WJTA Jet News

Water Jet Technology Association

FEBRUARY 1990

818 Olive Street, Suite 918 • St. Louis, MO 63101, USA • 314/241-1445

From the President's Desk

Planning has begun for the Sixth American Water Jet Conference to be held in August 1991 in Houston, Texas. George Rankin, of Aquadyne, is the chairman of the organizing committee.

This meeting will break with tradition by starting on a Saturday and concluding on the subsequent Tuesday. By staying over a Saturday night, the membership will be able to take advantage of discount airfares.

The meeting will begin on Saturday with a short course on waterjet technology. The short course at the Fifth American Water Jet Conference attracted 80 students and should also be very popular in Houston. This course will be based on the Water Jet Technology Association's new textbook on waterjet technology. Tom Labus is editing the textbook and will be in charge of the short course.

Technical sessions and an equipment exhibition will begin on Sunday. A reception will be held on Sunday and a banquet on Monday night. The Pioneer Award will be presented at the banquet.

Panel discussions by water-jet cleaning contractors will be held in an attempt to disseminate practical water jetting knowledge to a wider audience. Andrew Conn is the chairman of a subcommittee which will organize these panel discussions.

The following is a planning schedule for the Sixth American Water Jet Conference:

March 1, 1990
Selection of hotel

March 2, 1990
Announcement of conference

April 10, 1990
Call for papers

July 1, 1990
Call for exhibitors

Nov. 1, 1990
Abstracts due

May 1, 1991
Manuscripts due

Houston is a major center for practical waterjetting in the U.S. We are optimistic that the Sixth American Water Jet Conference will be successful and exciting.

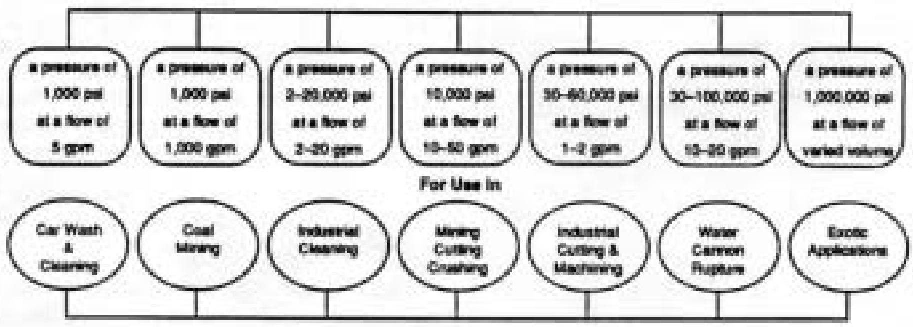
- George A. Savanick, Ph.D.

Fluid Jet Technology - A Historical Perspective

by Dr. David A. Summers, University of Missouri, Rolla, MO

Water jetting is not really new, and there is a considerable community of knowledge which can be obtained from the area of waterjet cleaning, or "hydroblasting," which has been developed for over 60 years. The word "hydroblasting" is used with caution because it creates the vision of cleaning at higher pressures, while the majority of the market, to date, has used 1,000 to 2,000 psi. Because of the confusion which may exist, and perhaps to review the scope of the different areas into which waterjetting has been used, this paper begins with an outline of the various segments of the community (Fig. 1). In so doing, some of the basic parameters controlling the use of waterjets can also be introduced.

Figure 1. *High Pressure Water Jet Systems Can Be Operated At*



with potential improvement by

Polymeric Additives Cavitation Bubble Collapse Abrasive Injection Hydromechanical Cutting

Low Pressure Usage

By this definition, the upper limit on pressure for this group will be considered to be 5,000 psi. This is not a completely arbitrary number. It is chosen because, in cleaning applications, this is the pressure above which industrial manufacturers usually feel that too much energy is required to improve jet performance by heating the water. This is not always true, since there are specialized applications where heat is added to higher-pressure systems, but stands as a general rule of thumb. In this segment, there are two main types of application, divided by the quantity of water which they use.

Low-Volume Flow

At 5 to 10 gpm, the major use is in industrial cleaning. Systems are available from many sources (for a list of which, contact the Cleaning Equipment Manufacturer's Association [CEMA] in Chicago). At its most simple, a unit will consist of a prime mover, such as a motor, which drives a small pump either directly or through a fan belt. Water from the pump is fed through a hose, to a handle, from which protrudes a long length of high-pressure tubing, known as a lance, on the end of which a nozzle is fixed.

In order to control the pressure at the end of the lance, the handle is fitted with a controlling trigger. By pulling the trigger, the operator will deflect the fluid flow from a larger diameter dumping circuit, along the lance and out of the nozzle. The jet acquires its velocity as a result of having to pass through the very small hole in the nozzle. The pressure from the pump is that which the pump puts out, through the hole in the end of the nozzle. Thus, with a pump which puts out a steady flow of water, the pressure of the jet which comes out of the end of the lance is controlled by the size of the orifice in the end of the nozzle.

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"A hundred times a day I remind myself that my inner and outer life are based on the labors of others...living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving."

Albert Einstein

Accident Case Study - Engineering Works

by Paddy Swan, S.P.D. Swan Consultants, Derbyshire, U.K.

A single operator was set to wash machine parts at about 1,500 psi (100 bar) and approximately 2 gpm (9 l/m). He was provided with an electrically-driven, hot-pressure washer operating at about up to 60° C which was of the dry shut-off type, i.e., having an unloader and a dry shut-off gun. The pump had a chemical injector and a detergent specified by the manufacturer was being used.

