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# The Application of Water Jets in Coal Mining

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# THE APPLICATION OF WATER JETS IN COAL MINING

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Abstract

Water is one of the natural erosion agents which through time has changed the face of the earth. Application of this principle to remove earth and rock by man is a long established technique. This paper briefly describes the changes in technology which have brought the application of water jets from the slow erosion of soil to the point where in Canada some 3,400 tons per shift are currently mined in a coal mine using high pressure water jet technology. The use of water jets has shown sufficient promise that there are several research programs currently being funded by the U.S. Bureau of Mines and other Federal agencies in the field of excavation technology. Three current areas of water jet mining are described. The first is the use of water at 10,000 psi as a modification of the cutting head of a longwall mining machine. The work which is being carried out at the University of Missouri is briefly described with the rationale for the jet parameters chosen for the experimentation. The second method of mining is a project currently under way in Canada where in a seam 50 ft thick and dipping at an angle of some 40 degrees, a low pressure, high volume flow rate up to 1,500 gallons per minute water jet system produced up to 3,400 tons per manshift. The third method of mining is an experimental program being carried out by Flow Research, Inc. in Washington state. With this method coal is mined from underground seams to boreholes driven from the surface, coal being reamed to the borehole by high pressure water jets and crushed in the bottom of the borehole prior to being pumped out of the borehole for external usage. This method does not, therefore, require access to the underground.

## 1. INTRODUCTION

The use of water as a means of extracting valuable minerals from the earth is something we learn from nature. The presence of gold in stream beds, the pulverizing of rock into valuable soil--these things indicate that my topic is as old as the Earth itself, and man has through the years learnt from nature and applied water to accomplish his own ends. We learn from ancient Egyptian stele that water was used in mining 4,000 years B.C. (1), and Pliny in his Natural History (2) talks of the Romans in Spain carrying water to reservoirs on hilltops, from which it was discharged onto ore veins, carrying the mineral down to the valleys where it was trapped on bushes, and one may conjecture sheepskins if one remembers the legend of the Golden Fleece. Agricola (3) talks of the use of water in "De Re Metallica" in the sixteenth century but it is not until about 100 years ago that hydraulic surface mining became of large interest. With the advent of pressure pumps, low pressure, high volume water was used to mine alluvial deposits of valuable material from California through Alaska, Siberia, Russia, and the Orient (4, 5). Around the turn of the century, the Prussians began to use water jets to mine peat, and the technique was also adopted in Russia. As equipment reliability increased, so jet pressure increased, and coal was mined in surface deposits. In 1935 Dr. Muchnik in the Soviet Union carried out experiments on mining coal underground in the Kuznetsk basin (6). These experiments were delayed by the war, and it was not until 1952 that the first underground hydraulic mine, the Tyrganskii-Uklony, was opened in the Kuznetsk coal basin (7). Output and costs per ton were much more favorable than with conventional mining and the methods were applied in many different mining conditions across the Soviet Union (8). As a result of these trials, experiments in hydraulic coal mining began in the United Kingdom (9), the United States (10), China (11), Japan (12), Poland (13), and Germany (14). Regretfully for the state of technology as methods of mining were being developed, two events occurred which put hydraulic mining temporarily out of the picture. The first of these was the introduction of the mechanized longwall face and the advent of the Anderton shearer loader, which promised very high productivity and fitted in with existing mining methods in a way that hydraulic techniques could not. The second was the collapse of the coal market. In more than one mine where hydraulic mining sections were established, although the hydraulic section remained profitable, the mine as a whole did not (15). The volume of coal mining research fell away, and hydraulic mining practice passed from the American scene. In Russia, however, the methods were being refined and hydraulic mining was also still being developed in China and Japan.

