as 5 times the orifice diameter, and limitations on vessel opening size or internal clearances are more likely to determine the length that can be used.

The purpose of this research was to evaluate the effects on jet performance through testing the proportions of upstream tubing and orifice sizes commonly in use. The ratios of tubing length, tubing inside diameter and orifice diameter were varied to determine their relationships and combined effects on jet performance, and which relationships in combination are best optimized.

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1. INTRODUCTION

The effectiveness and range of a high pressure waterjet can be as dependent on upstream conditions as the design of the nozzle orifice used to form the jet. Upstream conditions can vary from an orifice installed radially in a nozzle head for small pipe cleaning, to the orifice being placed axially in the end of a long straight pipe or tube, commonly called an extension arm, on a vessel cleaning tool such as a 3D or 2D swivel as illustrated in Figures 1 and 2. Within this range of upstream condition types, there exist relationships between the proportionate size of the orifice diameter relative to the inside diameter of the tube, and the length of the tube proportionate to the inside diameter of the tube.

In field applications, there is often a limitation to the maximum length of straight tube or extension arm that can be utilized due to internal obstructions of the vessel being cleaned. This also creates the need to have effective jet impact at ever greater standoff distances. While the orifice size is predetermined by the desired operating pressure and flow, and the maximum length of tubing behind the orifice is determined by physical constraints, it is still possible to select an inside diameter for the tubing feeding the orifice. The purpose of this testing was to determine the optimum relationship between the orifice size, tubing length and tubing inside diameter to produce the most effective jet impact.

2. TEST ARRANGEMENT

The test parameters consisted of tubing sections with inside diameters of 7.9 mm (.312”), 11.1 mm (.438”), 15.2 mm (.599”), 20.7 mm (.815”) and 27.9 mm (1.10”). Nozzle holders were fabricated that allowed the use of the same carbide orifice insert for all tests fitted to the ends of the different tubing sections, as shown in Figure 3. Tubing lengths of 102, 203, 305, 610 and 914 mm (4, 8, 12, 24 and 36 in.) were utilized in each tubing size. Orifice diameters of 1.6, 2.3 and 3.2 mm (.063, .090 and .125 in.) were tested with each tubing combination. All tests were conducted at 69 MPa (10,000 psi), traversing the jet at 305 mm/second (12 in./second) across machinable wax samples placed at standoff distances of 100, 400 and 700 times each orifice diameter. The depth of cut produced in the wax was measured and averaged for the three standoff distances to provide a value for relative jet impact.

3. TEST RESULTS AND ANALYSIS

3.1 Feeder Tube Inside Diameter

The result of varying the inside diameter of the feeder tube at each tubing length is shown in Figures 4 through 7. The performance shown for each orifice size is relative to itself, not overall performance. For all lengths and orifice sizes, there are general improvements in performance with increasing inside diameter, up to an optimum before falling off. In the shorter length, an optimum occurs near the 15.2 mm (.599”) inside diameter before performance deteriorates with increasing inside diameter. As the length is increased, the optimum shifts further to a larger inside diameter of 20.7 mm (.815”), indicating that a relationship exists between inside diameter and length. Relative to orifice size in the range tested, the curves generally show the same trends through the shorter lengths when expressed relative to inside diameter. At the longest length tested, the 2.3 mm (.090”) orifice shows continued improvement at the 27.9 mm (1.10”) inside diameter.

3.2 Feeder Tube Length and Inside Diameter

Figures 8-10 express the relationship of feeder tube length and inside diameter, showing the performance gains due to both parameters for a given orifice size. The horizontal axis in this chart series is displayed in terms of the ratio of the inside tube diameter to the orifice diameter.

The performance improvement gained by increasing length is greater with increasing orifice size, with a gain of 25% for the 1.6 mm (.063”) orifice, 50% for the 2.3 mm (.090”) orifice, and nearly 60% for the 3.2 mm (.125”) orifice, showing a greater dependence on upstream conditions with larger orifice sizes and proportionally higher flow rates.

The average improvement due to increasing the inside diameter of the feeder tube across all lengths and orifice sizes was 24%. The greatest gains occurred within the 305 and 914 mm (12 and 36 in.) lengths and the 3.2 mm (.125”) orifice size, each with a 32% improvement in relative performance.

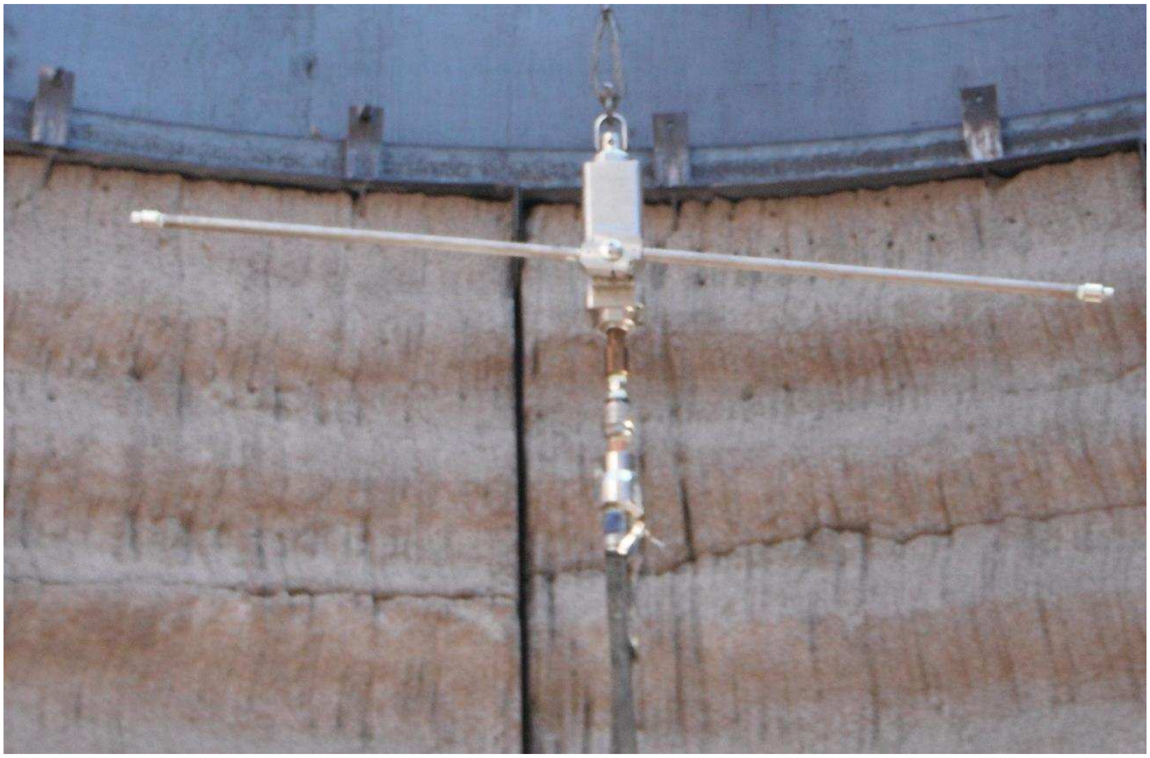
The other trend visible in these relative curves is the shift in optimum inside diameter to larger bore sizes with increasing feeder tube length. For the 1.6 mm (.063”) orifice size, the optimum stays within a 10 to 13 times ratio for inside tube diameter to orifice diameter; for the 2.3 mm (.090”) orifice size the optimum occurs at a 7 to 9 times ratio for the shortest length and shifts to 9 to 12 times at the longest length. The 3.2 mm (.125”) orifice shows an optimum at just less than 5 times this same ratio with the shortest length, shifting up to 6.5 times at the longest length tested. Continuing on this trend would predict that with longer allowable lengths, performance would improve further with larger inside diameters.

