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# Project Summary

# Bench-Scale Performance Testing and Economic Analyses of Electrostatic Dry Coal Cleaning

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**This study presents the results of preliminary performance evaluations and economic analyses of the Advanced Energy Dynamics, Inc. (AED) proprietary fine coal cleaning process. Coal is destined to play a dominant role in the national energy supply mix during the next century. This fact, coupled with the economic and environmental disadvantages of uncleaned coal, has generated intense interest in novel techniques for coal beneficiation. The AED "FC" Process relies on the substantial differences in electrical conductivity which exist between the organic coal matrix and the inorganic inclusions in the coal to separate these impurities from the coal. It also takes advantage of the additional liberation associated with pulverization of the coal used in most boilers. The electrostatic separation process is effected on a rotating drum (roll) separator which can be placed between the pulverizer and the boiler at a power plant. It can be retrofitted to existing boilers.**

**This report covers work accomplished jointly by Versar, Inc. and AED. Grab samples of feed and product coal were obtained from 25 operating physical coal cleaning (PCC) plants by Versar. Samples of PCC plant feed coal in a run-of-mine (ROM) condition were processed by Versar and a portion was provided to AED for testing on the AED bench-scale separator (Tech 1) Process. Comparisons of performance and costs between the AED Tech 1 Process and the PCC plants have been developed. The results show that the AED Tech 1 Process exhibits superior sulfur removal performance at equivalent cost and energy recovery levels. The design and scope of the project did not permit a complete evaluation of the ash removal capability of the process. Overall, ash removal results indicate that the AED Tech 1 Process did not perform as well as the PCC plants; however, the data obtained offer the expectation of improved ash removal with further work.**

***This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

As the most abundant fossil fuel resource in our Nation, coal is destined to play an increasingly significant role in the energy future of the U.S. Unfortunately, coal is generally also the dirtiest fuel in our energy supply mix. The presence of substantial amounts of inorganic material in coal has negative impacts on the availability and lifetime of coal-fired steam electric plants due to problems of corrosion and slag formation. Furthermore, the stack gas from such facilities contains high levels of air pollutants which, to satisfy national policy, most be removed by complex and expensive cleaning techniques. Thus, for both economic and environmental reasons, both the government and the private sector have a continuing interest in novel processes which offer the promise of being able to upgrade the fuel quality of available coal. AED has developed a novel fine coal cleaning process (Tech 1) which has shown encouraging results in a number of preliminary tests. This process removes inorganic matter (largely ash-forming minerals, including pyrite) from pulverized coal by a patented electrostatic separation process. The AED Process can be retrofitted to existing pulverized-coal-burning facilities and may, if its initial promise continues to be borne out, have substantial advantages, compared both to conventional coal cleaning and to stack gas cleanup technologies.

The AED Process has its foundation in research conducted during the late 1970s which suggested that the American Society for Testing and Materials (ASTM) method for determining organic sulfur in coals consistently overestimated the organic sulfur level (hence underestimating the potential of physical coal cleaning (PCC) to remove sulfur from coal). Microscopic studies of coal suggested that the ASTM method substantially understates the pyritic sulfur levels in most coal. Findings, using electron microscopy, were:

- A substantial quantity of pyrite is in noncrystal form, from colloidal size up to approximately 5 $\mu$m.
- Another group of pyrite inclusions (called framboids) is in the 20 to 50 $\mu$m size range, formed by aggregates of the monocrystals.
- A third class of pyrites is larger inclusions, basically rock fragments, sometimes referred to as "secondary" pyrite.

Monocrystals and framboids are so small that the ASTM tests have largely classified them as "organic" sulfur (thus assumed to be removable only by chemical means). But when the coal is finely pulverized, these small pyrite particles can be largely separated from the coal matrix (liberated) and thus more removable than conventional wisdom has dictated (see Figure 1). Thus, coal-cleaning systems capable of treating pulverized coal would generally have access to larger quantities of pyrite than the conventional coal-cleaning processes. Since most coal used to produce steam is pulverized before combustion, AED saw the possibility of a process which could use the increased liberation of pulverization and could be retrofitted to existing systems. In addition, AED sought a process concept that would remove as much pyrite and ash as possible after liberation in the pulverizing process

