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Paper

CONFIGURING A WATERBLAST SYSTEM

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ABSTRACT

When configuring a waterblast system, it is necessary to determine the pressure, flow rate and components to effectively complete a job. The purpose of this paper is to describe and explain the considerations involved in selecting the best combination of pump and equipment. Parameters such as deposit properties, pressure loss, nozzle effectiveness, standoff distance, and rotation speed are discussed and shown how to evaluate to achieve the most effective combination.

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1. INTRODUCTION

The planning of a waterblast operation begins with determining the type of material to be removed and the size and shape of the equipment to be cleaned; these are fixed parameters on which the selection of pressure, flow and tooling are based. The access is often fixed, but in some situations provisions may be provided by the plant to allow for more effective cleaning operations. The time allowed for setup and cleaning may be somewhat variable, but is still a controlling factor. Just as important as efficiency, the safety of the operators must also be taken into consideration when selecting the means for performing the cleaning.

2. SELECTION OF PRESSURE AND FLOW

2.1 Material Properties

The jetting properties of the material to be removed and the surface to which the material is attached determine the selection of the operating pressure and flow rate. Every material has a minimum energy impact at which it will begin to be cut or fractured by a waterjet; this is known as the threshold. If the material is being removed by cutting, such as a rubber lining or other thick non-brittle deposits, or materials well bonded to the surface to be cleaned, the most efficient pressure to operate at is typically three times the minimum pressure at which the waterjet just begins to cut the material. If the material is brittle, thin, and not well bonded to the surface, higher flow rates at pressures just above the threshold can be more effective and efficient than increased pressure.

For a given flow rate from a pump, the flow is divided among the orifices used in the cleaning head. As the quantity of orifices is increased in a head, the orifice sizes must all get smaller to maintain the same flow rate. If the material deposit is thick and massive amounts of material need to be removed, the fewest possible, largest orifices should be used. For thin deposits, or if just the top surface of a material needs to be evenly removed, then more, smaller orifices should be used.

2.2 Pressure Loss

Another consideration when selecting the operating pressure and flow is the pressure loss through the hoses, fittings, and the tooling used, particularly in small tube cleaning and in long runs through pipes. Pressure loss over long runs from the pump to the cleaning site should also be considered. The pressure loss is determined from the inside diameter and the length of the hose or lance being used and the flow rate passing through. The operating pressure has no effect on the amount of loss, but it is used to determine the pressure at the nozzle orifice. To calculate the pressure loss through a hose or lance, equation 1 is used.

$$(1)\ \text{Pressure loss (MPa)} = (\text{Flow (lpm)} / (.387 \times (\text{I.D. of hose (mm)}^{2.5} / \text{Length of hose (m)}^{.5})))^2$$

$$(1)\ \text{Pressure loss (psi)} = (\text{Flow (gpm)} / (53 \times (\text{I.D. of hose (in.)}^{2.5} / \text{Length of hose (ft)}^{.5})))^2$$

The allowable pressure loss depends on several parameters. If a specific pressure is known to remove the material being cleaned, the pressure loss subtracted from the pressure at the pump must be equal to or greater than this pressure, as in equation 2.

(2) Pressure at nozzle orifice = Pressure at pump – Pressure loss

The maximum power combination of pressure and flow occurs when the pressure loss equals 1/3 of the pump pressure, and the maximum pulling force occurs when the pressure loss equals 1/2 of the pump pressure. In no case should pressure loss be more than 1/2 of the pump pressure.

When cleaning small diameter tubes in heat exchangers, the size of the tube being cleaned limits the size of the flex or rigid lance, and the length of lance is determined by the length of the tubes being cleaned. In this case, the flow rate will be determined by the allowable pressure loss. If a pump is to be operated at 138 MPa (20,000 psi), and it is known that at least 103 MPa (15,000 psi) is needed to clean the tube, and the lance to be used has an inside diameter of 4 mm and a length of 15 m (50 ft), the maximum flow rate should be limited to 21 lpm (5.5 gpm), as this produces a pressure loss of 34.5 MPa (5,000 psi).

When making long runs from the pump to the cleaning location within a plant, the desired operating pressure and flow is typically considered to be fixed, and the hose size is increased to reduce the pressure loss. Another alternative in this case is to run two hoses in parallel as far as possible before combining the flow into a single hose. This reduces pressure loss because only half the flow rate is passing through each separate hose. For example, if 151 lpm (40 gpm) will be used, and the pump is 60 m (200 ft) from the cleaning site, a single 13 mm hose would produce a pressure loss of 25 MPa (3600 psi). If two 13 mm hoses were used in parallel, the pressure loss would only be 6 MPa (900 psi). The best solution is to use a larger hose, such as 19 mm, through which only 3.5 MPa (500 psi) would be lost.