3.3 Feeder Tube Length Proportional to Inside Diameter

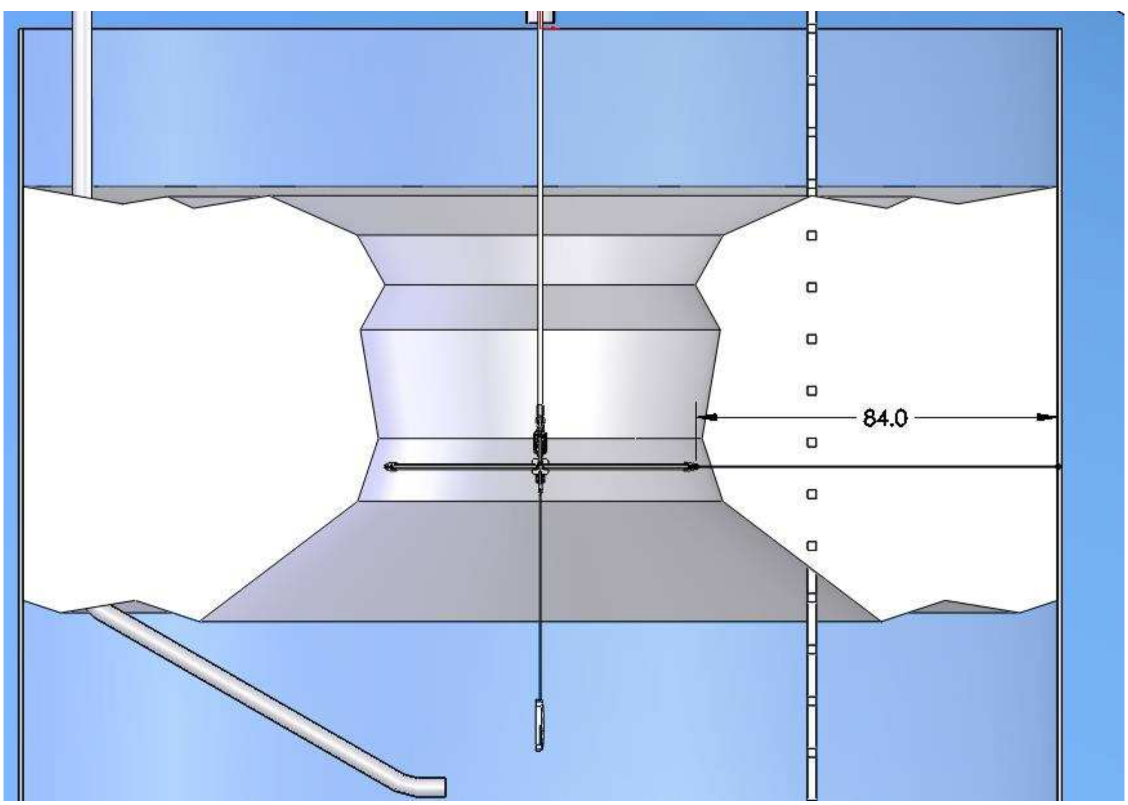
Feeder tube length can also be expressed as a relative proportion of the inside diameter, utilized in Figures 11 through 14, in combination with expressing the inside diameter as a relative proportion of orifice size. At lengths equivalent to a ratio of 12:1, the curves for the three orifice sizes show a trend toward a peak performance at nozzle diameter ratios in a range of 10 to 12 times the inside diameter. With an increase to ratios of 20:1 and 28:1, the small orifice size continues to show a peaking curve, while the curves for the two larger orifice sizes begin to trend more strongly upward and further toward higher inside diameter ratios. At a ratio of 40:1, all three curves are still trending upward and toward the higher inside diameter ratio, again indicating that with increasing allowable length, the optimum inside diameter ratio to orifice size would continue to increase beyond the optimums found in this range of testing.