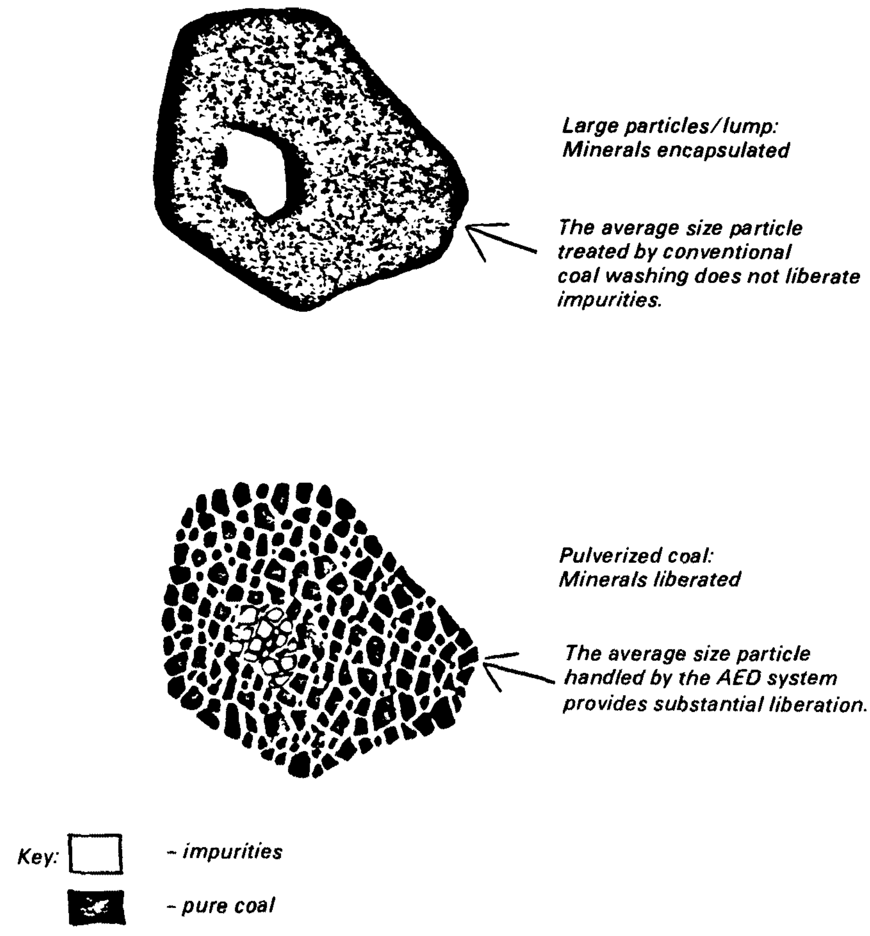


*Figure 1.* *Theory of liberation operation.*

without the use of water, chemicals, or other additives.

Electrostatic separation using the "roll" separator was selected as the technology for further development. This process uses as the principle of separation the differences in electrical conductivity (roughly 4 to 10 orders of magnitude) between the organic matrix and the inorganic inclusions in coal. Electrostatic separation for coal beneficiation had been studied earlier by a number of researchers in the U.S. and abroad. In these studies, it was found that, although some separation could be achieved, the clouds of fine coal dust formed made the process impractical and inefficient.

A model electrostatic cleaning system was constructed at AED in early 1979. It duplicated the results of earlier investigations where clouds of coal dust did indeed leave the rotating drum, rendering coal cleaning relatively inefficient. Furthe work showed that the reason for the los of coal from the drum was the presenc of a boundary layer of air which prevente the coal from contacting the surface ( the drum. Efforts to use this informatic have resulted in major improvement the technology. In the AED fine-co separator, the boundary layer is strippe from the rotating roll by a doctor bla( (usually employed in the removal of soli( and liquids from rotating rolls, but in tr case used to remove a gas layer). As result, the coal particles are deposited ( the rotating roll immediately followi the removal of the boundary layer, a are pressed onto the roll by the ne boundary layer formed downstream the doctor blade. This innovation in tec nology has resulted in issuance of U Patent No. 5,325,820 to AED. Figure schematically represents the principle operation for the process.