The operator had adapted the gun by shortening the barrel so that he could hold small engine parts in one hand while jetting them with the gun held in his other hand. The jetting area was confined and signed and the operator with 6 year's experience was jetting, sitting at a bench which had a sump and splash screens to avoid spray back and to allow water to be drained away from the workplace.

The operator had, in addition, a foot pedal attached to a solenoid valve which allowed him to switch the pump on and off. He was provided with the following protective clothing which he only wore as a rule when he was asked to jet outside away from his normal working area: helmet, goggles, ear defenders, waterproof clothing, steel toe-capped wellington boots, and gloves. The operator was paid on a bonus system based on productivity and had received a large consignment of engine parts.

While jetting off the engine parts using the jetting unit with water at about 30-40° C and chemical, the operator hit himself with the jet making a pinhole injury on the thumb of his left hand. He reported to the work's sickbay, who investigated the injury, dressed it, and he returned to work, but carried out no further jetting during the rest of the day.

In the night after leaving work, the operator felt sick and went to see his doctor in the morning. The doctor diagnosed shock, and though the injury was now red and angry did not prescribe antibiotics, but told the operator to take 2 or 3 days off work and call back if there was any further discomfort. Twelve hours later he was rushed to the hospital with general blood poisoning and his life was at risk.

WHAT STEPS MIGHT THE OPERATOR HAVE TAKEN TO AVOID THE ACCIDENT AND LESSEN HIS SUBSEQUENT PROBLEMS?

(see answer on page 10)

The Cutting Edge

by George A. Savanick, Ph.D.

The following are some unresolved issues being debated currently among water jetters:

- How long should hand-held lances be?
- How can you safely clean silicon carbide grinding wheels?
- How many hydroblasting units are working?
- How can large items be cut?
- What is the thinnest cut that can be made in thick metal tubes?
- Can storage tanks be cut safely with abrasive jets?

Short lances can be dangerous (see Paddy Swan's article) and long lances can be cumbersome. The debate continues on what minimum length should be specified for shotgunning.

Grinding wheels can be cleaned with waterjets, but the jets can also degrade the strength of the wheel. Does anyone know the maximum energy and the optimum mode of placement of this energy for this application?

A census of waterblasting units working worldwide is needed. This information is not available now.

Cutting large objects or thick items can strain the creativity of water jetters. A communication company wants to cut microwave antennas in pieces so that they can be transported and placed on top of tall buildings.

Cutting thin kerfs in tubular metal pieces is difficult because the jet expands in the airspace in the tube bore. A bearing manufacturer is looking for a way to make 0.010-inch cuts in 1-inch-thick tubular bronze. The state of the art now appears to limit these cuts to about 0.040-inch.

Tank farm decommissioning is also of interest. An environmental company needs to know if it is safe to use abrasive jets to dismantle chemical tanks which had been used to store explosive or reactive chemicals. The question revolves around the ability of potential sparks to cause a chemical reaction or explosion.

Jet News would welcome any comments that readers would like to make on these issues. Write us a letter and join the debate.

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Pressure and Nozzle Diameter

Making sure that the nozzles are in good condition is an important part of running a waterjetting operation. It is interesting to find, in many cases, that people who willingly spend tens of thousands of dollars on a system will buy the cheapest nozzle available, despite the fact that it this component, as much or more than any other, which controls how well their system works.

Cleaning generally involves the need to remove relatively large volumes of material from considerable areas of surface as fast and cheaply as possible. Until fairly recently, rotary swivels were not widely and reliably available to work at high pressure. For this reason, fan jets have become widely used to give a wider dispersion of the water over the surface and give a faster areal coverage of the target. Such fan jets are often found on the ends of the lances similar to those found in a car wash operation. The same principles apply for these nozzles, except that the opening in the end of the nozzle is more often oval, and an equivalent diameter must be calculated for the nozzle, rather than the actual diameter which can be used with a round orifice.

The Use of Heat

Because of the need for a cheap, fast system, various solutions have been proposed to increase the performance of the equipment. Cleaning systems which use burners to heat the water have become popular in certain applications. Some competition exists between the proponents of these systems and those who advocate the steam cleaning approach where the water is heated beyond boiling before being applied to the surface. It does appear that there is a significant advantage, particularly in the removal of hydrocarbon and similar dirt if the water is heated to a high degree, although to be effective this would appear to require temperatures in excess of 185° F. However, if heat is added to the water, it must be added after the water has passed through the pump. The reason for this is that if the water enters the pump at more than 120° F, then Heron has pointed out that the pump may well cavitate, causing severe damage. Heating the water is usually accomplished by wrapping the tube carrying the water around a heating coil or burner.

The Use of Chemicals

In the car wash industry, a large user of jet systems, the addition of chemicals in the cleaning stream has been proposed as a means of improving productivity. The chemicals, which are advised as being able to help, are most commonly sold on the basis that they help in reducing the surface tension which holds the dirt onto the surface.

If the jet is traveling at some 500 ft/sec and it impacts over a distance of 2 inches of the target, then the time the jet will be on the surface is on the order of 0.0003 secs. Chemists will tell you that this is too short a time for the chemical to work. The chemical should, therefore, be applied to the surface before the jet cleaner is used in order to give it time to work.