Then, in about 1969 interest in water jet technology began to increase again. Initially Dr. Maurer in his review of novel drilling techniques indicated many advantages to the use of high pressure water jets (16), and just prior to my arrival Dr. G.B. Clark had, at UMR, completed a review of the potential application of jets in excavation (17). Initially, in part because of funding availability, the research concentrated on the application of water jets for rock excavation. This program which has passed through several stages recently led to the addition of a set of water jets on a tunnel boring machine in Washington state (18) and is worthy of a paper itself. Unfortunately, in the author's opinion this research led to a misconstruction of results. In experiments at IIT Research Institute it had been found that the greater the jet pressure, the more effectively the jets cut rock. This conclusion was considered equally valid for coal, despite the many differences in structure between coal and the sandstones and granites used in most of the jet testwork. As a result of this misconception, initial development of water jets in coal mining in this "new era" of the 1970's was in the design of mining machines which operated at water jet pressures in excess of 50,000 psi (19, 20).

## 2. EXPERIMENTS AT UMR

Concurrently with other programs, the U.S. Bureau of Mines funded the University of Missouri - Rolla (21) to investigate the relationship between nozzle diameter, jet pressure, and cutting effectiveness in the design of a longwall water jet mining machine. The results of this study indicated that, for a given horsepower, coal would be mined more effectively with a lower pressure, larger diameter water jet than with an ultra high pressure, small diameter jet.

The results can be illustrated with reference to two curves which were derived from the results of the study. In the first curve (Figure 1) the effects of jet cutting are plotted against increase in pressure. It can be seen that as pressure increases so does the volume of coal mined; however, concurrently the energy contained in the jet also increases. Thus, if the energy of the jet required to remove unit volume of the coal, the specific energy, is plotted, there is only a slight decrease in required energy as pressure increases.

Conversely, when the curve is examined for the relative change in effect with increase in nozzle diameter (Figure 2), the volume of coal removed increases with diameter but, in this case, at a much greater rate than the energy contained in the jet. Thus, the specific energy of cutting drops with increase in nozzle diameter. This data can be expressed simplistically thus: If the jet energy is doubled by increasing the pressure, then approximately twice the volume of coal will be mined. Conversely, if the jet energy is doubled by increasing the diameter, then the volume of coal removed is quadrupled. Thus, for equivalent power it is better to put the jet energy into nozzle diameter rather than pressure, with one important proviso. Every rock has a certain threshold jet pressure below which the jet will not cut the rock, and this must first be substantially exceeded. For an example (Figure 3), UMR has a 75-hp pump which can be used to produce 10 gpm at 10,000 psi or 4 gpm at 30,000 psi. At 10,000 psi, 10 gpm will flow through four nozzles of 0.04-in. diameter, while at 30,000 psi only one nozzle of 0.02-in. diameter can be used. Thus, on a relative area basis, the lower pressure jet will cover 16 times the area of the higher pressure jet.

If the above derived relationships are considered, this will give a six times greater volume of coal removed by use of the lower pressure system. Because the jets can be used to exploit weakness planes in the coal and break to free surfaces, the lower pressure jet is more effective.

The current trend is, therefore, to water jet mining machines operating at between 2,000 and 10,000 psi at flow rates from 200 to 50 gpm at nozzle diameters from 1 mm to 1 in. in size. The method of application to a large extent governs the jet operating parameters, and three examples will serve to illustrate this.

## 3. CANADIAN MINING

The most dramatic application of water jets to mining is currently in the Sparwood Mine of Kaiser Resources in British Columbia (22). Entries are driven in the center of the 50-ft thick seam at intervals down the dip. Working from the top drift down a water jet monitor then mines out the overlying coal washing it down into the entry where it is collected and broken to a small enough size to be put into the flume and carried out of the mine with the spurt water from the operation. This system has produced 3,400 tons in a six hour shift