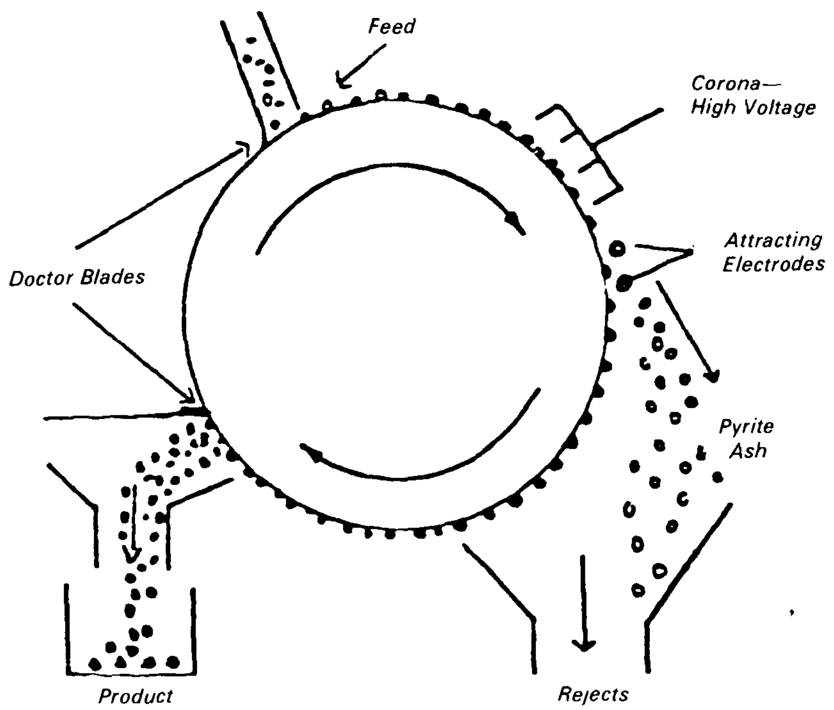


*Figure 2. Principle of operation of electrostatic roll separator*

## Project Approach

The premise of the AED Process concept — that separation of small inorganic inclusions from the coal matrix will enhance coal quality — is undoubtedly true, to a degree. The question is to what degree? There is a great deal of variability in the nature of the inorganic contamination of coals — by type, between coal seams, and even within a single seam. Hence, since no data base existed which could allow an evaluation of this new technology by addressing the validity of the fundamental premise, it was decided that two goals for this project were:

- To develop a broader information base on the performance of the AED Process on various coals
- To provide information which would allow comparison of the AED bench-scale fine coal cleaning process (Tech 1) with conventional PCC technologies.

The ultimate objective was to provide a basis for assessing the merits of the technology in the context of other coal cleaning techniques. The project was a joint effort by Versar, AED, and EPA. The program involved comparison of the performance of the AED Tech 1 Process with PCC plants presently in operation.

Representative coal seams in the U.S. were identified. Twenty-five PCC plants cleaning coal from these seams were then selected (see Figure 3). The feed and product coal at these plants were grab sampled and then split into various fractions. A fraction of each feed coal sample was sent to AED to be tested in the AED Tech 1 Process. Another fraction of each feed coal sample and each product coal sample was analyzed at Versar's coal laboratory for ash, sulfur content, and heating value.

Twenty-seven feed coal samples were delivered to AED for processing. Note that these were run-of-mine (ROM) coals destined for treatment in a PCC plant. As such they were not typical of the coals which would be fed to the pulverizer of a coal-fired boiler. Boiler feed coals have usually been through a preliminary cleaning (to remove large inorganic inclusions incidental to the mining operation) before shipping them to the boiler. AED did not attempt such a step. The sample coals were pulverized by AED in a small hammermill to pulverized coal (p.c.) size (60 to 80 percent, <200 mesh) before processing. Thus, any larger inclusions (rocks and pebbles) were pulverized and sent through the process. The pulverized sample was separated into three fractions: ultrafine (<20 $\mu$m), very fine (53 x 20 $\mu$m), and fine 246 x 53 $\mu$m). The ultrafine fraction was not processed, but was incorporated with the product from the (separate) processing of the other two fractions. These latter fractions were processed on the Tech 1 Unit at a feed rate of 125 kg/hr (275 lb/hr). Drum rotation rate and electrode voltage were constant for all runs. Measurements were made of the total sulfur, ash, and heating value for each fractional product as well as the sulfur, ash, heating value, yield by weight, and energy recovery for the total product of the Tech 1 Process.