There are however chemicals, most particularly of the long-chain polymer variety, which act instead by reducing the friction in the waterjet delivery line and by seemingly "gluing" the water together allowing the jet to be cast a greater distance.

More recently as the need for an efficient, large-scale system for cleaning structures such as the hulls of ships has been defined, the use of cavitation bubbles, and on occasion, the induction of abrasive particles into the water, has been found to help in increasing the areal coverage of the cleaning unit without an increase in fluid horsepower. These two subsystems can be used to clean materials which might otherwise require higher jet pressures and thus more powerful units. They can also find application in other ranges of the cutting and cleaning industry and will be discussed in much more detail later. There is, of course, a price to pay for this benefit and it is most easily seen in the increased complexity which can develop in the equipment required. If the jet containing these additives is directed at the same spot for any length of time, the surface may also be damaged, but under general conditions cleaning with a waterjet system imparts no surface damage to the cleaned part.

To give an example of the benefits which can accrue with these additives, comparative cleaning rates are available for cleaning surface areas found in such applications as removing the barnacles from ship hulls. (See Figure 2, page 5)

High-Volume Flows

At the other end of the low-pressure spectrum are the flow rates used in hydraulic mining. Depending on the mineral to be mined, the pressure will range from 1,000 to 4,000 psi while flow rates will typically be in the hundreds of gallons per minute.

The use of water monitors for mining is now some 136 years old. Within that time, pressures have gradually increased for the jets from the 40 ft of head that existed with the first unit which mined soft, gold-bearing ore in California, to the 4,000 psi used by the Bureau of Mines in borehole mining.

Although hydraulic mining is usually thought of in connection with its use in the mining of gold, it has also been used extensively for the extraction of other minerals. For example, in Virginia alluvial iron ore has been mined hydraulically, and in Perak (now Malaysia), Australia, and New Zealand, tin has been mined hydraulically. The monitors used in this program grew at times to be very large; and waterjet systems throwing 17.8-cm-diameter streams to a distance of 133 m were not uncommon.

While initially the pressure available for the hydromonitors was relatively small, by the turn of the century pumping equipment of suitable small size for transportation into the remote areas where the mines were located had been developed. In Burma, the ruby mines were using a pump capable of producing 200 L/min at 0.75 MPa and throwing the waterjets to a distance of over 167 m. Such systems of mining have been widely developed around the world, but in recent years have fallen into disfavor. A major reason for this has been the stream pollution caused by detritus from the mining operation. The *Los Angeles Times* reported that in 1974 only one hydraulic operation still existed in that state, and that was protected by a "grandfather" clause. However, hydraulic mining can still be found in remote areas of the Yukon.

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Figure 2. *Effective Cleaning Rates for Ship Hulls*

Material	Process	Cleaning rate, ft³/hr
Light scale	Cavitation	900
	Dry sand	160
	High pressure sand/water	450 - 725
	Wet sand	192
Heavy scale	Dry sand	135 - 140
	High pressure sand/water	300 - 550
	Wet sand	150
Heavy encrust	High pressure sand/water jets	200 - 400

Figure 3. *Minimum Cleaning Pressures Required (after Swan 1986)*

Pressure, psi	Material removed
1,500	Silt, loose debris.
3,000	Light marine fouling, light scale, fuel oil residue, aluminum cores and shells.
4,500	Weak concrete, medium marine growth, sandstone and mudstone, light millscale, limited core removal, loose paint and rust.
6,000 - 10,000	Concrete in pipes, severe marine fouling, ferrous casting moulds, runway rubber, soft limestone, lime scale, burnt oil deposits, medium millscale, petrochemicals.
10,000 - 15,000	Concrete cutting and removal, most paints, medium limestone, most millscale, silica cores, burnt carbon deposits, heavy clinkers.
15,000 - 30,000	Granites, marble, limestone, marine epoxies, aluminum, lead, rubber, frozen food.

High-Volume Flows (continued)

For the mining of alluvial clays and sand, the system still, however, has considerable benefit. Monitors for such operations can throw a 15-cm-diameter jet at 2.4 MPa and can be obtained for under $10,000.

In the 1973 war between Egypt and Israel, the Egyptians very effectively used waterjets to breach the Bar-Lev Line. The Egyptian Chief of Staff described how the Israeli defense was based on a 24-hour period being required to establish bridges across the canal, beyond which large sand barriers had been created as part of the Bar-Lev Line. The combined obstacle was considered likely to delay the Egyptian tank force by approximately 48 hours.

Calculations of the time needed to breach this barrier were based on the fact that a hole 6.8 m wide, which is the size needed to get a tank through, required the removal of approximately 55 cubic meters of sand. To move the tank force, there would need to be approximately 60 such holes on the east bank. To make the holes alone using bulldozers or explosives would, the Israelis calculated, have taken a period of between 10 to 12 hours. However, the Egyptians used high-pressure waterjets to make the holes in 3 to 5 hours, and gave a substantial advantage to their army, underlying their early success in this particular encounter.

The Soviet Union has large deposits of gold in and around the Lake Baykal area in Siberia. These deposits were mined hydraulically starting with a hydraulic device developed by A. P. Causov in 1867. However, the source of the technology is perhaps revealed by the reference to part of the equipment as "Amerikanol" In the early 20th century, the use of very low-pressure waterjets was applied to the mining of peat deposits in central Prussia, and following the First World War similar methods of application developed in the Soviet Union. By 1915, the method had been turned to an application in the mining of coal.

