

THE USE OF ULTRASOUND FOR CLEANING COAL

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ABSTRACT

Sound waves having frequencies higher than those to which the human ear can respond (about 16 kHz) are called ultrasound. Ultrasound in the range of 20 to 100 kHz produces high energy waves sometimes referred to as power ultrasound. Power ultrasound is used for a variety of purposes including cleaning, welding, rupturing cell walls in biochemistry studies, and dispersing solids in liquids.

Power ultrasound produces its effect via cavitation bubbles. When power ultrasound is applied to a liquid in sufficient intensity, the liquid is alternately compressed and expanded forming bubbles. When power ultrasound is applied to a mixture of particles and liquid and the bubbles collapse near a solid surface, a high-speed jet of liquid is driven into the particles and this jet can deposit enormous energy densities at the site of impact.

Cavitation tends to occur preferentially along gas-filled crevices in particles, creating the conditions necessary for a violent cavitation event termed "transient cavitation". The interfaces that exist where mineral matter is attached to coal are potential sites for transient cavitation and this focused application of energy can selectively break the bonds between the mineral matter and the coal. In addition, cavitation on the surface of the coal particles removes clay, water gel, and any products of oxidation.

Six tests of an ultrasound technology have been performed at three different commercial coal cleaning plants. Ultrasound was found to increase yield from three to ten percentage points. In addition, significant reductions in clean coal moisture, ash, sulfur, and mercury were noted.

INTRODUCTION

Higher frequency ultrasound (1 to 10 MHz) may be used to measure the effect of a medium on the ultrasound wave in applications such as medical imaging, SONAR, and non-destructive testing of materials. Ultrasound in the range of 20 to 100 kHz produces high energy waves sometimes referred to as power ultrasound. Power ultrasound is used for a variety of purposes including cleaning, welding, rupturing cell walls in biochemistry studies, and dispersing solids in liquids.

Power ultrasound produces its effect via cavitation bubbles (Mason and Lorimer, 1988). When power ultrasound is applied to a liquid in sufficient intensity, the liquid is alternately compressed and expanded forming bubbles that may contain vapor extracted from the more volatile components of the liquid or gases dissolved in the liquid. These bubbles have very short lifetimes and, when they collapse, hot spots with temperatures of around 9,000°F (about the temperature of the surface of the sun) can be produced along with pressures of about 14,000 psi (Suslick and Price, 1999).

Successful application of power ultrasound on a commercial scale requires a practical method of applying power ultrasound to a mixture of coal and water in an industrial environment. A practical method of applying ultrasound was developed by Bradley Vujnovic in 1993 (a process that was granted U.S. Patent No. 5,577,669). This technology is designed to be retrofitted into existing coal cleaning plants and does not require any change in either the flowsheet or the method of operating the cleaning plant.

When power ultrasound is applied to a mixture of particles and liquid and the bubbles collapse near a solid surface, a high-speed jet of liquid is driven into the particles and this jet can deposit enormous energy densities at the site of impact. The impingement of these microjets and associated shockwaves can expose fresh, highly-heated surfaces (Suslick and Matula, 1998). Cavitation tends to occur preferentially along gas-filled crevices in particles, creating the conditions necessary for a violent cavitation event termed "transient cavitation" (Suslick, 1998). The interfaces that exist where mineral matter is attached to coal are potential sites for transient cavitation and this focused application of energy can selectively break the bonds between the mineral matter and the coal. In addition, cavitation on the surface of the coal particles also removes clay, water gel, and any products of oxidation (Tao and Parekh, 2000, Buttermore, et al., 1988, and Fairbanks, 1986).

COMMERCIAL TESTING

To demonstrate the advantages of this ultrasound technology, six tests were performed at commercial coal cleaning plants that had been retrofitted with the Vujnovic ultrasound technology. The technology is applied in advance of conventional sizing, cleaning, and dewatering equipment.

The first five tests were performed at two cleaning plants in Pennsylvania and Test No. 6 was performed at a cleaning plant in the Illinois Basin. Except for the application of ultrasound, all three cleaning plants utilize conventional flowsheets and equipment.