4. CONCLUSIONS

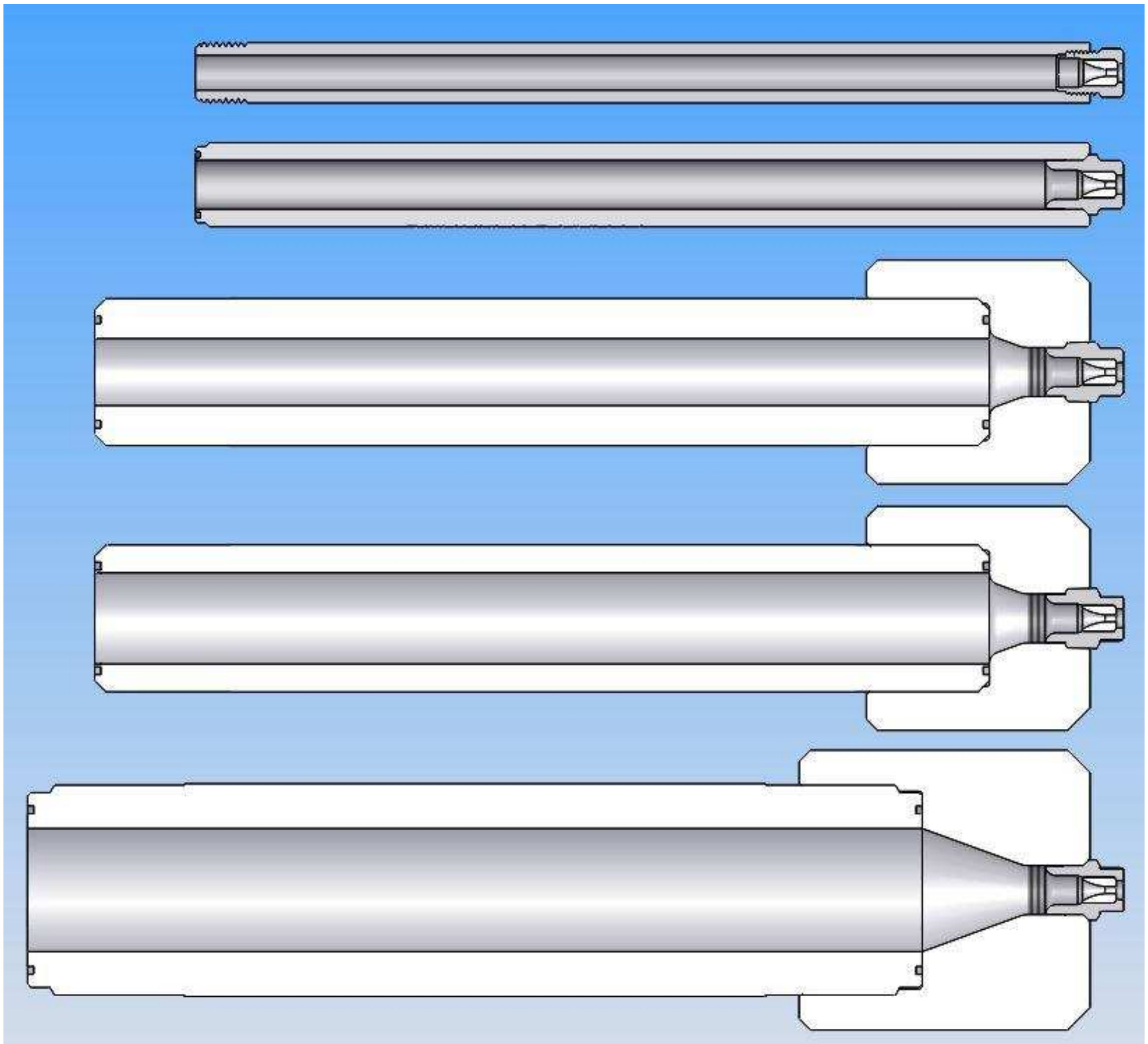
The purpose of this testing was to determine the effect that the inside diameter of a tube feeding a waterjet nozzle has on jet quality, as well as to determine if there was a relationship between the inside diameter and the overall length of the tube. The results show a dependent relationship between the orifice size, the inside diameter, and the length of the feeder tube. Performance gains due to feeder tube length can be on the order of 50 to 60%, while performance gains due to optimization of the inside diameter of the feeder tube relative to the orifice size can be on the order of 20 to 30%. In shorter feeder tube lengths combined with larger orifice sizes, the optimum inside diameter may be as low as 5 to 7 times the orifice size, while increasing the length of the feeder tube shifts the optimum inside diameter into a range of 7 to 13 times the orifice size.



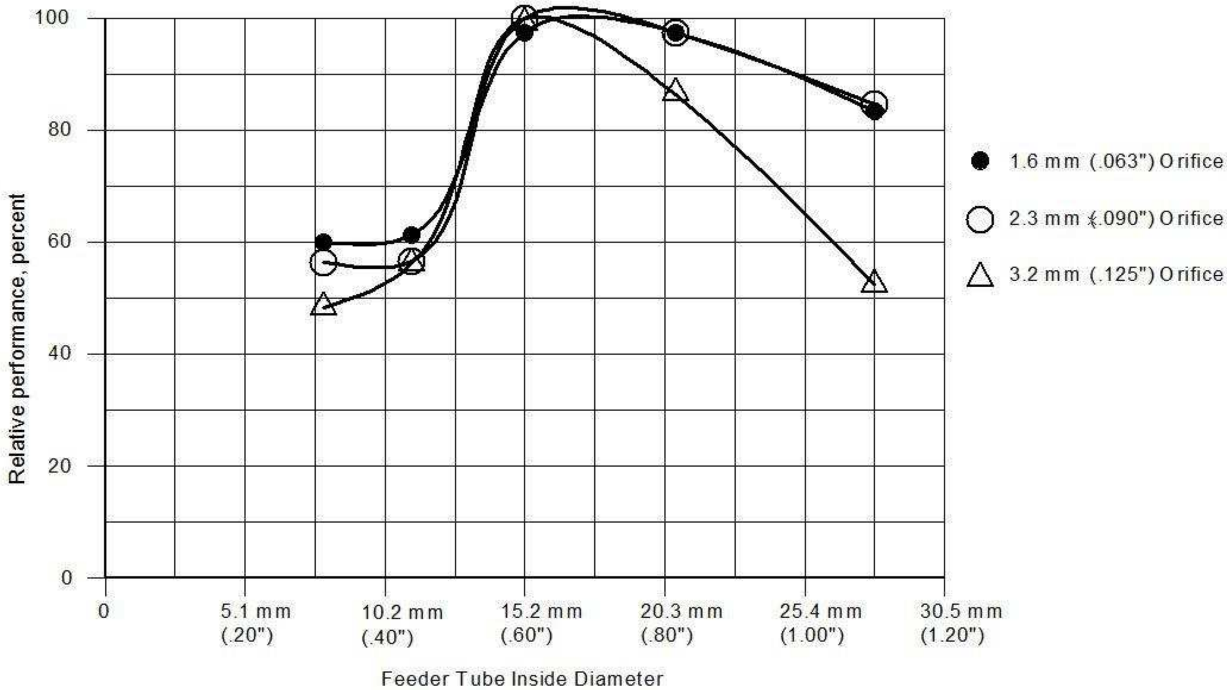
3D Tool with Long Extension Arms Used in Vessel Cleaning
Figure 1.