2.3 Standoff Distance

The size and shape of the equipment being cleaned, as well as the waterjet tooling being used determine the standoff distance, which is the distance that the jet must travel through the air from the exit of the orifice to the surface being cleaned. As a jet travels through the air, it loses power at a rate proportional to the orifice diameter. This loss has been measured by testing, and a typical chart of these results is shown in Figure 1. If you are at a standoff distance of 400 nozzle diameters, the jet power will be 40% of what it would be with no standoff distance. So if you are operating at 69 MPa (10,000 psi) at the pump, the impact at the surface is comparable to 27.6 MPa (4,000 psi) in this case. To determine the standoff distance in nozzle diameters, divide the standoff distance by the orifice size; for example, this ratio with a 610 mm (24 in.) standoff distance using a 1.6 mm (.062 in.) nozzle is 387.

If it is known that the material to be removed requires an equivalent impact of at least 34.5 MPa (5000 psi), one can use this curve to calculate the required combination of pressure and flow to achieve this. Increasing flow while keeping the pressure at 69 MPa (10,000 psi) would increase the size of the orifice being used, thus changing the ratio of standoff distance to nozzle diameter. To achieve a relative impact of 50%, the orifice size would have to be increased to achieve a ratio of 250; the orifice size can be determined from this by dividing the 610 mm (24 in.) standoff distance by 250, which would be a 2.4 mm (.096 in.) orifice.

The other approach would be to increase the operating pressure; if it were increased to 103 MPa (15,000 psi), the power could deteriorate to 33% and still achieve the relative impact of 34.5 MPa (5000 psi). This occurs at a ratio of 550, resulting in an orifice size of 1.1 mm (.044 in.) The power to produce these two possible combinations can be compared as well: the lower pressure, higher flow requires 100 kW (134 hp), while the higher pressure, lower flow requires only 42 kW (56 hp). While it is obvious which is the most efficient, the decision may be based on available pumps, hoses, fittings and tooling.

In some situations, it is possible to use extension arms to reduce the standoff distance, which has an additional beneficial side effect beyond just moving the jet closer to the surface to be cleaned. The extension arm acts as a flow straightener for the water going to the nozzle orifice, resulting in a more coherent jet that travels further with less deterioration. Figure 2 compares the curves for jet performance with an extension arm to the curve from Figure 1, which was measured with a jet exiting directly from a nozzle head, as illustrated in Figure 3.

3. SELECTION OF TOOLING

The selection of tooling to use on the end of the hose is primarily based on what will fit into the pipe or vessel to be cleaned, and on getting the jets close enough to the surface being cleaned to be effective. The other criteria in tool selection are pressure and flow capacity of the tool, the possible porting configurations, and the rotation speed range.

3.1 Pipe Cleaning

The basic parameters for tool selection in pipe cleaning are the pipe diameter, whether the pipe is straight or has elbows, and the length of the run. Depending on the difficulty of the material to be removed, the use of centralizers and extension arms may be needed to reduce the standoff distance in larger pipes, and whether the pipe has scale or is partially or fully blocked will determine the location and number of orifices in the cleaning head. Rotation speed of the head is determined by the size of the pipe and the nature of the deposit to be removed.

3.1.1 Tool Selection

Many sizes and configurations of self-rotary pipe cleaning tools are available. Typically, larger tools are more durable and have greater flow capacities than smaller tools. Figure 4 illustrates a self-rotary tool with a centralizer and extension arms as would be used in straight runs of pipe larger than 305 mm (12 in.) diameter, while Figure 5 shows a shorter self-rotary tool specifically designed for use in pipes with elbows. Always make sure that the rigid length of the tool and hose end is at least 1.5 times the inside diameter of the pipe to prevent the tool from turning around; use a rigid stinger between the hose and the tool if necessary to achieve this, as shown in Figure 6. The tool will still be able to go around an elbow at this 1.5 ratio.

3.1.2 Jetting Configurations

Self-rotary tools have the advantage of using fewer and thus larger orifices than non-rotary heads while achieving complete coverage of the walls of the pipe being cleaned. The location and quantity of the orifices in the rotary head are dependent on whether the pipe is blocked requiring forward facing jets, or has scale on the walls, requiring outward (radial) jets, and how much pulling force is needed, requiring rearward facing jets. Orifices of equal sizes should be installed opposite each other to balance the head from side to side.
When a tool is making a horizontal run, each pound of pulling force from the jets will pull between 1.5 and 3 m (5 and 10 ft) of hose, depending on the weight of the hose and the vibration created by the pump pulsations. If a tool must climb straight up, the jet pull must be at least equal to the weight of the tool and the weight of the length of hose being lifted.

