Advanced coal cleaning meets acid rain emission limits

Advanced coal cleaning processes allow high-sulfur coal to meet New York's stringent new acid rain emission regulations

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A study of advanced coal cleaning technology was done for the state of New York to investigate methods to use high-sulfur coal in view of anticipated lower SO_2 emission limits.

The study showed that physically cleaned, northern Appalachian high-sulfur coals are a promising alternative to low-sulfur coals from southern Appalachian fields. Testing showed that a combination of conventional coal cleaning with advanced methods that should be commercially available in the 1990s can reduce SO_2 emissions up to 77%.

Recently, New York acted to reduce SO_2 emissions by passing the "State Acid Deposition Control Act" (Ref. 1)—considered this country's first acid rain law. The act establishes measures to reduce SO_2 emissions from New York sources by 30%, based on 1980 emission levels, in two stages.

The first stage, scheduled to take effect January 1, 1988, calls for an 11% reduction. The second stage, to be formulated by January 1, 1991 in the absence of federal acid rain control legislation, would bring the total New York SO_2 emission reduction to 30%.

The reductions correspond to those that might be required of New York if federal acid rain legislation is enacted. Other northeastern states are now considering acid rain legislation in view of New York's precedent.

Coal cleaning study

Objectives of the coal cleaning study were to conduct a comprehensive technical evaluation of new coal cleaning technologies that can produce a low-sulfur and low-ash product from mid- to high-sulfur northern Appalachian coals and to assess the cost competitiveness of the clean coal product in the New York state market in comparison to low-sulfur coal from the southern Appalachian coal fields.

Target emission levels of 1.2, 1.6 and 2.2 pounds of SO_2 per million Btu were identified to cover a range of emission limits that might result from current New York or pending federal acid rain legislation.

A combination of advanced and conventional physical coal cleaning technologies was used to process three candidate northern Appalachian coals (Upper Freeport, Lower Freeport, and Pittsburgh).

Conventional processing was done at the EPRI Coal Cleaning Test Facility (CCTF) at the Homer City power plant. Samples were collected and split at the Bituminous Coal Research National Laboratory (BCRNL) to provide representative coal samples for each advanced process developer.

The approach at the EPRI facility involved removing the 28-mesh x 0 natural fines from each coal, processing the plus-28-mesh material in a heavy medium cyclone at 1.7 specific gravity and reprocessing the float-1.7 material in a heavy medium cyclone at 1.3 specific gravity.

The float-1.3 material provided product coal while the natural fines (28-mesh x 0) and plus-28-mesh middlings (float-1.7/sink-1.3 specific gravity) fractions provided feed material for the advanced physical coal cleaning processes.

Advanced processes

Thirteen physical coal cleaning processes were identified from an initial tabulation of nearly 30. (All chemical coal cleaning processes were eliminated from consideration because it was assumed that they would not be commercially available by 1995.)

The evaluation was based on weighted rating factors in three main categories: commercial availability by 1995, technical performance, and economics. Upon completion of the evaluation, the developers of the highest ranked processes were surveyed to determine their willingness to participate in the detailed process evaluation program. As a result of the inquiries, the following processes were selected for study:

•Fine-coal, heavy-medium cyclone separation/flotation,

•Advanced flotation,

•Dow true heavy liquid separation,

•Advanced Energy Dynamics (AED) electrostatic separation, and

•National Research Council of Canada oil agglomeration.

These five technologies are at various stages of development, and we caution the reader not to take the results presented as a direct comparison of their capabilities.

Cost estimates were based on design

Table 1. Selected process results (integrated plant)