## Findings

Because the field samples obtained were grab samples and not time-averaged, it has not been feasible to conduct a detailed assessment of the performance of the AED Tech 1 Process or the individual PCC plants. Such assessments require the continuous processing (and sampling) of fairly large (several tons per hour) quantities of coal over a period of days — clearly beyond the scope of this project. A qualitative comparison was made by simply counting the number of times the Tech 1 Process performed significantly better or worse than the appropriate PCC plant. The Tech 1 Process exhibited a much better capability of removing sulfur than the coal washing plants from which the coals were obtained (see Table 1). The sulfur removal was greater for the high- to moderate-sulfur coals than for the very-low-sulfur coals. Ash removal capability of the Tech 1 System was found to be lower than the ash removal capability of the conventional coal preparation plants (see Table 2). This relatively low overall ash removal reflects the very high mineral content of the ROM feed coals. Much of this mineral matter is probably rough rock inclusions from the mining process, usually removed at the mine before shipping to any customer. In the fine sub-fraction of the process, where ash particles are larger than 53 $\mu$m (270 mesh) in average diameter, the Tech 1 Process removed slightly more ash than did conventional coal washing. This fraction of the ash particles is responsible for most slagging in boilers.

Cost evaluations of PCC were performed using the actual process flow diagrams from six PCC plants visited during the sampling period. These flow diagrams were modified and process equipment was sized to provide a common basis for the designs. The results of these cost