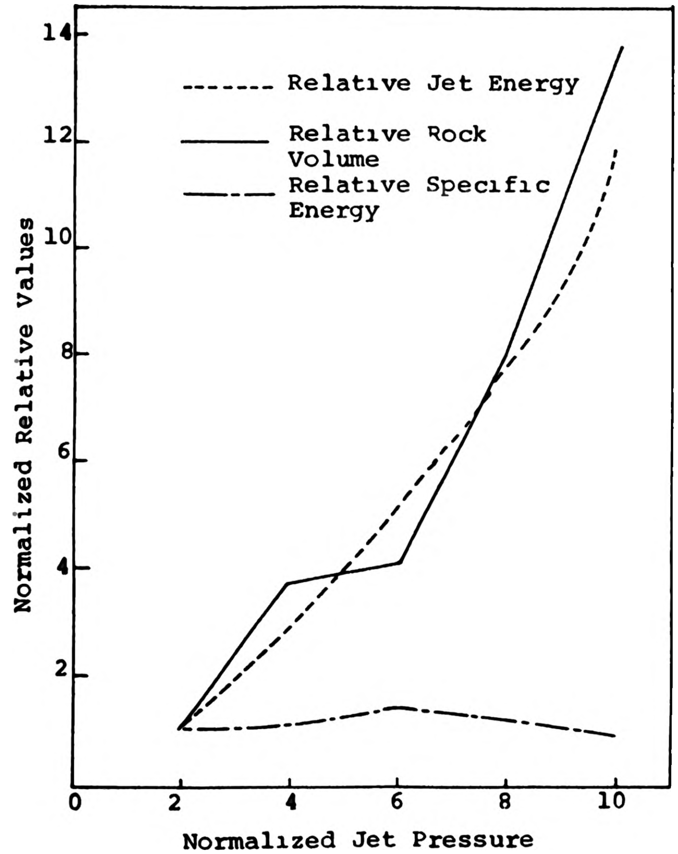


Figure 1. Relative variation in energy of the impacting jet, volume of rock removed and specific energy of cutting with relative change in jet pressure.

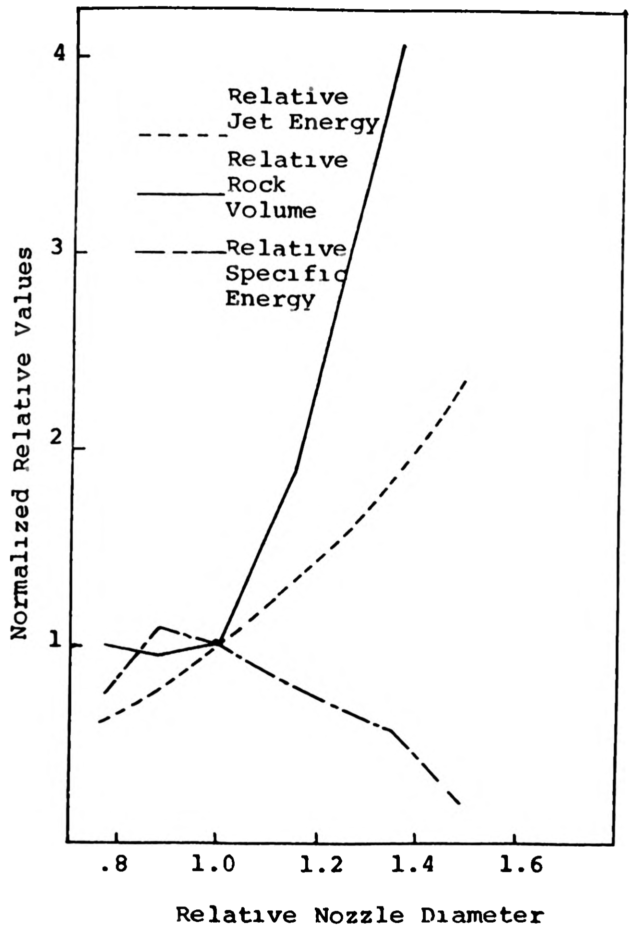


Figure 2. Relative variation in energy of the impacting jet, volume of rock removed and specific energy of cutting with relative change in nozzle diameter.