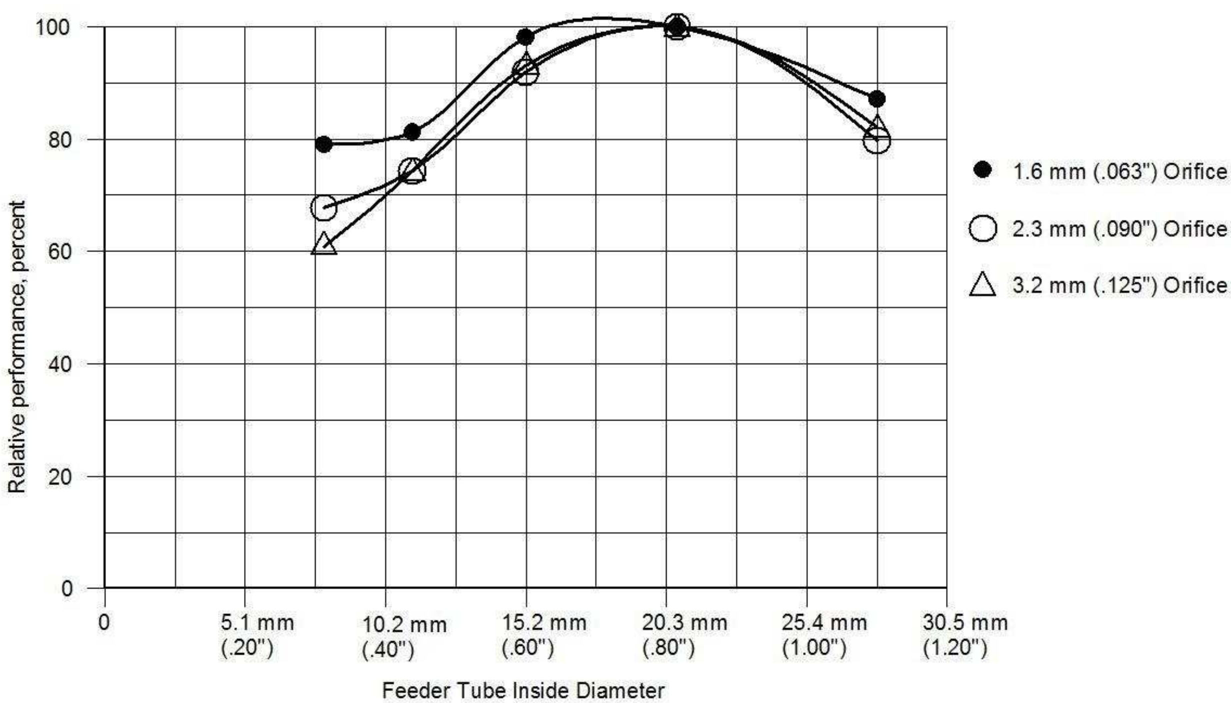
2D Tool with Long Extension Arms Used in Vessel Cleaning at Large Standoff Distances
Figure 2.



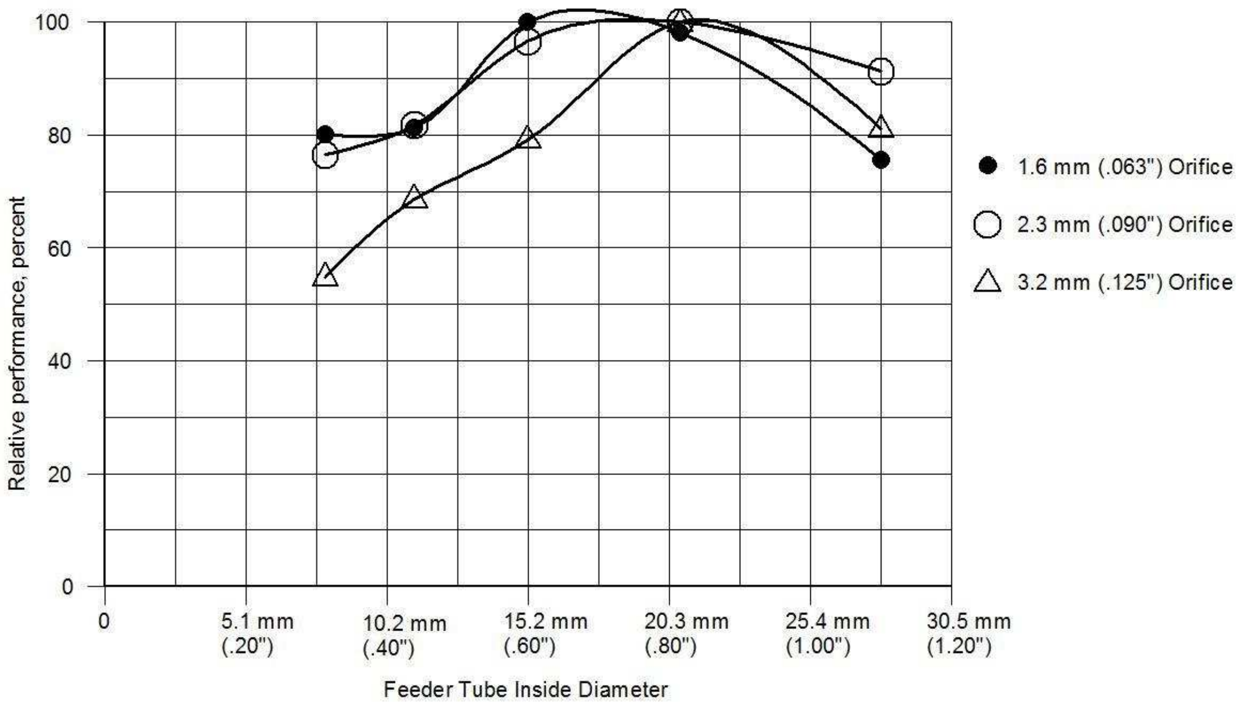
Feeder Pipes and Carbide Nozzle Holders Used in Testing
7.9 mm (.312”), 11.1 mm (.438”), 15.2 mm (.599”), 20.7 mm (.815”), 27.9 mm (1.10”)
Figure 3.