Large volume earth moving by waterjet is practiced still in Russia where, for example, Yufin reported that the Moscow canal was driven using waterjets for earth removal. The rates which can be obtained with this system can be estimated from production rates which were achieved in Alaska in the 1900's. Longridge cites a bank of gravel 300 m long by 8 m wide by 1.8 m high which was removed in 3 weeks by a single monitor. The technology has moved on from that time. One of the advantages of the system is that the high volume of water used in the mining of material also provides a carrier system to transport the extracted ore away from the mining operation. Consolidation Coal Co. has used hydraulic transport to pump 10 tons/min of coal from one of their mines. Hydraulic transportation, in general, has now a widespread range of applications.

Dredging Applications

One area of application that has not been given a great deal of attention lies in the underwater use of jets for material removal and channel cutting. In many cases, low-pressure water is most useful. On a simple level, the average crab pot

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cost around $60.00 (1973), but could quite easily become buried in sediment so that a fisherman may lose up to 100 pots in a bad season. In order to find and free such pots, waterjet systems have been used operating at pressures around 1,000 psi through four 0.8-inch-diameter nozzles, and these can create a hole up to 5 ft deep in 3 minutes while casting the debris over 3 ft from the hole. Working on the same principle, pipe-laying equipment is in operation, wherein a pair of nozzles ride forward on the pipe, cutting a trench underneath the pipe and casting the debris far enough so that the debris settles back into the cavity after the pipe has sunk into the trench. In soft material, it has proven possible to bury a pipe 3 ft in diameter to a depth of 3.3 ft at a rate of one-half knot.

At the first U.S. Waterjet Symposium, the U.S. Navy reported that a 2-ft-deep slot could be cut in clay soil with a jet pressure of 68 psi, providing that a flow rate of 3,900 gpm was used, requiring 150 hp. A cutting speed of 1 knot could be developed with this system, the main disadvantage of which was that in the clay, the trench which was cut would not be a clean one.

Low-pressure water can also be used to cut frozen ground. The Bureau of Mines described tests which they carried out in the cutting of frozen gravel, a material closer in response to concrete than to soil. Small holes for waterwell drilling and posthole creation in permafrost can be excavated with low-pressure water. Water at a pressure of 250 psi will cut through permafrost at a rate of 18 ft/min in summer, but rates of only 1-inch/min will be reached where the material is a frozen sand in winter.

INTERMEDIATE PRESSURES

In general, intermediate pressure systems are considered to lie in the pressure range from 5,000 to 20,000 psi. This covers the range from which commercially available, reliable pumps are easily available at flow rates in order of 10 to 40 gpm, and where a sufficiently reliable set of component parts exist. While the greatest part of the current use of equipment in this pressure range still falls within the category of cleaning, significant growth in the use of these jets for cutting of concrete and geotechnical materials is now evident and with the addition of abrasives to the water, industrial cutting applications are starting to appear with greater regularity.

Many of the "improved" versions of jets which have been suggested for use in the lower-pressure ranges will also have application in this pressure range though not always with the same level of success, for various reasons. For example, the power requirements to heat flow rates above 10 gpm become too expensive for the gain that can be achieved.

Many claims have been made for different configurations of waterjet systems which operate in this pressure range. However, one of the more dramatic examples that purchased equipment from one company does not perform in the same way as that from another was carried out by the U.S. Navy on the cleaning of heat exchanger tube bundles. The Navy set up a comparative test between five manufacturers of nominally the same performance equipment. The measured effectiveness of the cleaning achieved by nominally equivalent systems ranged from 36 to 92 pct, an almost threefold variation. This points out the risk in venturing an opinion on the ability of a system to perform without a more detailed evaluation of the components of the system. It is worth mentioning that the Navy now uses high-pressure waterjets to clear ship boilers and a job that used to take a week, using brushes, takes less than 2 days using a 10,000-psi jet flowing at 2… gpm. Of this time, only 8 hours is required for cleaning of each 450-psi boiler.

The realism of the Navy approach is shown by the fact that it took only 5,400 psi to effectively clean the tubes, measuring the pressure at the nozzle. By specifying the higher pump pressure however, the Navy allowed for pressure losses in the line. This point is often neglected in assessing the size of system to use. The pressure measured at the gauge of a pump reflects only the pressure measured at that point and not that at the point of application, which may be some 200 ft or more away.

The most common faults which give rise to losses in the delivery line arise from passing the fluid through narrow openings. These require that the jet be speeded up to pass through. This requires that pressure be expended at these areas, which commonly occur at fittings and couplings. In poorly designed systems however, large pressure losses can occur in hoses which may have too small a diameter for the application in which they are used. It is possible to incur pressure losses of over 15,000 psi in 50 ft of connection line between a pump and a delivery nozzle.

Tube Cleaning

Water has always been used as a cleaning medium, but in large measure until recent times, the major reason for this has been its properties as a solvent and lubricant. Within the past 20 years, the use of water at high pressure as a cleaning agent has become extensive throughout the world. A major innovator in the use of high-pressure waterjets for cleaning has been the chemical industry. Many large chemical plants use heat exchanger tubes to pass heat between different phases of the various processes. The heat exchanger itself consists of small-diameter tubes, frequently in the order of perhaps 700 - 900 in number, jacketed together in a container through which the second fluid will pass. As the exchanger works, the tubes over a period of time will experience a buildup of precipitate from the material flowing through them. The tubes are initially in the order of 19 mm diameter, and as the bore becomes smaller, so the effectiveness of the heat exchange process becomes reduced, requiring that the tubes be cleaned.