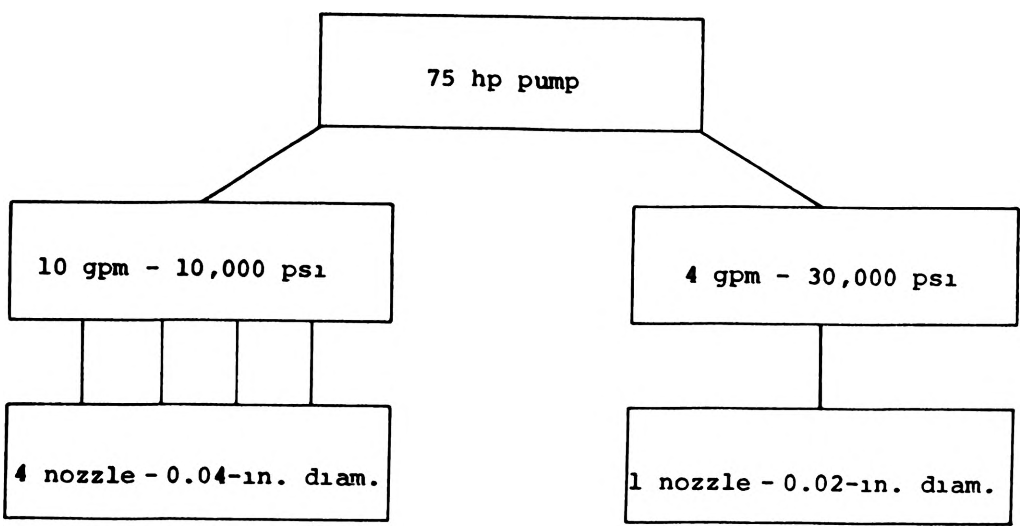


Figure 3. Options available with a 75-hp water pump.

with two men operating the unit; although because of other operations associated with the mining process, the overall output per man at the mine is only 60 tons per shift. Nevertheless, this compares well with the American average of 11 tons per manshift. There are plans for more mines of this type to be opened in the western coal seams where such operations will be feasible. Unfortunately, most of the coal seams being worked in this country are thinner and more horizontal than the Canadian case and a second method of mining must be developed.

This is the system being developed at the University of Missouri - Rolla.

## 4. PROJECT HYDROMINER

The vast majority of mines in this country use the room and pillar method of mining in which parallel tunnels are driven in the coal and periodically cross-connected to leave large pillars, required to hold the overlying ground in place (Figure 4).

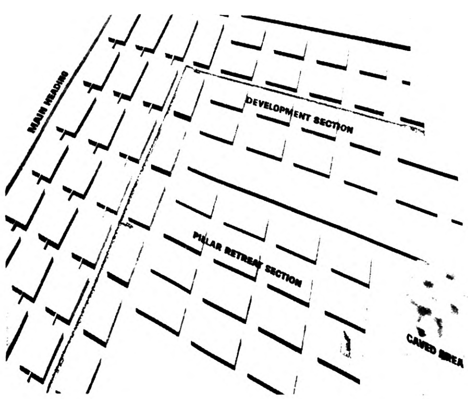


Figure 4. Room and pillar layout.

Unfortunately, these pillars may contain more than 50 percent of the available coal which has thus been "sterilized." In order to overcome this problem a method of mining called longwall has been introduced with which almost all the coal can be extracted. In this method access tunnels are driven to the boundary of the section, and then a crosscut is established. Within this crosscut steel supports are located which hold the roof up, and a conveyor is laid along the tunnel. A mining machine is then mounted on top of the conveyor so that it can travel the length of the tunnel (Figure 5).

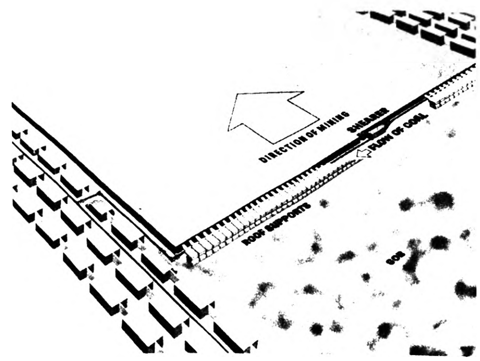


Figure 5. Longwall layout.

The machine then starts at one end of the tunnel and takes a slice of coal from the tunnel wall and loads it onto the conveyor. After the machine has passed the conveyor and roof supports move forward, and the unsupported roof behind the operation collapses. The machine is then moved back along the conveyor, taking a second slice of coal, and the cycle repeats. In this manner most of the coal is mined; the face workers are always protected from roof falls and by the time the subsidence of the ground reaches the surface it is so spread out over the ground as often to be unnoticeable.

However, a problem with this equipment lies in the amount of dust it generates and the environmental problems. In order to overcome these problems and demonstrate the use of water jets in this area, the University of Missouri - Rolla contracted with the Bureau of Mines to develop a design for this situation.