3.1.3 Rotation Speed

The rotation speed of the head is limited by the available speed range of the tool being used, but many have adjustable speed. Rotating slower than necessary will increase the time it takes to complete the cleaning, as the rate at which the tool is advanced through the pipe should be reduced to achieve complete coverage. However, in the case of very thick deposits on the pipe wall, a slower rotation speed may be most effective. The jet can penetrate through the deposit and by means of pressurizing between the pipe wall and the material, cause the material to break loose from the pipe wall.

The maximum rotation speed is dependent on the diameter of the pipe and the standoff distance. As the pipe gets larger, the jet will be moving faster across the surface for the same rotation speed. In a pipe with 305 mm (12 in.) diameter and a head rotating 300 rpm, the surface speed is 4.6 m/s (15 ft/s); the same rotation speed in a 915 mm (36 in.) pipe has a surface speed of 14.3 m/s (47 ft/s). The effect of surface speed is shown in Figure 7; at close standoff distance, a surface speed of up to 16.8 m/s (55 ft/s) does not lose any effectiveness, but as the standoff distance increases, the maximum surface speed decreases to 13.7 m/s (45 ft/s) before showing deterioration. This becomes a very important consideration in very large pipes, tanks, and stack cleaning, where diameters of 3 m (10 ft) or more are common. With a 3 m (10 ft) diameter vessel, the rotation speed should be no more than 80 rpm to maintain a surface speed of 12 m/s (40 ft/s) or less. The surface speed in a round pipe or vessel is calculated using equation 3.

$$\text{(3)} \quad \text{Surface Speed (m/s)} = \text{RPM} \times \text{Diameter (m)} / 19.1$$

$$\text{(3)} \quad \text{Surface Speed (ft/s)} = \text{RPM} \times \text{Diameter (ft)} / 19.1$$

3.2 Tube Cleaning

Tube cleaning may be done by hand held flex lancing, machines that feed flex lances, or rigid lances mounted on a machine, with rotation provided by a motor. There exists two basic tube cleaning jobs, those with scale on the walls of the tubes but tubes are otherwise open, and completely plugged tubes. Cleaning of scaled tubes is often referred to as polishing. Because of the small sizes of hoses or lances used, the flow rate may need to be limited to minimize pressure losses.

3.2.1 Nozzle Selection

Tube nozzles are typically either non-rotating tips with as many as 20 orifices, self-rotary nozzles with 2 to 7 orifices that are installed on the end of a non rotating flex or rigid lance, or tips with 2 to 7 orifices to be installed on the end of a rotating lance. As with pipe cleaning, the use of rotation allows complete coverage with fewer, larger jets. The tube size determines the maximum size of the lance tip and the lance. When cleaning plugged tubes, the nozzle used should be no larger than 2/3 to 3/4 of the tube diameter. The nozzle diameter should be larger than any couplings or hose ends to prevent material from catching on these.

3.2.2 Jetting Configurations

Flex lance nozzles are usually jetted to produce several pounds of pulling force; this is accomplished by the use of rearward facing jets. In unplugging patterns, this requires about 60% of the water to the back jets; this water is practically wasted, as the rearward facing jets are too poor in jet quality to do much effective material removal. They are only there to provide counterbalance to the forward facing jets, and when a rigid lance is used on a securely supported lancing machine, there is no need for backward facing jets. There is no extra flushing provided by the rearward facing jets; in a plugged tube, the water has nowhere else to go but out the clean end of the tube, carrying cuttings with it.

3.2.3 Rotation Speed

The same surface speed parameters apply in tube cleaning as in pipe cleaning; the biggest difference being the much smaller size of the tubes. In a 25 mm (1 in.) tube, the rotation speed to achieve the maximum recommended surface speed of 16.8 m/s (55 ft/s) is 12,600 rpm, which is why the high speed self rotary nozzles can be effective in small tube cleaning. But with this high speed comes rapid deterioration with standoff distance, so a nozzle with a larger diameter should be used in larger tubes.

3.2.4 Feed Rate

In both tube and pipe cleaning, an estimated feed rate can be determined using the rotation speed and the number and size of the jets. This is only an estimation, as the material may need to be hit several times by the jet before being completely removed, but it does serve as a useful starting point. Equation 4 is used to calculate the feed rate. Typically a jet spreads and has an effective impact path greater than the orifice diameter; this factor may be included as a multiple in this equation.