	Feed	FCHMC flotation Product	Advanced flotation Product	Dow true heavy liquid Product	AED FC Product	AED UFC Product	Oil agglomeration Product
Upper Freeport coal							
Weight % of feed	100.0	64.4	70.8	67.4	72.7	64.2	71.7
Total Sulfur, Weight %	2.5	1.3	1.5	1.1	1.5	0.9	1.5
lbs SO_2 per million Btu	4.7	1.8	2.1	1.6	2.3	1.1	2.3
SO_2 reduction, %		62.6	55.0	66.4	51.6	74.4	52.0
Ash Weight %	29.8	8.9	10.5	9.5	14.9	3.0	11.3
Heating value, Btu/lb	10570	14150	13870	14020	13090	15150	13310
Btu recovery, %	100.0	86.2	92.9	89.4	90.0	91.6	90.3
Lower Freeport coal							
Weight % of feed	100.0	68.0	71.3	71.0	77.0	69.5	75.6
Total Sulfur, Weight	4.3	1.5	1.8	1.4	1.9	1.3	2.0
lbs SO_2 per million Btu	7.5	2.1	2.6	2.0	2.8	1.7	2.9
SO_2 reduction, %		72.1	65.3	73.9	62.5	77.4	61.1
Ash, Weight %	21.4	5.6	7.0	6.0	10.4	2.9	7.6
Heating value, Btu/lb	11470	14090	14270	14090	13260	14420	13680
Btu recovery %	100.0	83.5	88.9	87.2	89.0	89.9	90.1
Pittsburgh No. 8 coal							
Weight % of feed	100.0	80.9	81.2	84.2	85.0	83.6	85.0
Total Sulfur, Weight %	3.6	2.3	2.4	2.2	2.4	2.0	2.6
lbs SO_2 per million Btu	5.6	3.2	3.4	3.1	3.4	2.8	3.7
SO_2 reduction, %		43.3	39.0	43.9	39.7	49.0	33.8
Ash, Weight %	13.3	5.7	6.2	6.3	7.9	3.6	6.8
Heating value, Btu/lb	13030	14350	14270	14180	14340	14600	14050
Btu recovery, %	100.0	89.1	88.9	91.6	93.5	94.1	91.7

parameters for the conventional coal cleaning plant including cleaning plant capacity factor (111%), operating hours (3500 hr/yr), availability (90%), and clean coal yield (70%). Coal feed requirements for a 500-MW power plant operating at 65% load factor with a heat rate of 9500 Btu/kWh were then determined. These design and operating parameters provided information for equipment requirements and capital cost estimates.

Costs for each advanced process covered in the study and for conventional coal cleaning and coal-water mixture (CWM) plants were prepared for Lower Freeport coals only. Capital costs for the conventional coal cleaning and CWM plants are estimated at $25 million and $22.5 million, respectively, in 1985 dollars.

Table 1 summarizes the results of conventional coarse coal cleaning combined with the advanced process for each coal. The SO_2 emissions, emission reductions, and Btu recoveries achieved for each process on the selected coals are summarized in Table 2.

Capital and operating cost estimates, expressed in 1985 dollars, were made for the facilities required to receive and crush run-of-mine (ROM) coal, wash 450 tph of raw coal in a coarse coal cleaning plant, dispose of the rejects from coarse cleaning, separate the clean coal (float-1.30 specific gravity) from the middlings coal, and process the ground middlings and the 28-mesh x 0 ROM coal in the advanced coal cleaning plant.

The capital costs for an integrated facility located at the mine site and the annual integrated cleaning plant operating costs are shown in Table 3.

Levelized cleaning costs for Lower Freeport coal to fuel a 500-MW power plant at 65% load factor are shown in Table 4.

Fine-coal, heavy-medium process

The fine-coal, heavy-medium cyclone/flotation process involves cleaning the fine coal in a heavy medium cyclone using a magnetite-water mixture as the separation medium. Raw coal is mixed with a medium and then directed under pressure to a cyclone, where it separates into a clean coal fraction and a refuse fraction based on the specific gravity of the particles and the medium (Ref. 2).

Test work indicated that coals of plus 150-mesh could be treated by this process. Rougher-cleaner flotation was used to process the minus 150-mesh coal.

Table 1 shows that the process was unable to clean any of the candidate coals to their prescribed SO_2 emission targets. However, Upper and Lower Freeport coals were cleaned to less than the highest target emission level of 2.2 lb SO_2/million Btu. SO_2 reduction ranged from 43.3% for Pittsburgh No. 8 coal to 72.1% for Lower Freeport coal.

Advanced flotation

The rougher-cleaner, advanced multistage flotation process was also evaluated. The first stage rougher flotation cells are operated to separate out the high-ash, least floatable materials as refuse. The froth product from the rougher stage is then reprocessed in cleaner cells in which a pyrite depressant is used in addition to a coal collector. The froth product of this stage was low in ash and sulfur and became the final product. The rejects from the cleaner cells were combined with the rougher stage refuse.

Table 1 shows that flotation was unable to clean any of the coals to their targeted emission levels. Only rougher-cleaner flotation of Upper Freeport coal, combined with conventional coarse coal cleaning, meets the highest target emission level of 2.2 lb SO_2/million Btu.