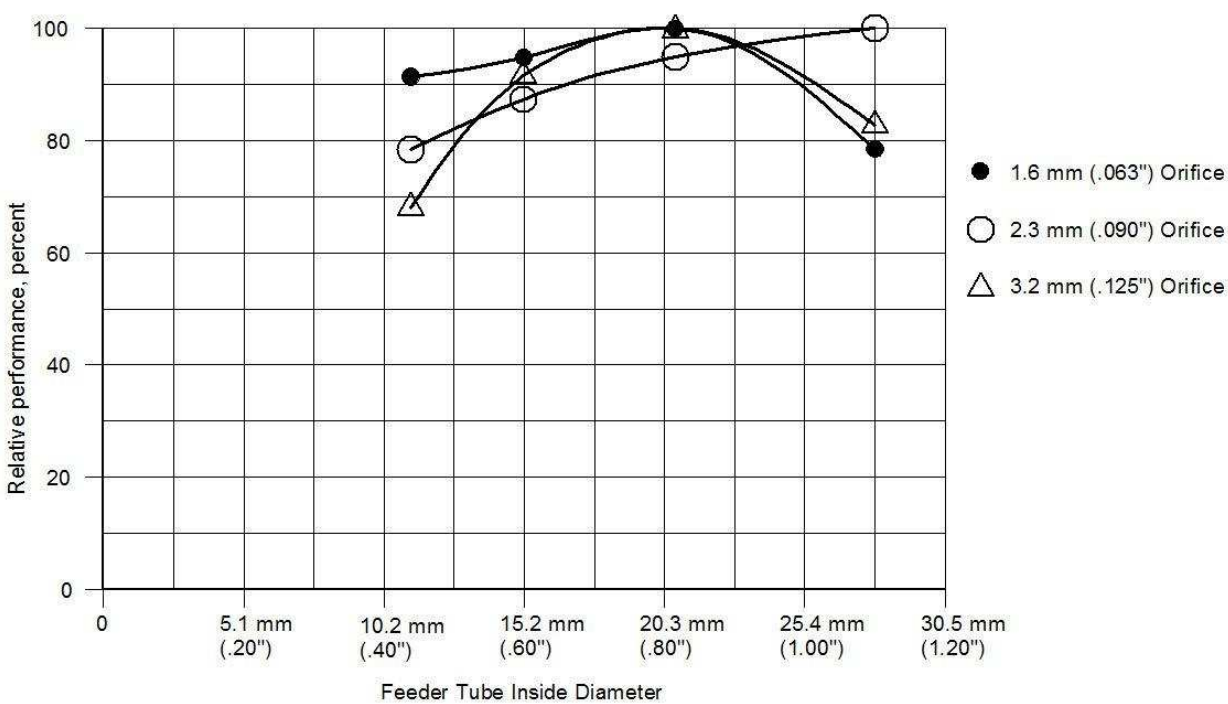
Relative Performance with Increasing Feeder Tube Inside Diameter at a Feeder Tube Length of 102 mm (4 in)
Figure 4.



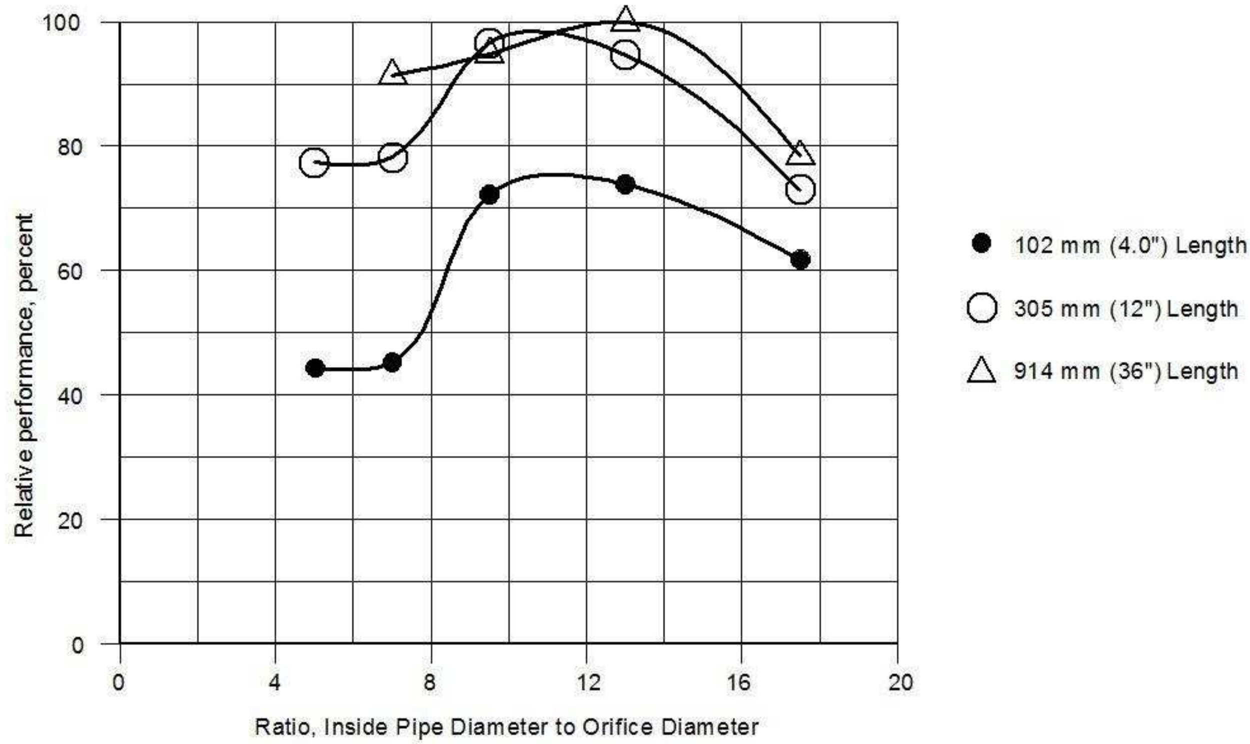
Relative Performance with Increasing Feeder Tube Inside Diameter at a Feeder Tube Length of 203 mm (8 in)
Figure 5.