(4) Feed Rate (mm/min) = RPM x Number of Jets x Orifice Diameter (mm) x Jet Spread

(4) Feed Rate (in./min) = RPM x Number of Jets x Orifice Diameter (in.) x Jet Spread

3.3 Vessel and Tank Cleaning

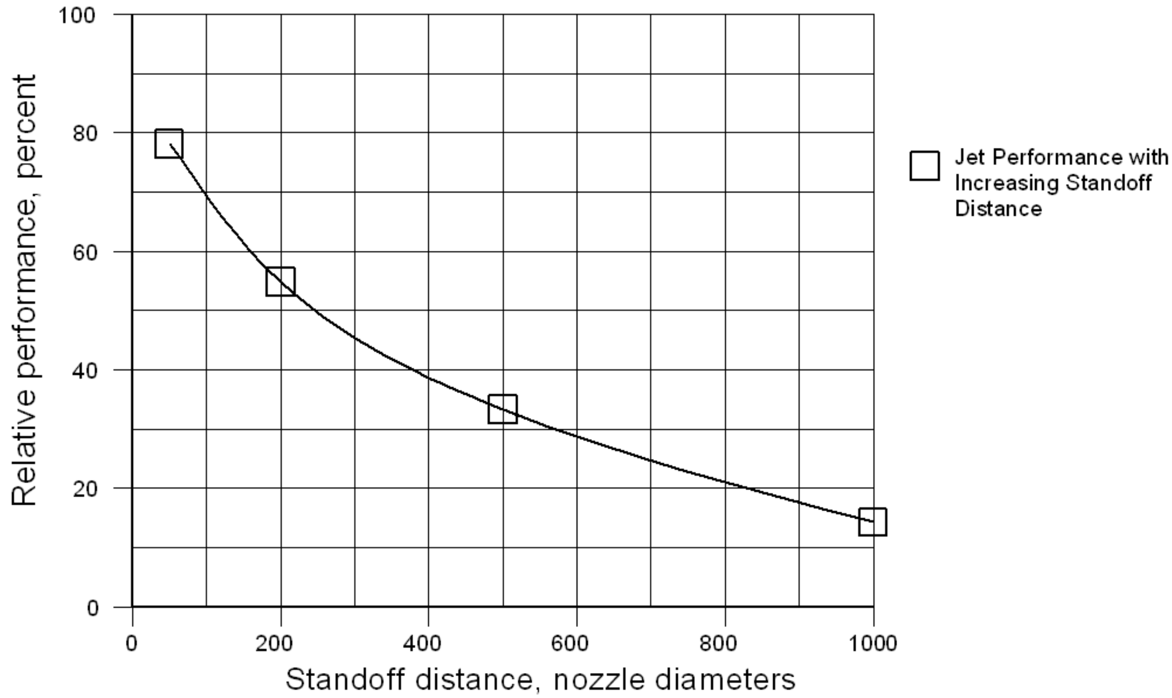
Large tanks and vessels can be among the most difficult cleaning challenges due to their large size, limited and confined space access and internal geometries. The simplest equipment to use is a 3-D type tool, although the most efficient means is a 2-D tool moved along the axis of the vessel. Unfortunately, in most tanks this is not possible due to central obstructions such as agitators. Standoff distances can be quite large; the effective cleaning range can be estimated as explained in Section 2.3 of this paper. Rotation speed and surface speed are also important considerations due to the large size of the vessels being cleaned.

The simplest method for using a 3-D tool is to hang it by the high pressure hose as shown in Figure 8. A 3-D tool is most effective if left in place to operate through a cleaning cycle, as opposed to continuously moving it as is done with a 2-D type tool. Several types of positioners for 3-D tools allow placing the tool closer to the surface to be cleaned, and to position the tool on the far side of obstructions, as shown in Figures 9 and 10.