In the experimentation it was found that the use of water jets to mine the total seam by themselves would, in this case, require too much energy, and a combination water jet action with mechanical assistance system was proposed. In order to demonstrate the method as simply as possible it was determined that the best method would be to modify an existing mining machine. Accordingly, in the design the cutting heads of a shearer were removed and replaced by two high pressure pumps which together fed 50 gpm at 10,000 psi to the cutting head (Figure 6). The jets in the cutting head are then used to cut slots in the top, back, and bottom of the slice of coal being mined. This leaves a cantilever of coal which is readily broken off by the wedge shape of the cutting head. In the design experimentation it was found that a single jet would not cut a slot sufficiently wide to introduce the edge of the wedge into the slot (Figure 7). For this reason a dual orifice system was developed which produced (Figure 8) slots of sufficient width. This unit is now in construction under a Bureau of Mines contract. I am proud to announce that the initial design of this machine won this year's Student Design Award Competition run by the Lincoln Arc Welding Foundation.

## 5. BOREHOLE REAMING

A third application for water jets is also being considered and will shortly be tested by Flow Research at a Carbon River coal property in Washington state. Much expense is normally required to gain access to coal seams, and the process may take a number of years. In order to reduce both factors in the steeply dipping seams of that region a novel method of approach is being taken. Water jet drills will be used to drill from the surface down the dip of the seams. Once the required depth has been reached the nozzle system will be changed and the jets will be directed vertically outward widening the hole and washing the coal to the bottom or sump. Here it will be collected and pumped back up to the surface. The method, which is also being funded by the Bureau of Mines, is similar in some respects to earliest experiments in this technique carried out in the Gilsonite seams of the Green River basin in this country (23) and in Russia and Germany (24, 25).

## 6. ACKNOWLEDGMENT

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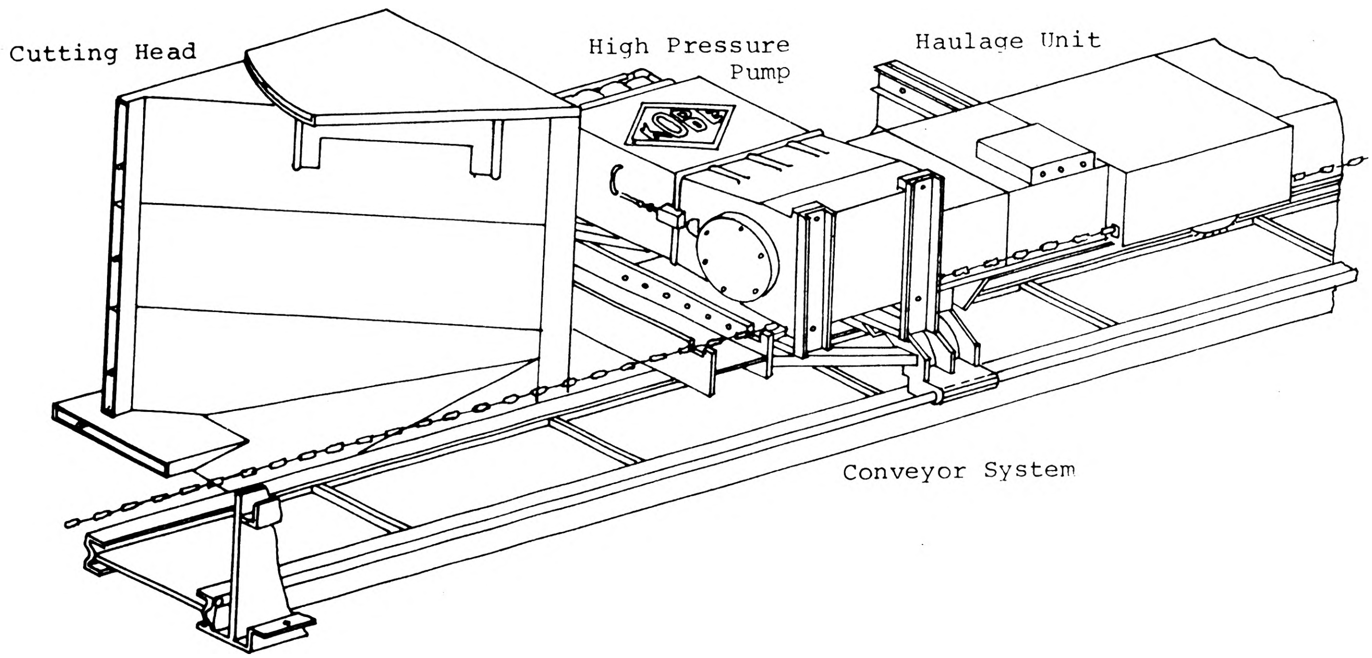