Test No. 1 was conducted to determine if the ultrasound technology would recover additional energy from the parent coal. In Test No. 1, the quantity of clean coal produced using ultrasound was measured for one hour, then the ultrasound was switched off and the quantity of clean coal produced was measured for one hour. Finally, the ultrasound was switched on and the quantity of clean coal produced for one hour was measured again to confirm that the cleaning characteristics of the feed coal had remained constant for the test period. The results of this test demonstrated that an additional four percentage points of clean coal yield (20 tons per hour for a 500 ton per hour cleaning plant) was recovered using ultrasound. Without ultrasound, this fuel would have been landfilled as waste along with the high-ash, high-sulfur refuse from the cleaning plant.

Test No. 2 confirmed these results. The test, performed under the supervision of Mr. Al Deurbrouck, a noted coal processing expert recently retired from the U.S. Department of Energy, utilized similar test procedures. Mr. Deurbrouck's report states that yield increased by 3.45 percent without any loss of fuel quality.

Test No. 3 was conducted to provide evidence to the Pennsylvania Department of Environmental Protection that combustion of coal cleaned using ultrasound would not create additional air pollution compared to coal cleaned without ultrasound. To prove that the treated coal would be no worse than untreated coal of similar quality, more middlings were recovered to product to match the higher ash and sulfur content of untreated coal.

As shown in the Table, the untreated clean coal had an ash content of 10.0% and a sulfur content of 1.88% and the treated coal had an ash content of 10.6% and a sulfur content of 1.89%. The laboratory measured slightly higher ash in the treated coal which signals higher mineral content. Analysis of both samples revealed that the treated coal was 21% lower in mercury content and 8% lower in arsenic content in spite of the additional mineral matter caused by the inclusion of a substantial amount of middlings.

<u>Parameter</u>	<u>Untreated Coal</u>	<u>Ultrasound Treated Coal</u>	<u>Percent Change</u>
Ash (%)	10.0	10.6	+ 6
Sulfur (%)	1.88	1.89	0
Arsenic (ppm)	2.64	2.43	- 8
Mercury (ppb)	388	307	- 21

TABLE 1
MERCURY AND ARSENIC REDUCTION
(Analysis on a Dry Basis)

In Test No. 4, two samples were collected to quantify the ability of ultrasound to improve clean coal quality. One sample was collected during a normal operating shift utilizing ultrasound. A second sample was collected during an operating shift after the ultrasound had been turned off

for approximately eight hours. The conventional cleaned coal contained 7.63% moisture, 11.24% ash, and 1.89% sulfur and the ultrasound treated clean coal contained only 7.14% moisture, 9.83% ash, and 1.39% sulfur.

Test No. 5 was performed at a second cleaning plant in Pennsylvania. The results of this test show an increased yield of 10 percentage points. In addition, the ash and sulfur content of the ultrasound treated coal was lower than the conventional clean coal.

Test No. 6 was performed at a mid-western coal cleaning plant. In this test, yield increased by three percentage points when ultrasound was used while clean coal quality was unchanged.

The specific impact of the ultrasound technology (increased yield, improved clean coal quality, or both) depends on the characteristics of the coal being cleaned and the cleaning plant flowsheet. For example, if the clean coal is contaminated with clay, ultrasound tends to improve clean coal quality without any loss of yield by dispersing the clays and increasing the efficiency of classifying and cleaning unit operations. If significant amounts of clean coal are being lost to refuse, ultrasound tends to increase clean coal yield. Large improvements in both yield and clean coal quality tend to occur in difficult cleaning situations such as overloaded circuits or the presence of large amounts of near-gravity material.

SUMMARY

As a retrofit to an existing coal cleaning plant, the Vujnovic ultrasound technology has been shown to increase clean coal yield by from three to ten percent. In addition to increasing profits, the technology conserves energy by extracting considerably more energy from as-mined and waste coal feedstocks than conventional processes. As a result, the use of ultrasound can reduce the size and number of mine waste landfills.

The technology can also reduce the moisture, ash, sulfur, and mercury content of coal. Increasing coal quality reduces air emissions and the use of transportation fuels because less moisture and ash is transported to the consumer.

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