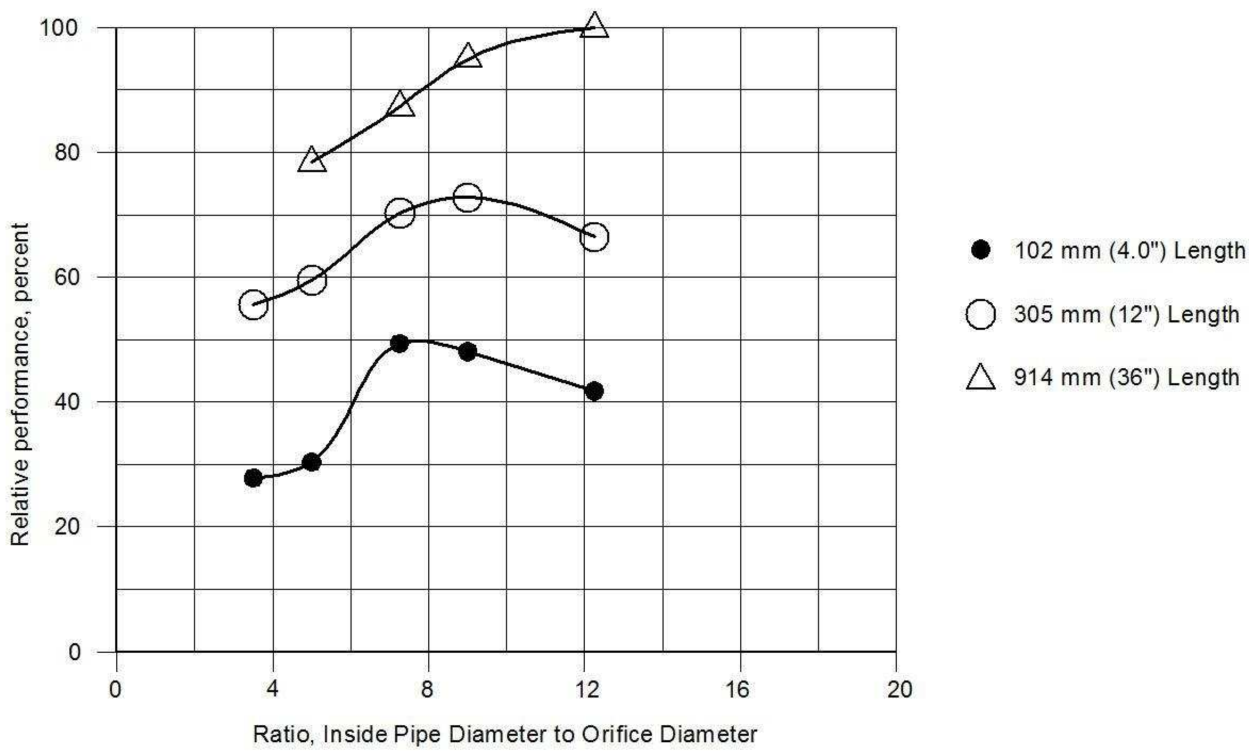
Relative Performance with Increasing Feeder Tube Inside Diameter at a Feeder Tube Length of 305 mm (12 in)
Figure 6.



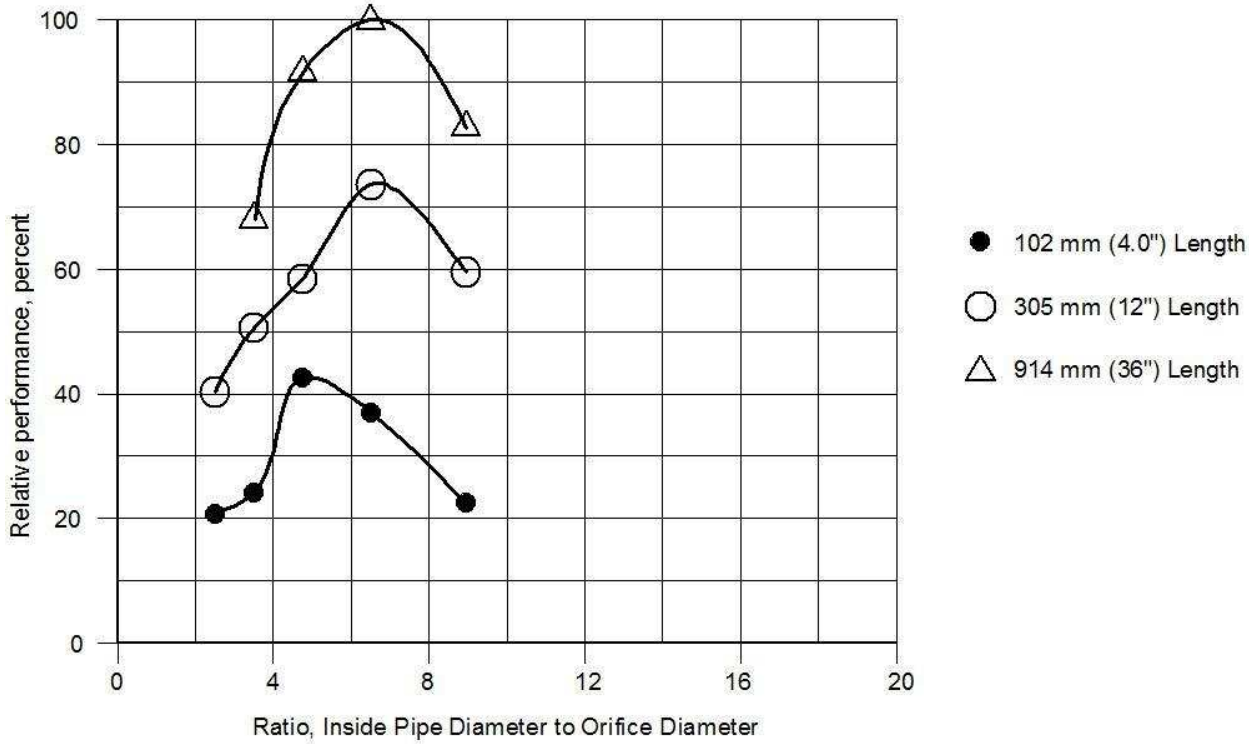
Relative Performance with Varying Feeder Tube Inside Diameter at a Feeder Tube Length of 914 mm (36 in)
Figure 7.