Figure 6. Artist concept of the Hydrominer unit.

Figure 7. Slot cut by single jet in coal.

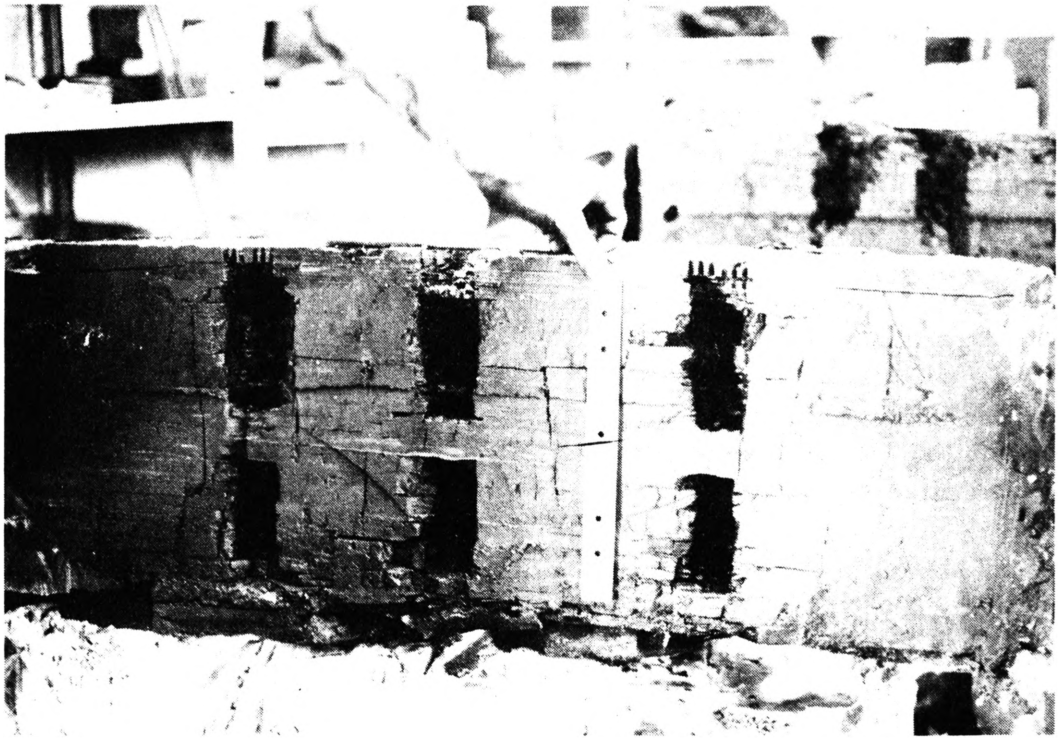

Figure 8. Slots cut by dual jets in coal.

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## 8. BIOGRAPHY

Dr. David A. Summers spent a year in the National Coal Board in the North of England prior to going to the University of Leeds, Yorkshire, England where he obtained a Bachelor of Science (Class I) in Mining Engineering in 1965 and a Ph.D. in Mining Engineering in 1968. His Ph.D. thesis dealt with water jet excavation of rock and since that time he has been on appointment at the University of Missouri - Rolla, Rock Mechanics & Explosives Research Center working in the field of applied jet cutting. He has produced over 30 papers dealing with this subject and is presently working on two research contracts developing a longwall water jet mining machine for the Bureau of Mines and a water jet drilling device for the Energy Research and Development Agency. He is currently Associate Professor of Mining Engineering and Senior Research Investigator at the Rock Mechanics & Explosives Research Center of the University of Missouri - Rolla, Rolla, Missouri.