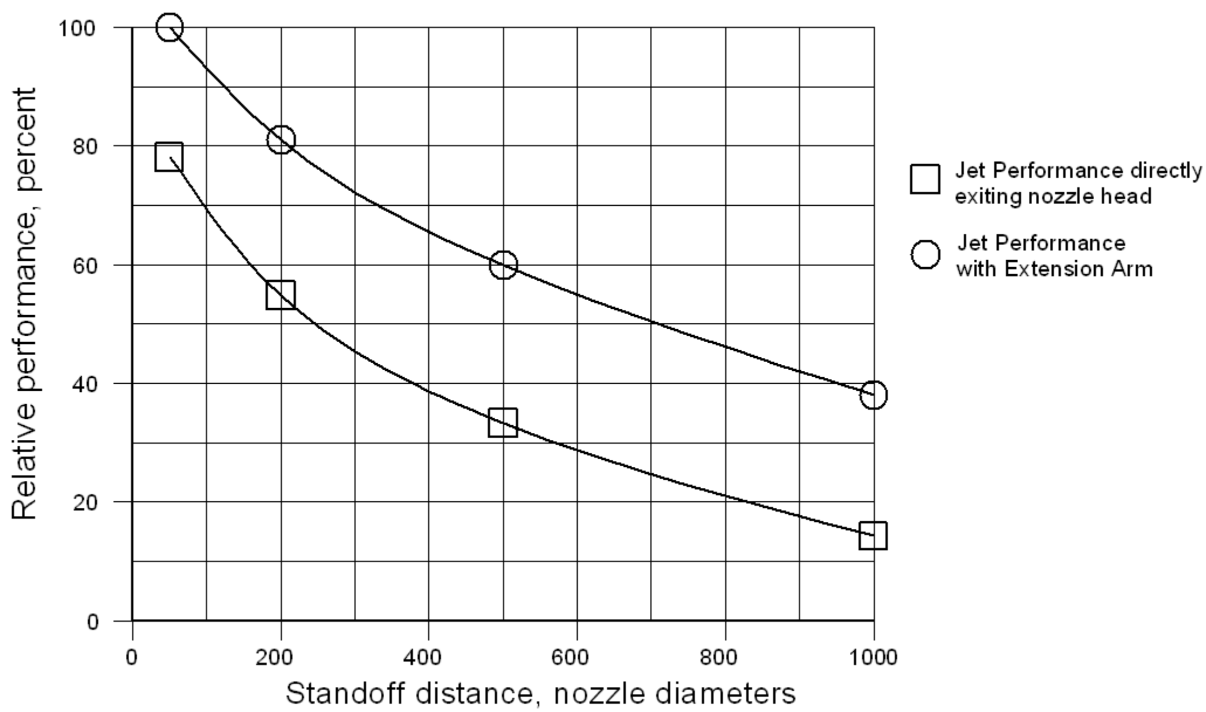
Large diameter tanks, stacks and vessels that have an open center and a means of accessing the center can most effectively be cleaned using a 2-D rotating tool that is slowly raised or lowered to achieve complete coverage, as shown in Figure 11. In this fashion, the jets are always directly aimed at the wall with a relatively close and constant standoff distance.

4. SUMMARY

There are many variables in waterblast cleaning applications, from types of equipment to be cleaned to the deposits that must be removed. This paper covered the basics to methodically approach these tasks and the parameters that influence all applications.



Jet Performance Relative to Standoff Distance
Figure 1.



Relative Jet Performance of Extension Arm Compared to Directly Exiting Nozzle Head
Figure 2.