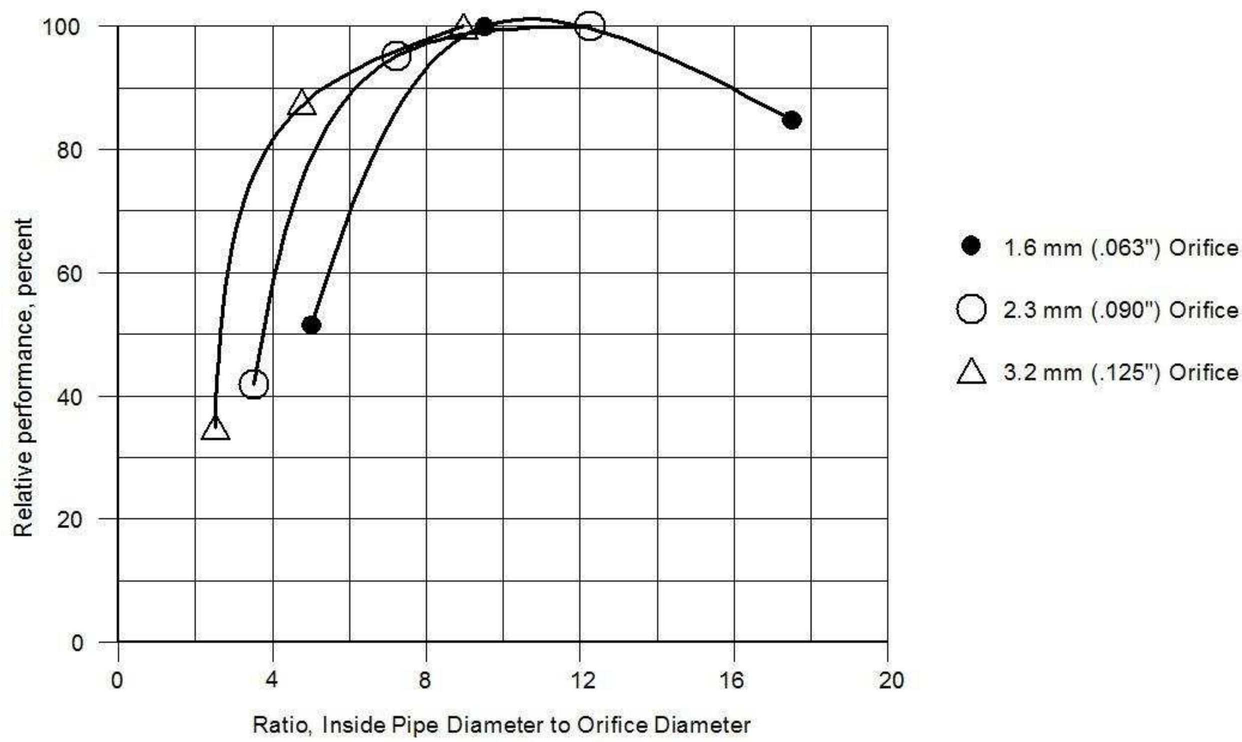
Relative Performance with Increasing Feeder Tube Inside Diameter at 1.6 mm (.063") Orifice Size
Figure 8.



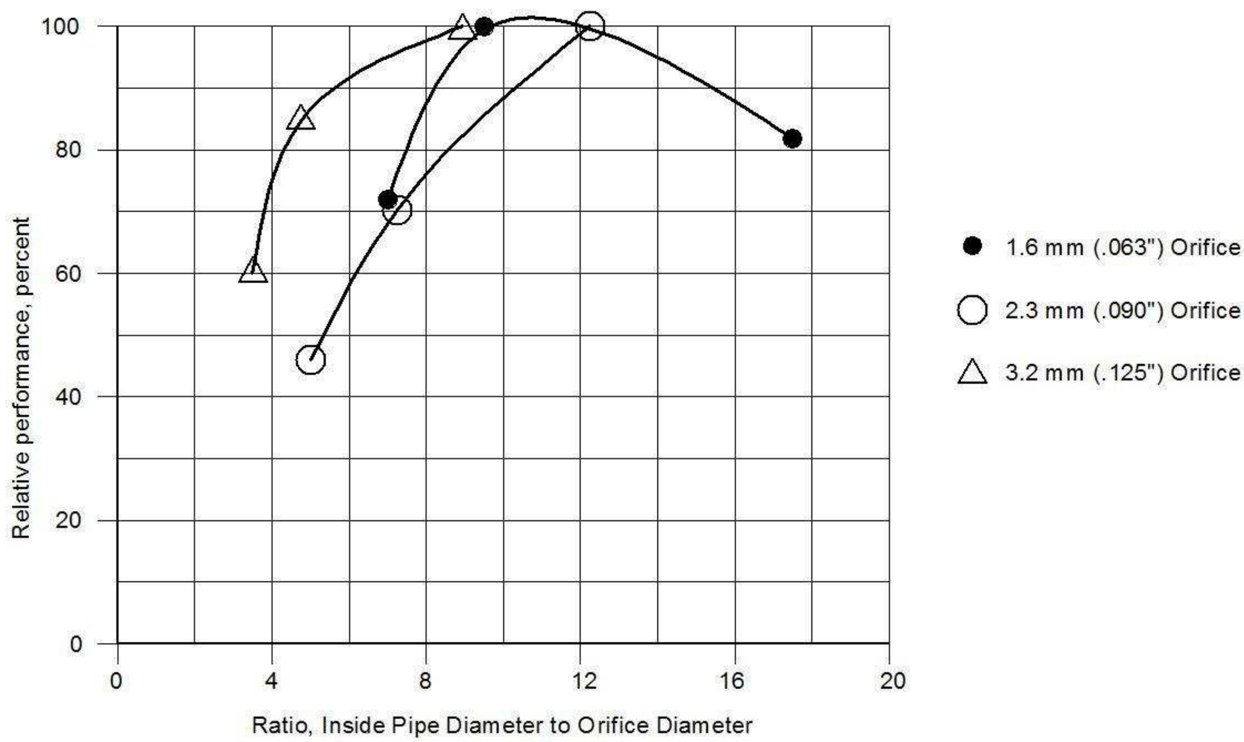
Relative Performance with Increasing Feeder Tube Inside Diameter at 2.3 mm (.090") Orifice Size
Figure 9.