Historically, several methods have been used to clean the tube, including driving rods down through the tubes, flame torches to burn out the deposits, a sand or grit blasting operation, and mechanical drilling. Of these, the first three can only be used in very particular types of materials and drilling has been by far the most common method used. Drilling, however, requires that considerable care be taken by the operator to insure that the tube bundles themselves are not damaged and it also consumes a large labor force and time. Ward has given one example of a 990-tube bundle, some 3.6 mm long, which took 450 manhours to clean. At a pressure of 70 MPa and a flow rate of 5.5 m^3/hr, it now takes less than 24 manhours to clean the same bundle using waterjets.

The resulting surface obtained from the use of the high-pressure jet cleaning is much smoother than that found with the historical drilling or grit blasting techniques. As a result of this, the build-up of material when the bundle is reintroduced

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into service is much slower, increasing the service life of the heat exchanger before cleaning becomes necessary again by some 50 pct or more. This advantage is not restricted to heat exchanger tubes. For example, ship hulls must be cleaned of animal and vegetable life, old paint and rust must be removed, and in coke ovens the buildup of tar and other deposits from doors and vents must be removed. Waterjet systems have been developed both on a hand-operated basis and as a semiautomatic system for cleaning these surfaces.

Reactive Force

The change from mechanical drilling and the use of the jackhammer to waterjet brings with it an additional benefit. It also requires that an additional aspect of waterjet applications be introduced. This is the concept of backthrust, or the force required to hold a water-jet nozzle in position. The backthrust from a linearly directed jet can be calculated from the equation:

$$\text{Backthrust (lb)} = 0.052\,Q(P)^{0.5}$$

where:

Q is the flow rate in U.S. gallons/min
P is the jet pressure measured in psi

This reactive force value must be considered in the design of any holding fixture which will retain the piece being washed, or which is used to retain the nozzle during a washout. This force is, however, considerably less than that which would be required with a mechanical method of cleaning, particularly those which use compressed air at the method of providing power to the tool.

In many cases, the waterjet is directed through a hand-held lance. This limits the maximum pressures and nozzle diameters which can be used, since the average operator is only capable of holding about one-third of their body weight. As Topley has pointed out, this means that the maximum horsepower which the operator can handle runs in the region of 15 - 20 kW, with the maximum level probably being at the order of 30 kW. Such a system, however, provided that the driving pressure of the jet is between 50 and 70 MPa, is sufficient to clean most industrial surfaces. Where this is not in itself the case, certain varying parameters can be applied to the nozzle such that the system does cut the material.

In 1978, David Odds described one of the more graphic illustrations of the benefits of jet cleaning which arise from suitable design of waterjet systems. By balancing the reactive force from the cleaning jet with a second jet of large diameter and the lower pressure, a tool could be built for use by divers in cleaning the legs of the oil rigs in the North Sea. Odds cited the case of the diver who first used a jet cleaning unit underwater on a rig. A few minutes after the trial began, the diver halted the test, came to the surface, and without a word walked over to the jackhammer unit previously used and with an insulting farewell, threw it over the side.

In cleaning ship structures, waterjets are usually fanned rather than circular to cover a larger surface. Such fan jets operating at pressures of approximately 20-35 MPa are also used for cleaning ship's holds, particularly of the crude oil residue between the different loads which oil tankers must carry. It must be pointed out, however, that the use of such a technique is one which requires considerable care. Explosions have occurred where petroleum vapor buildup has been allowed inside the tank before cleaning began. In such circumstances, the mist around the waterjet can acquire an electrical potential sufficient that sparks are generated, igniting the surrounding petroleum gas and blowing the ship apart.

One way in which more power can be transmitted to the face is to redesign the nozzle system so that not only are jets directed forward to do the cutting, but backward pointing nozzles are incorporated into the nozzle assembly itself. In this manner, an operator can handle an input power of up to 50 hp, increasing productivity. Torpey pointed out, a 6-m-tube bundle containing some 200 tubes can, and has been, cleaned in under 18 minutes. In another example, the Parteck Corp. found that a tube bundle which took 300 manhours to clean using hand tools and chemicals could be completely cleaned by two men within an hour.

Industrial Applications

Many applications of waterjets for cleaning in industrial structures can be cited. Waterjets are used to clean structural surfaces of deposits in chemical plants, refineries, and petrochemical processes, and in the building and construction industry, to remove concrete, and clean off aggregate and other material prior to reworking the surface. The flexibility of the waterjet system and its ability to clean materials from areas difficult to access for a number of reasons have meant that the waterjet cleaning industry has grown considerably in the 30 years or more since high-pressure waterjet cleaning was begun.