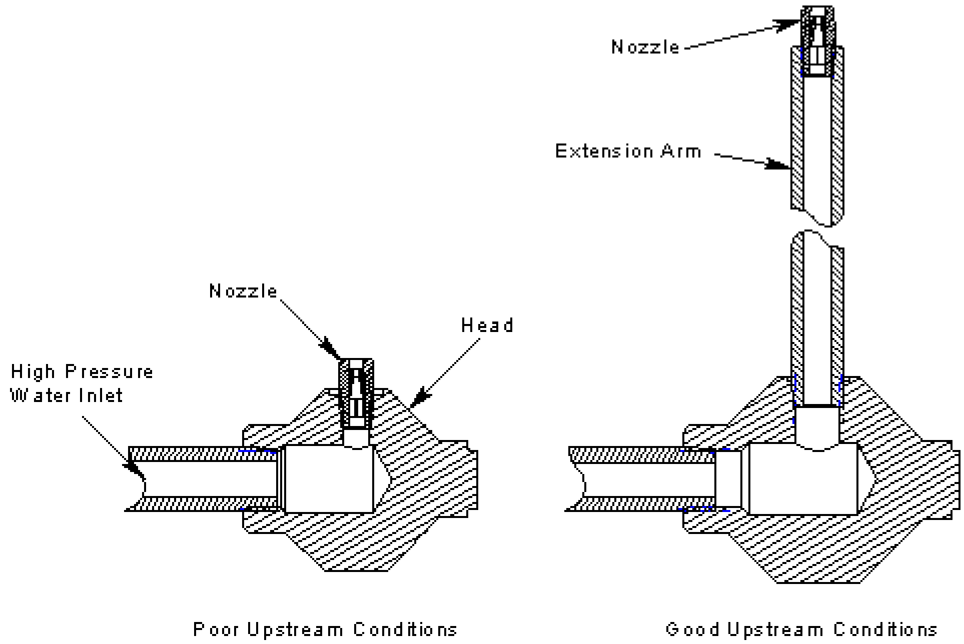
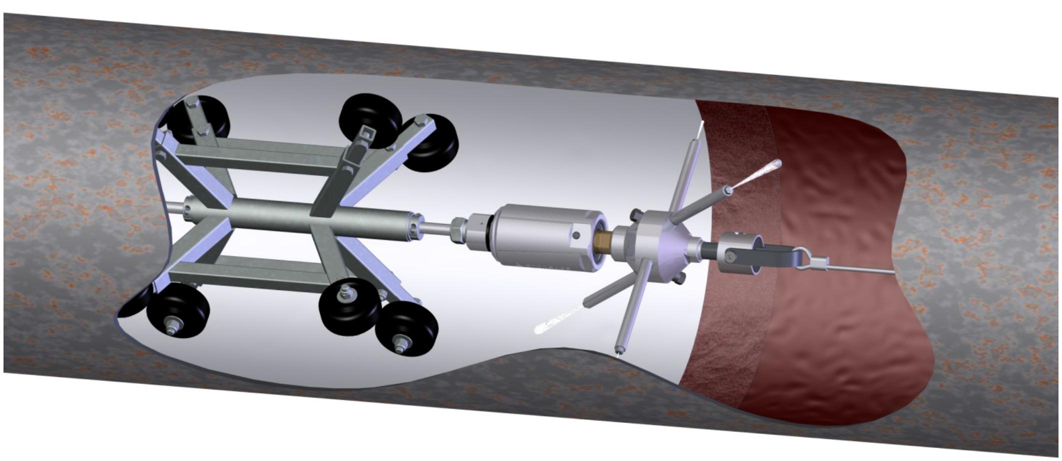
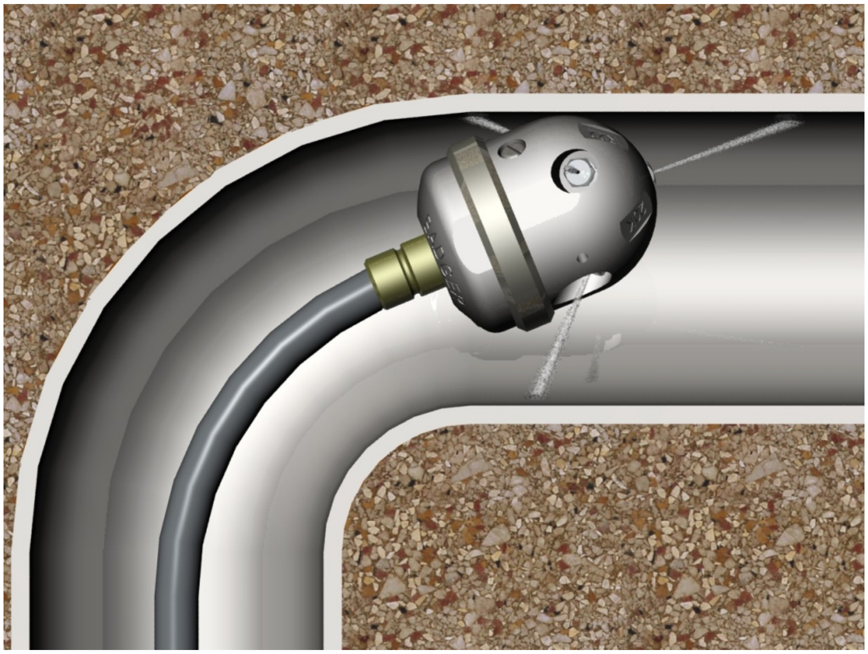


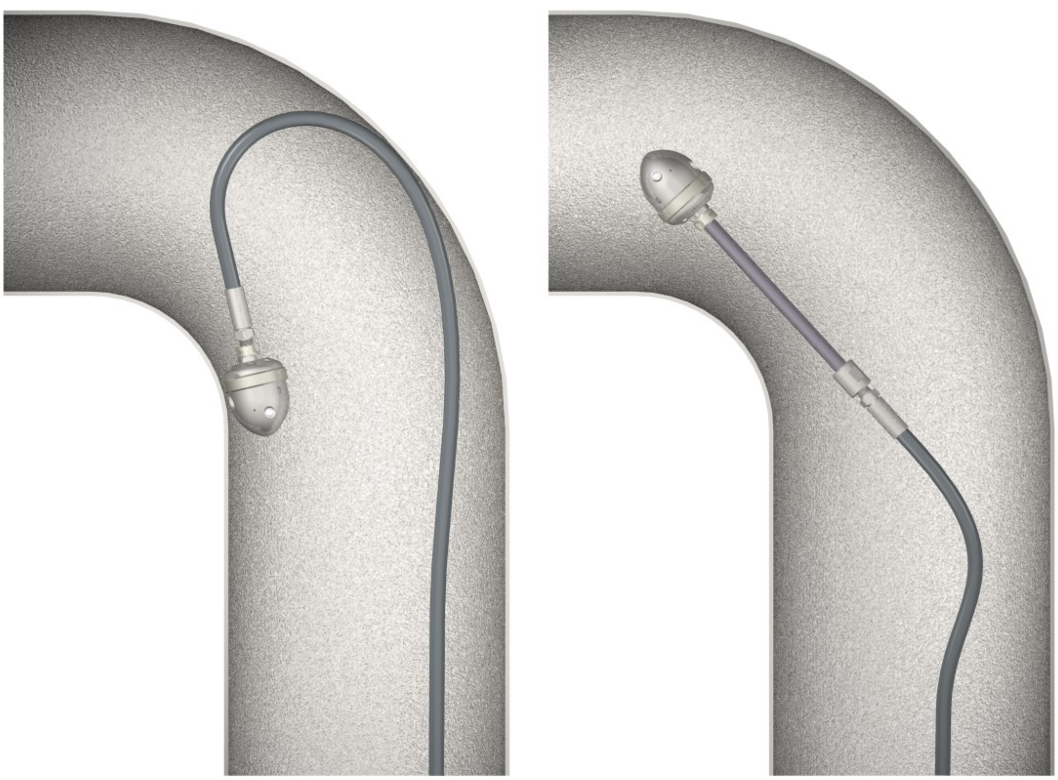
Illustration of Nozzle Exiting Head and Nozzle Exiting from Extension Arm
Figure 3.