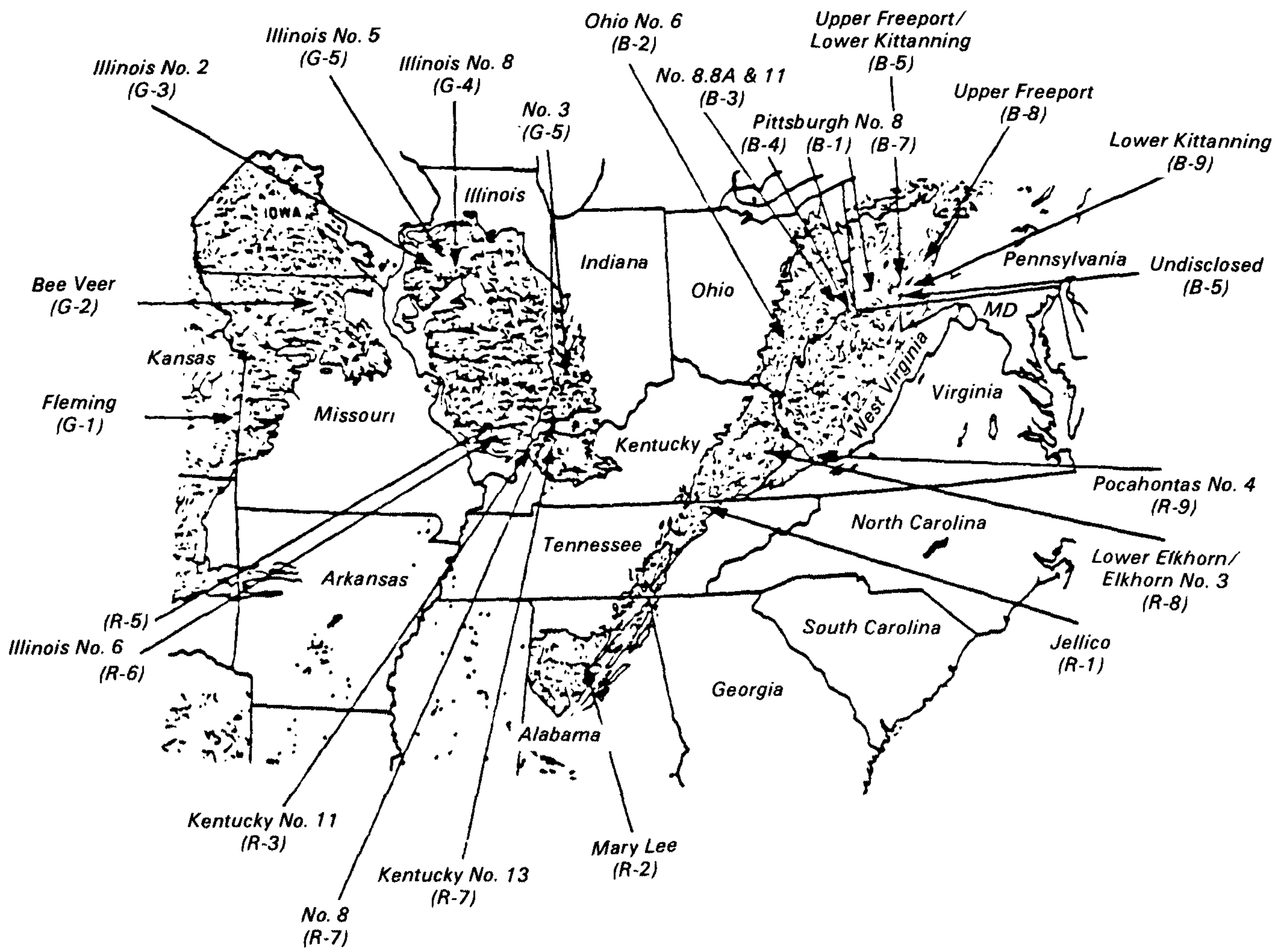


***Figure 3.*** *Geographical distribution of the selected coal seams and the PCC plants sampled.*

analyses were reduced to unit costs for product, based on the energy content of the grab samples and estimates of mass recovery provided by the plant operators. Two conceptual designs were developed for the AED Tech 1 Process: one at a minemouth (this required briquetting the product coal) and one at an existing power plant. The unit costs for these designs indicated that costs of coal cleaning by the AED Tech 1 Process are equivalent to (and perhaps less than) the costs for the PCC plants examined. The unit costs reported for the AED Tech 1 Process were in the range of $2 to $4 per ton of cleaned coal.

## Analysis and Conclusions

In general, the overall results of the study suggest that the AED Tech 1 Process merits further study. Its superior performance on sulfur removal, competitive energy recovery, moderate costs, and potential for retrofit all argue in its favor. The ash removal results, although ambiguous, do seem to offer cause for concern: toward the conclusion of the project three brief exploratory studies were made to assess the significance of this potential problem with the AED Tech 1 Process. These brief studies involved:

- Optimizing process operating variables for a single coal sample.
- Exploring the impact of precleaning on process results for a single coal.
- Developing a process for cleaning the ultrafine fraction of the pulverized coal.

In each case, significant improvement in ash (as well as sulfur) removal results was observed, reinforcing the apparent merits of the AED Process.

**Table 1.** *Comparison Of Sulfur Content In Process Product Streams*

| Versar Sample Designation | Average Observed Feed S (wt. %) | PCC Process Product (wt. %) | AED Process Total Product (wt. %) | AED Process Total Product Comparison | AED Process Fine Product (wt. %) | AED Process Fine Product Comparison |
|---|---|---|---|---|---|---|
| B-1 | 3.98 | 2.81 | 2.73 | o | 2.67 | + |
| B-2 | 3.16 | 2.48 | 2.44 | o | 2.17 | + |
| B-3(8/11) | 3.41 | 2.61 | 2.66 | o | 2.50 | + |
| B-3(11) | 2.25 | N.A. | 1.76 | ? | 1.61 | ? |
| B-4 | 3.92 | 3.55 | 3.22 | + | 3.42 | o |
| B-5 | 2.36 | 2.22 | 1.72 | + | 1.69 | + |
| B-6(UF) | 1.63 | N.A. | 1.15 | ? | 1.00 | ? |
| B-6(LK) | 3.96 | N.A. | 2.91 | ? | 2.29 | ? |
| B-6(MIX) | — | 1.47 | | | | |
| B-7 | 2.06 | 1.87 | 1.20 | + | 1.04 | + |
| B-8(H) | 4.01 | N.A. | 2.58 | ? | 2.24 | ? |
| B-8(V) | 1.84 | N.A. | 1.31 | ? | 1.17 | ? |
| B-9 | 1.76 | 1.48 | 1.31 | + | 1.31 | + |
| R-1 | 1.08 | 0.86 | 0.81 | o | 0.78 | + |
| R-2 | 1.16 | 1.43 | 0.93 | + | .99 | + |
| R-3 | 3.68 | 3.43 | 3.25 | + | 3.16 | + |
| R-4 | 2.48 | 1.60 | 1.45 | + | 1.41 | + |
| R-5 | 0.89 | 0.83 | .76 | o | 0.76 | o |
| R-6 | 3.54 | 3.35 | 2.60 | + | 2.53 | + |
| R-7 | 4.11 | 3.71 | 3.39 | + | 3.17 | + |
| R-8 | 0.56 | 0.80 | 0.59 | + | 0.69 | o |
| R-9 | 0.52 | 0.35 | 0.57 | - | 0.59 | - |
| G-1 | 4.40 | 3.67 | 3.72 | o | 3.20 | + |
| G-2 | 6.78 | N.A. | 3.96 | ? | 3.57 | ? |
| G-3 | 4.61 | 3.96 | 3.41 | + | 3.23 | + |
| G-4 | 4.04 | 3.12 | 3.05 | o | 2.91 | + |
| G-5 | 2.87 | 2.97 | 2.25 | + | 2.26 | + |
| G-6 | 5.66 | 5.20 | 4.33 | + | 3.73 | + |
| S-1 | 2.48 | 1.30 | 1.53 | - | 1.14 | + |