Waterjets have applications in areas normally inaccessible, not only by reason of geometry but by reason of environment. For example, in the steel industry, steel billets initially start out with a thick deposit of scale around them. While much of this is removed by movement of the billet itself, some will adhere to the steel, raising the potential for damage in equipment downstream. In order to remove this material, waterjets at pressures of 10 - 20 MPa are directed onto the billet removing the scale by a combination of thermal and mechanical actions. In a similar operation, the National Research Council of Canada has developed a system for cleaning out the gas collector pipe which leads from large coke ovens. This pipe rapidly becomes clogged with materials from the coking process and must frequently be cleaned. Normally this is done by a hydraulically-driven mechanical device, but this does not completely clean the surface and buildup of material occurs relatively quickly once the process is restarted. Working at a pressure of 70 MPa and flow rate of 81.4 m/min, two nozzles of 16 mm diameter were rotated at a speed of 300 rpm and completely cleaned the pipe in a period of some 30 sec at a feed rate of 8.5 mm/revolution. As a subsidiary advantage to the system, Brierley points out that not only was the service period of the coking oven extended, but the cleaner pipe surface reduced the operating pressures within the coke oven.

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Mining Applications

Piggybacking on the development of equipment for the high-pressure cleaning industry has been the growth of waterjets as a cutting tool in rock and mineral production. Many rocks cannot be cut at the lower pressures which were available for conventional mining. At the same time, only a few coal seams around the world have the necessary conditions for hydraulic mining to be carried to a successful conclusion. The recent closing of the Hansa Mine in Germany bears testimony to this, as do the earlier failures of the British experiments at Trelewis Drift and the American trials in Washington State.

If waterjets were to have a success in the more commonly prevailing conditions of most coal mines where the seams lie relatively flat and the floor will soften to an unacceptable degree if too much water is applied, then a better method of using water will be required. An increase in pressure will allow some reduction in flow volume and if this is taken with a modification of the design of the machine so that the waterjet does not do all the cutting of the material, then an effective machine can be developed. This requirement has been part of the reason for the recent success of the waterjet-assisted cutting techniques. Beginning with work carried out by Dr. Hood in South Africa in the mid-70's, a new system has been developed in which high-pressure waterjets are placed at the leading edge of cutting tools. The success that this allows can simplistically be illustrated by comparison. As a general rule, a mechanical cutting machine of the type used in many mines requires greater weight to cut stronger rock. To cut an 18,000-psi rock, the machine must normally weigh around 100 tons. Where a waterjet assistance was added to the cutting tools however, a 25-ton machine was able to cut rock of over 19,000-psi strength. The difference in the cost of the machines approaches $500,000.

Waterjet systems have been developed which cut into material with relatively high efficiency, but produce material of relatively small size. Such a process is of advantage in the crushing of coal, or the pulverizing of ore to extract the valuable material. It is not the best way of removing large volumes of material. The concept of using a higher-pressure waterjet system to cut slots into the material, and then to develop some form of mechanical assistance to remove the large volume of material between the cuts has been developed in the last 10 years. In almost all cases, however, the development of the equipment has been dependent on the creation of good nozzle designs and of a reliable rotary swivel, or union, which will allow the waterjet streams to move very quickly over a surface. Such equipment development has only occurred this decade and the penetration of the technology into the mining and civil construction arena is still a relatively young one.

VERY HIGH-PRESSURE SYSTEMS

There are two major ways in which very high-pressure waterjets can be created. In the pressure range from 20 to 60,000 psi, it is possible to purchase continuous duty pumps which will, in most applications, produce flow rates on the order of 1 or 2 gallons/min. The alternative, and the system which is most likely to be used at pressures of 100,000 psi and above, is the single-shot, water-cannon.

The earliest work was probably at the higher pressure, since the system complexity is somewhat higher in developing continuously operating high-pressure systems than is the single-shot devices. Water cannon development began in Russia. Nozzle designs were developed there which would accumulate the velocity of the leading edge of the water slug as it was driven down through the barrel. The driving pressure for such a device has been provided historically either by the collection of a large volume of highly compressed gas, either nitrogen or air, which is then suddenly released behind the water, or by igniting a small explosive or propellant charge in the barrel of the gun behind the water.

The reason for this development, and its popularity through the 1970's, lay in a misconception of waterjet penetration mechanics. Early experiments in rock cutting had led to the erroneous conclusion that it was necessary to use waterjet pressures at a level of roughly 15 times the rock compressive strength in order to most efficiently cut material. A granite, which has a compressive strength of 200 MPa would require a jet pressure of 3,000 MPa. On this basis, it was necessary to develop very powerful delivery systems.

Two efforts in the U.S. predominated in this effort. Dr. Cooley, of Terra Space, developed a gun based upon the Russian design which generated a pressure on the leading edge of the jet of 4,000 MPa. The research group at IIT Research Institute in Chicago built a smaller device which would reach pressures of 1,000 MPa. The rapid decay, with time, of the jet pressure and the rapid wear of the cannon barrels has, however, reduced their popularity, and in recent years there has been a return to more conventional means of generating waterjets. Concurrently, continued research has shown that it is not necessary to go to the high pressures which formed the basis of the original effort. The UMR Stonehenge, for example, was cut at jet pressures which were less than half the value of the compressive strength of the rock.

Two machines remain in operation at this pressure range. The Russian investigators have lowered the operating pressure of this machine to 125,000 psi and have successfully used it to drive a tunnel. Atlas Copco has modified a waterjet gun to drive a slug of water at high speed into a previously drilled hole in the rock. Where the hole is in a boulder, the result is a relatively quiet way of breaking rock. Although this machine has had some success in Europe, it has not been found to be successful in the U.S. at this time. A pulsating high-pressure system has been under development by Briggs Engineering for several years now as a means of breaking up concrete pavement. Although capable of generating successive pulses at a high rate, it has yet to become a commercial reality.