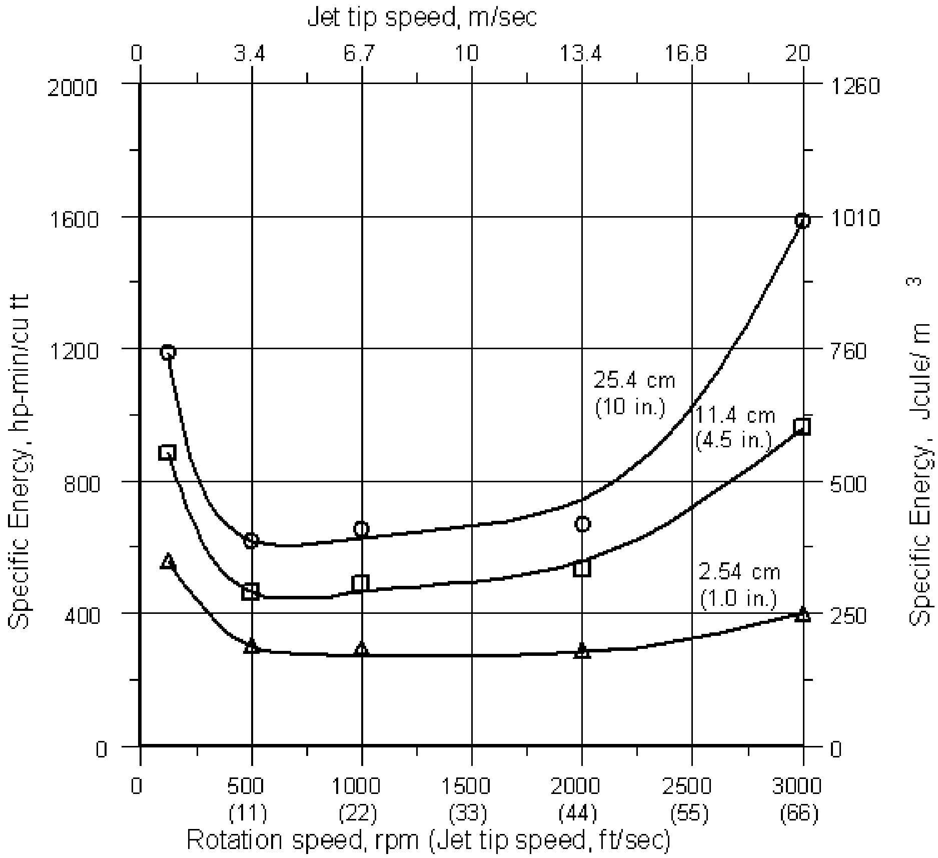
Self-Rotary Nozzle with Extension Arms and Centralizer for Large Pipe Cleaning
Figure 4.



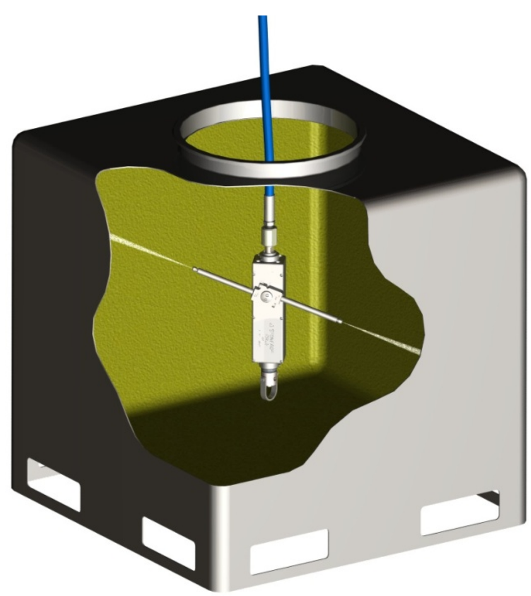
Self-Rotary Nozzle for Cleaning Pipe with Elbows
Figure 5.