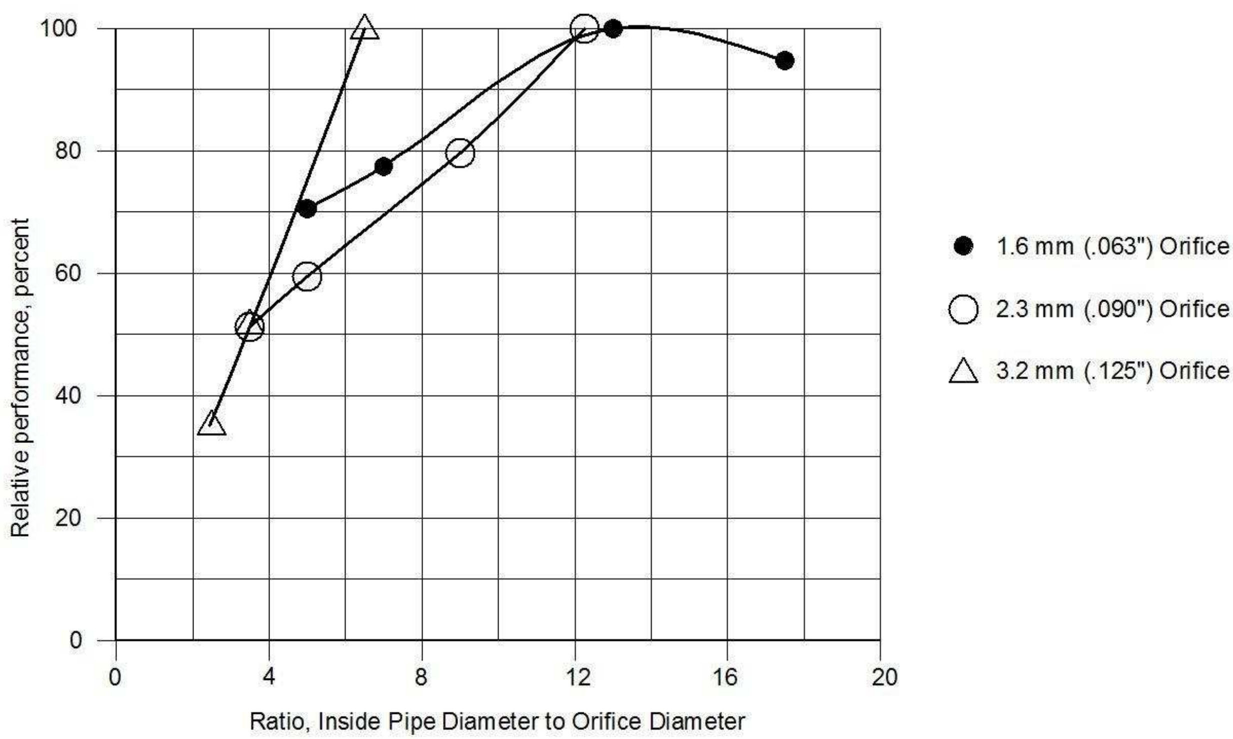
Relative Performance with Increasing Feeder Tube Inside Diameter at 3.2 mm (.125") Orifice Size
Figure 10.



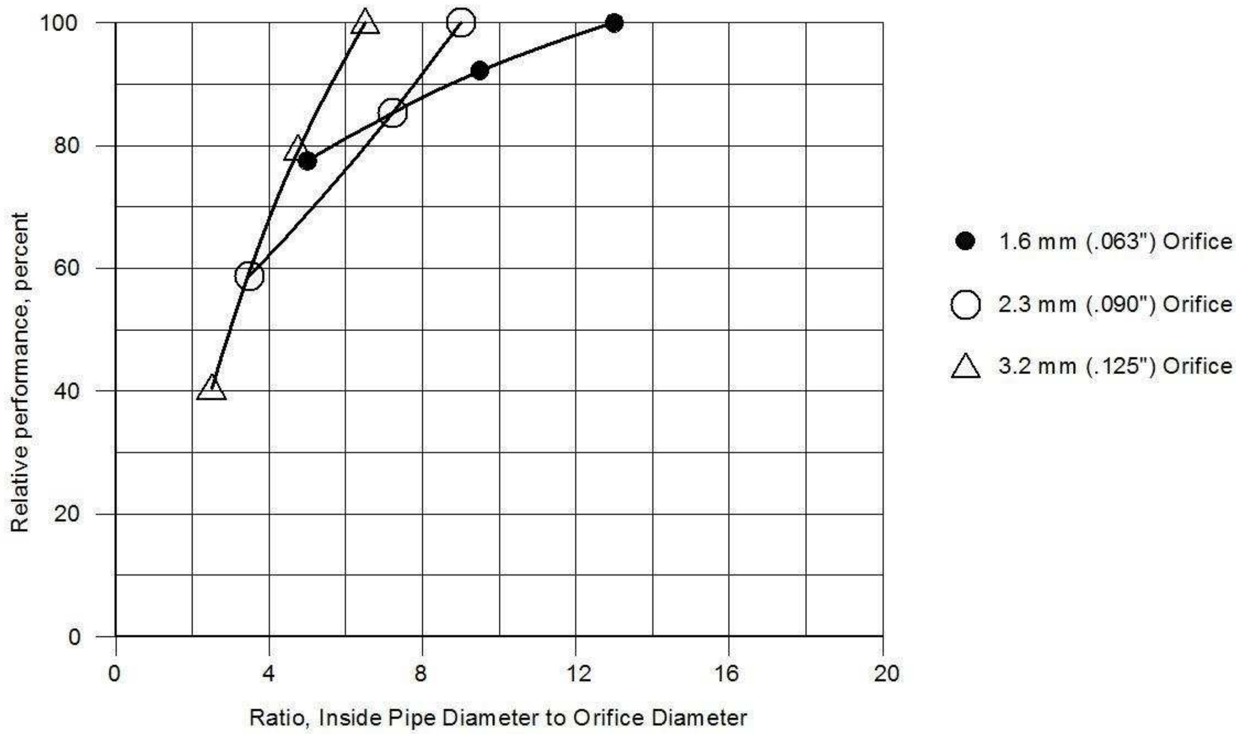
Relative Performance at a Feeder Tube Length to Inside Diameter Ratio of 12:1
Figure 11.



Relative Performance at a Feeder Tube Length to Inside Diameter Ratio of 20:1
Figure 12.



Relative Performance at a Feeder Tube Length to Inside Diameter Ratio of 28:1
Figure 13.



Relative Performance at a Feeder Tube Length to Inside Diameter Ratio of 40:1
Figure 14.