Industrial Machining

The most successful innovation in waterjet applications has been the use of jets at pressures of between 200 and 300 MPa in continuously operated jet cutting systems. At these pressures, water is capable of cutting through materials with a much more satisfactory performance than conventional tools, in many situations. The limitation of these systems to cut through harder materials has been overcome in the last 8 years through the addition of abrasives to the cutting water.

In many industrial processes, the product must be cut to shape. This involves removing material from a parent block and during cutting some of the material is lost. The speed and maneuverability of the operation is, to a large extent controlled by the flexibility of the cutting tool. At the present time, most cutting processes use mechanical tools. While

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these have many advantages, they are speed limited, become blunt, and generate dust, which may for certain materials such as asbestos, be health hazards.

Waterjets have been one of several novel candidate methods considered as a solution to these problems, in the company of such novel tools as lasers and electron beams. A particular example of the benefits which waterjets bring to cutting, in contrast to other methods, is illustrated by tests carried out by the National Research Council of Canada. The NRC had been asked to find a way of cutting Freestone peaches in half. Comparative tests were carried out using waterjets at a pressure of 55 MPa and diameters of 0.076 and 0.20 mm, and a CO_2 laser of equivalent power. The peaches were satisfactorily sliced by the waterjet within 0.25 sec, the cut going transversely around the peach through approximately 1 cm of flesh to the pit. On the other hand, in 6 sec the laser cut a wide slot only partially through the peach and over only a section of the circumference. The power level required per peach was in the order of 0.1 kW for the waterjet.

The high fluid velocity of the jet, from 300 m/sec at 70 MPa to over 1,000 m/sec at higher pressures, will allow a very rapid cutting speed to be achieved while the very narrow width of jet (0.3 mm) means that less product will be lost during the cutting application. An example of the speeds attained is given by other tests carried out by the Canadian National Research Council, where cutting rates of over 600 m/min were achieved in cutting newsprint.

The first company to foresee and commercially develop this concept was the McCartney Manufacturing Co., of Baxter Springs, KS, an Ingersoll-Rand subsidiary. Their involvement rose from research carried out by Dr. Franz in 1970, on the cutting of wood products and led initially to a modification of an existing pump system to produce 100 MPa at 95 liter/hr. The very narrow jets which are produced by such a pump, typically of the order of 0.2 mm diameter, and the high fluid velocity made them ideal for this cutting application. The pump was initially used in 1968 as a research tool, but in 1971, the first commercial unit was installed in the Papertube Div. of Alton Box Board Company.

Although the original equipment is no longer performing the same task as it was installed to do, it is still in operation in the factory some 17 years later. The original use was in cutting cardboard tubes 1.25 mm thick for the furniture manufacturing industry. The advantage developed by the waterjets included being able to penetrate a hole and follow an intricate contour. Two pumps were used in this system at speeds of up to 5 m/min to provide 378 liter/hr flow at 275 MPa pressure. At these pressures, conventional nozzle materials do not have the ability to withstand prolonged operation. Nozzles are, therefore, now made from an artificial crystal, most typically sapphire or ruby. By use of these materials, nozzle life in excess of 3 months has been attained.

The commercial success of the first system and its ability to cope with three-dimensional contour cutting and the high degree of precision in its application initially led to its incorporation in a tape-controlled mode, where the cutting cycle and the tool guidance operated completely under computer control. From that initial installation, and the demonstrated technology it pioneered, a major change in industrial practice has grown. The very low levels of water flow, at even the higher pressures, means that the reaction force exerted on the manipulator is very small. This makes it relatively easy to fit the nozzle system on the end of a robot arm, and to use this for manipulation in cutting. When this is combined with the ability of the jet to cut its own access hole for internal contour cutting of parts, it can be seen that a major revolution in machining has been foretold.

Recent reports at the 1988 clinic on automated waterjet cutting illustrate how far the technology has moved since that time. One of the first applications was the cutting of jigsaw puzzles, cut under computer control, ten at a time on a 24-hr production basis. The precision of the cut achieved with the jets was such that in the initial trials of the system, the slots were too narrow for the easy removal of pieces and this normal advantage of minimizing product loss was, in this case, a disadvantage in that the jets were made to cut less efficiently in order that the slot be cut wider and facilitate piece removal.

Other examples include the cutting of the struts on aircraft wings and the preparation of turbine blades for aircraft engines. The savings which have arisen in these applications come from several sources. For example, a new product will conventionally require that a set of machine tools be specially fabricated for the different machines involved in the shaping of the part. For a complicated piece of equipment, this might cost as much as $3.6 million. In contrast with a waterjet robotic installation, once the original installation is in place (perhaps at a cost of $1.6 million for an equivalent setup to perform the same machining), then it is only necessary to write the programs for the controlling computer to get the jets to carve the shapes required in the target material. This is not totally cost free, but once done can be held resident on disks so that at any future time required, those parts can again be prepared with a minimum of new set-up time. This is of significant advantage as we move further into the generation of "Just in Time" manufacturing.

Many products cut by waterjet action are made of organic materials capable of taking up moisture; for example, all the disposable diapers in the U.S. are cut to shape with waterjets. Further, the requirements of many manufacturers include rigid specifications on edge quality control. As the waterjet tends to disperse with distance, this has meant that high jet quality control must be observed. In the original McCartney development, use was made of the long-chain molecular polymers such as polymerized ethylene oxide dissolved in the water to keep the jet together over long distances from the nozzle and to reduce surface wetting.