Use of a Rigid Stinger in Pipe Cleaning to Prevent Tool from Turning Around in Pipe
Figure 6.

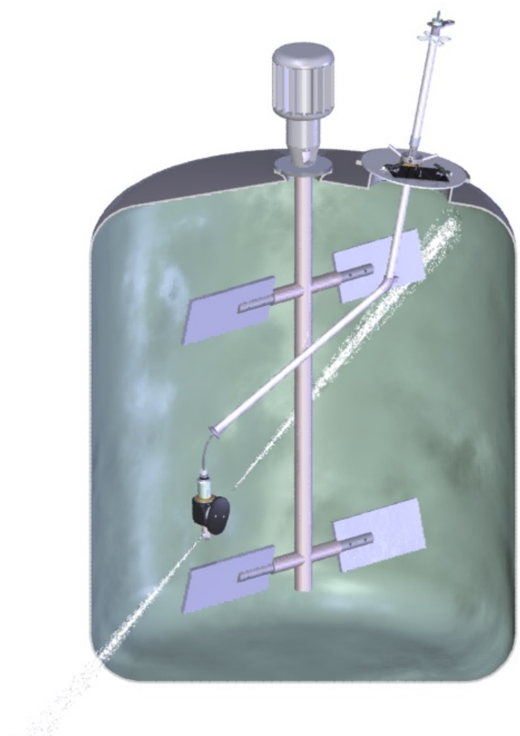


Effect of Surface Speed on Jet Performance
Figure 7.

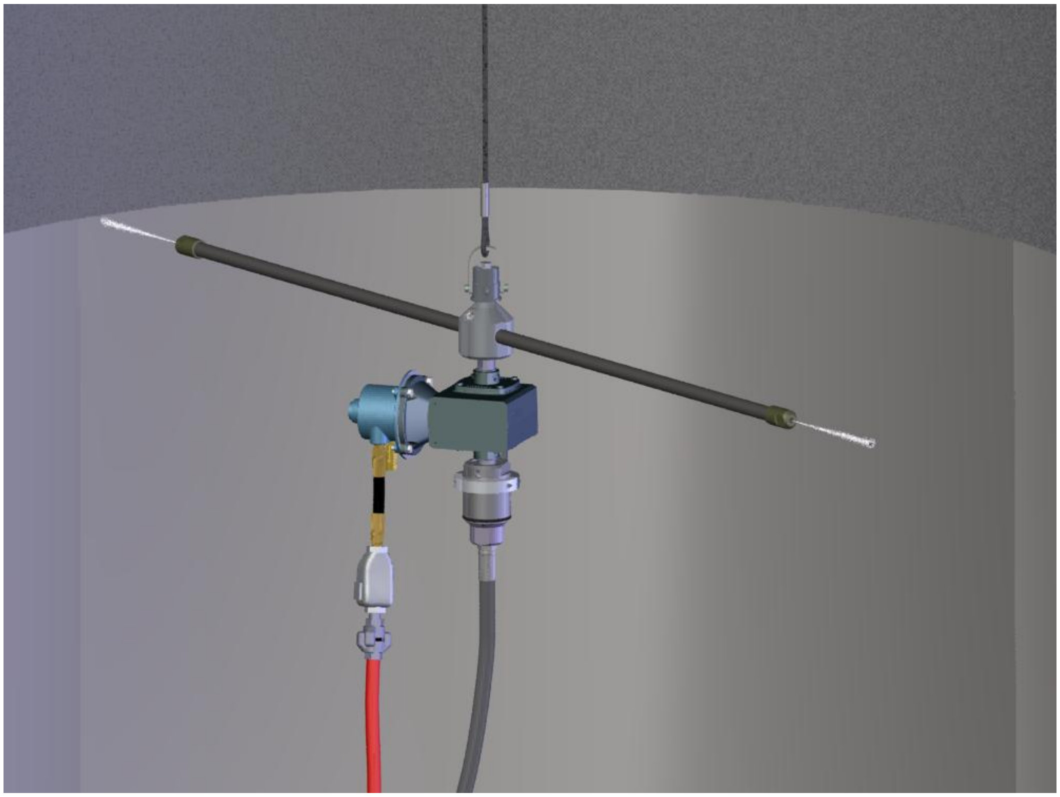


3-D Cleaning Head Hanging from High Pressure Hose
Figure 8.

Positioning of 3-D Cleaning Head Closer to Wall of Tank
Figure 9.



Positioning of 3-D Cleaning Head on Far Side of Obstruction
Figure 10.



2-D Head in Large Tank and Stack Cleaning
Figure 11.