Dow true heavy liquid separation

The Dow process uses two beneficiation steps to clean coal and a proprietary solvent recovery technology to remove

Table 2. Process performance results (Integrated plant)

Process	Coal Seam	SO_2 emission (Lbs. $SO_2/10^6$ Btu)	SO_2 emission reduction (%)	Btu recovery (%)
FCHMC/ flotation	Upper Freeport	1.8	62.6	86.2
	Lower Freeport	2.1	72.1	83.5
	Pittsburgh No. 8	3.2	43.3	89.1
Advanced flotation	Upper Freeport	2.1	55.0	92.9
	Lower Freeport	2.6	65.3	86.0
	Pittsburgh No. 8	3.4	39.0	88.9
Dow true heavy liquid	Upper Freeport	1.6	66.4	89.4
	Lower Freeport	2.0	73.9	87.2
	Pittsburgh No. 8	3.1	43.9	91.6
AED-FC	Upper Freeport	2.3	51.6	90.0
	Lower Freeport	2.8	62.5	89.0
	Pittsburgh No. 8	3.4	39.7	93.5
AED-UFC	Upper Freeport	1.1	74.4	91.6
	Lower Freeport	1.7	77.4	89.9
	Pittsburgh No. 8	2.8	49.0	94.1
Oil agglomeration	Upper Freeport	2.3	52.0	90.3
	Lower Freeport	2.9	61.1	90.1
	Pittsburgh No. 8	3.7	33.8	91.7

solvent from water circulating through the system. The latter step reduces the chlorinated solvent content in the wash water to less than 10 ppm, allowing water to be safely discharged from the system, as well as recovering solvent for recycle. The two beneficiation steps are a liquid-liquid partitioning step treating the minus 100-mesh coal particles and cyclone separation steps for all sizes (Ref. 3).

The liquid-liquid partitioning step is used to remove clay from coal fines. The process is carried out with a chlorinated solvent and water. The hydrophobic coal-rich particles collect in the heavier chlorinated solvent phase. This step separates only particles that are hydrophilic in nature from those that are hydrophobic.

In the cyclone separation step, coal-rich particles from the liquid-liquid partitioning step (minus 100-mesh) and the coarser coal fractions (28 x 100-mesh) are slurried with solvent and pumped under pressure into cyclones. In the cyclones, the coal-rich fraction separates at or near the specific gravity of the solvent as the overflow. The high-gravity ash and pyrite-containing particles (refuse) discharge as underflow from the cyclones. Each of the streams passes through a series of solvent removal/recovery steps to yield a clean coal product and a refuse.

Total SO_2 emission reductions ranged from 44% for Pittsburgh No. 8 coal to 74% for Lower Freeport coal. Table 1 shows that Upper Freeport coal was cleaned to the target emission level of 1.6 lb SO_2/million Btu, and Lower Freeport coal was cleaned to 2.0 lb SO_2/ million Btu.

AED fine coal electrostatic separation

The AED fine coal (FC) process developed by Advanced Energy Dynamics, Inc. (AED) of Natick, Mass. uses an electrostatic drum-separator technology. The pulverized coal is subjected to electrostatic charging and then fed onto the surface of a rotating drum. The charge remains on the nonconductive coal particles, attracting them to the drum. The charge on the conductive sulfur and ash-bearing materials drains off to the grounded drum, releasing these materials.

Centrifugal and gravitational forces effectively separate the impurities from the coal. The coal adhering to the drum is scraped off using a doctor blade. The FC process operated most efficiently on particles larger than 37 microns (400-mesh).

The lack of effectiveness below 400-mesh concerned AED, since 20 to 40% of conventionally pulverized coal is found within this range. A significant fraction of inorganic (pyritic) sulfur exists in this size range, and pyritic sulfur is the most easily removed by physical cleaning.

Ultrafine coal (UFC) process

The UFC process is based on the phenomenon that fresh surfaces created when any solid material is broken emit electric charges. When a mixture of two types of particles is introduced into a system in which at least some of the particles are broken, a differential charge is created. One type of particle is charged positively and the other negatively.