Other equipment manufacturers, most particularly Flow Industries, who began marketing competing equipment in the early 1970's sought a different solution using a proprietary nozzle design which has better performance characteristics. Both systems now are in widespread commercial usage and have been shown to create many advantages over pre-existing equipment. These advantages developed have included the elimination of dust hazards in locations where this previously has been a problem and because of the very localized cutting action, an improvement in the number of pieces which can be obtained from a particular volume of material.

An example of this comes from the shoe industry. The size of the hides from which shoe components are cut is a function of the size of the originating cow. Historically, the patterns which have been stamped or cut out of material have been controlled by skilled craftsmen, and based on their skill, the number of parts which can be cut from a particular piece of material has been controlled. In order to improve on this productivity, research programs in the 1970's combined computer

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Conference Proceedings Available

A limited supply of the official Proceedings of the 5th American Water Jet Conference, held August 27-31, 1989, in Toronto, Ontario, Canada, are now available in a single, hard cover volume. A variety of presentations relating to the following general topics are included: Rock Cutting, Basic Studies, Concrete, Construction, and Industrial Applications, Coal and Soil Cutting, Medical Applications and Safety Considerations.

The Proceedings are available for $75.00 each, plus $5.00 for shipping and handling (in continental U.S). **Additional shipping charges apply for destinations outside the U.S.** To order, contact: **Water Jet Technology Association, 818 Olive Street - Suite 918, St. Louis, MO 63101, (341)241-1445, FAX: (314)241-1449.**

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control and waterjet cutting. The result has been the installation of such systems in factories with significant economic benefit to the manufacturers. One of the studies in the U.K. showed that using typical materials required for ladies shoes, material savings of between 5 and 15 pct were possible, leading to an immediate benefit of $20/hr in material. The single shoe pieces were cut at a velocity of approximately 40 cm/sec, giving a cutout time of approximately 3 sec/piece, depending upon the intricacy of the part. Support of the workpiece has been a continuing problem for these applications. This is because the jet will either cut through the supporting material or bounce back from it, wetting the edges of the piece cut, an unacceptable result.

Many companies in the food industry have expressed an interest in jet cutting since the high-pressure waterjets minimize the amount of food loss because of the narrowness of the kerf which they cut. As a result of trials, several companies now use the system to cut food products, although in many cases, for health reasons, they do not use water, but rather oil as the cutting fluid. McCartney Manufacturing Co. has an intriguing film which shows some of these applications under test. One particular example which springs to mind and indicates the versatility of the system is that the operator pushes a bag of marshmallows through the waterjet and the bag emerges from the far end with no evidence of having been under the jet. The plastic container has retained its shape and the marshmallows remain intact. The bag is then parted and it is shown that all the marshmallows in the bag have been segmented. This demonstration shows very dramatically the precision nature of the waterjet cutting system and the high speeds of which it is capable.

The restriction which the use of water alone placed upon the applications, since waterjets alone cannot effectively cut all materials, was overcome in the beginning of this decade with the addition of abrasive to the waterjets. In the original concept, this grew out of the practice of the lower-pressure waterjet cleaning industry, in which abrasive was aspirated into the jet after it had left the accelerating nozzle at the end of the delivery line. While this worked well, the short distance over which the abrasive can be accelerated has meant that operating jet pressures must run around 200 MPa. However, the system which results has been able to cut through metals and advanced ceramic materials at economic rates. When this benefit is combined with the continued use of the computer cutting control, then it can be appreciated that the applications of this new tool are only just unfolding. If one adds to this the recent commercial development in which abrasive is added to the waterjet system earlier than the final nozzle so that the jet pressure can be significantly lowered, then the dawning of a new day in manufacturing and geotechnical excavation can be foretold.

International Journal Of Water Jet Technology

The following are Donors and Patrons of the International Journal of Water Jet Technology which will begin publishing in 1990: National Research Council of Canada, Canada; Water Jet Technology Association, U.S.A.; Autoclave Engineers, U.S.A.; Ceda Reactor Ltd., Canada; The Flow Industries, U.S.A., Noranda Minerals Inc., Canada; and Schoeller-Bleckmann Gesellschaft M.B.H., Austria.

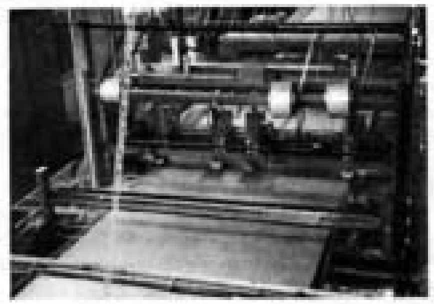
Accident Case Study - Engineering Works, from page 2

Answer: The operator should not have held castings in hand even at low pressure. Subsequent problems were caused by an injection caused by microbes in the water.

Moral: Even minor waterjetting injuries need medical treatment if "microbes" are likely to be injected into the flesh.

CORRECTION

The editor regrets that Jet Edge Corp. was not given credit in the December 1989 issue for supplying the photograph shown at right. Credit incorrectly assigned to Ingersoll-Rand.



Waterjet slitting of corrugated boxboard (photograph courtesy of Jet Edge, Inc.)