In practice, the UFC system includes a "charger" in which the pulverized coal is introduced and subjected to impact and breakage by being accelerated to a high velocity and projected against or along surfaces. The charged particles then exit into a collector, where an electric field is maintained between slowly rotating electrode disks. Alternate disks are maintained at positive and negative potential. The negatively charged inorganic particles are attracted to the positive electrodes and are scraped off in the

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Table 3. Capital and operating costs estimates (1985 dollars)

Process	Capital cost	Operating cost
FCHMC/flotation	$48,800,000	$7,865,000
Advanced flotation	$55,100,000	$9,910,000
Dow true heavy liquid	$45,500,000	$7,380,000
AED conventional plant	$33,000,000	$4,300,000
AED FC	$ 6,630,000(1)	$1,365,000(1)
AED UFC	$20,500,000(1)	$3,347,000(1)
Oil agglomeration	$42,600,000	$9,910,000

(1) Estimated by AED, exclusive of material handling system. Process is located at power plant.

Table 4. Levelized cleaning costs (1985 dollars)

Process	Mills/kWh	$/10⁶ Btu	$/t Clean coal
FCHMC/flotation	7.56	0.80	20.60
Advanced flotation	9.50	1.00	25.40
Dow true heavy liquid	7.09	0.75	19.40
AED-FC	6.19	0.65	12.64
AED-UFC	7.64	0.80	21.35
Oil agglomeration	11.20	1.18	23.20

reject removal zone of the collector. The positively charged coal particles are attracted to the negative electrodes and are scraped off into the product stream (Ref. 4).

The UFC system can clean coal in the particle size range of 140-mesh (106 μ) to 0. This range overlaps with the FC system, giving flexibility in optimizing an overall system using FC, UFC, or a mix of FC and UFC processing.

The AED process equipment would be located at the power station between the pulverizers and the burners. This process would require handling, storage, and shipping of two coal streams, combined middlings and raw coal fines, and coarse clean coal from the conventional coal cleaning plant to the power station.

It is anticipated that the coarse clean coal and the combined middlings/raw coal fines would be fired in separate burner systems on the same boiler.

The two-stage FC electrostatic separation plant cost estimate is based on two identical 50-tph modules installed adjacent to the power plant and operating on the same schedule, without storage capacity for finished product.

Table 2 shows that the FC process test program was unable to clean any of the candidate coals to their targeted SO_2 emission levels. Only test results from Upper Freeport coal approached the highest emission level of 2.2 lb SO_2/million Btu with a combined coarse/advanced cleaning process coal product of 2.3 lb SO_2/million Btu. Combined product weight yields ranged from 73 to 85%, and Btu recoveries ranged from 89 to 94%.

The overall results from the FC process tests were mixed. The quality of the coals was improved in all of the cases; however, more test work is needed to determine the optimum operating parameters.

Information on AED's UFC process is based on theoretical calculations from test data by AED which simulate the performance of multistage electrostatic separation in various stage arrangements. The results shown in Table 4 are subject to verifying the theoretical calculations through pilot plant testing.

With the above-mentioned reservations, AED's tests indicate that Upper Freeport coal can be cleaned by the UFC process to meet the 1.2 lb SO_2/million Btu target emission level with a combined product weight yield of 64% and a Btu recovery of 92%. Lower Freeport coal test results were close to the 1.6 lb SO_2/million Btu target emission level with a 70% combined product weight yield and a Btu recovery of 90%. The 2.2 lb SO_2/million Btu target emission level for Pittsburgh No. 8 coal was not achieved by the UFC process. The reported results were based on seven-stage processing without test data on the impact of the circulating loads.

NRC of Canada oil agglomeration

Agglomeration relies on the surface property differences between coal, pyrite, and ash for separation. When a small amount of a liquid (fuel oil, halogenated solvents, Freon, CO_2, etc.) is added to a strongly agitated coal-water mixture, the carbonaceous components of the coal become wetted with this liquid and collect as a cluster (i.e., agglomerate). The agglomerated coal can then be separated from the water and unagglomerated particles (Ref. 5).

Scotia Liquicoal Limited is the owner and operator of a 3- to 5-tph pilot plant at Dartmouth, Nova Scotia, as sublicensee to the National Research Council of Canada. Testing of the candidate coal sample of 3/4-in. x 28-mesh middlings and 28-mesh x 0 raw coal samples of the candidate coals from EPRI's Coal Cleaning Test Facility was done here.

Only the Upper Freeport coal met the highest target emission level of 2.2 lb SO_2/million Btu. Several coal sizes were investigated. Test results obtained with 100-μ particle size feeds were generally better than those with 50-μ feeds. The best test results were generally obtained with low dosages of agglomerating oil. The process developer's pilot plant experience with other coals suggests that the rates of oil addition required for continuous plant operation are significantly lower than those used on a laboratory scale for equivalent results, which is attributed to the self-nucleating nature of the flow-through agglomeration process. **END**

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