*Comparison Key:* - *AED Process Significantly Worse*
o *No Significant Difference*
+ *AED Process Significantly Better*

**Table 2.** *Comparison Of Ash Content In Process Product Streams*

| Sample Designation | Average Observed Feed Ash (wt. %) | PCC Process Product (wt. %) | AED Process Total Product (wt. %) | AED Process Total Product Comparison | AED Process Fine Product (wt. %) | AED Process Fine Product Comparison |
|---|---|---|---|---|---|---|
| B-1 | 15.6 | 8.39 | 10 4 | - | 8 2 | o |
| B-2 | 24.0 | 12.4 | 13 6 | o | 10.8 | + |
| B-3 (8/11) | 22.4 | 13.3 | 17.0 | - | 13.7 | o |
| B-3 (11) | 21.1 | N.A | 16.4 | ? | 13.3 | ? |
| B-4 | 41.3 | 13.2 | 26.9 | - | 9.9 | + |
| B-5 | 32.0 | 20.2 | 25.6 | - | 19 6 | o |
| B-6 (UF) | 25 4 | N.A. | 19.4 | ?(-) | 17.6 | ?(-) |
| B-6 (LK) | 22.5 | N.A. | 21.6 | ?(-) | 21.2 | ?(-) |
| B-6 (MIX) | N.A. | 10 1 | N.A | | | |
| B-7 | 27 5 | 12.0 | 21.2 | - | 13.0 | o |
| B-8 (H) | 28.5 | N.A. | 18.7 | ? | 13 5 | ? |
| B-8 (V) | 21.5 | N.A. | 17.2 | ? | 14.0 | ? |
| B-9 | 27.6 | 9 8 | 23.3 | - | 21.6 | - |
| R-1 | 32.1 | 12.0 | 23.2 | - | 10 4 | + |
| R-2 | 34.2 | 10 9 | 26 2 | - | 17.1 | - |
| R-3 | 31 7 | 10.2 | 20.9 | - | 10.2 | o |
| R-4 | 24. | 12 7 | 10.3 | + | 7.5 | + |
| R-5 | 25.2 | 16.1 | 17.2 | o | 8.8 | + |
| R-6 | 25.8 | 13.0 | 14.1 | o | 10.1 | + |
| R-7 | 23.8 | 11 3 | 14.9 | - | 9.8 | + |
| R-8 | 39.6 | 7.3 | 24.1 | - | 14 2 | - |
| R-9 | 23.8 | 5.9 | 17.8 | - | 12.1 | - |
| G-1 | 37.9 | 11.9 | 24.1 | - | 11.0 | o |
| G-2 | 23.9 | N.A. | 15.0 | ? | 8.4 | |
| G-3 | 27.6 | 8.10 | 13.2 | - | 9 6 | - |
| G-4 | 37 7 | 12.1 | 25.9 | - | 13.9 | - |
| G-5 | 40.6 | 14.0 | 30.2 | - | 13.3 | o |
| G-6 | 25.1 | 14 5 | 20.2 | - | 11.2 | + |
| S-1 | 32.2 | 9.2 | 24.2 | - | 15.8 | - |

*Comparison Key* - *AED Process Significantly Worse*
o *No Significant Difference*
\+ *AED Process Significantly Better*

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*The complete report, entitled "Bench-Scale Performance Testing and Economic Analyses of Electrostatic Dry Coal Cleaning," (Order No. PB 87-168 407/AS; Cost: $18.95, subject to change) will be available only from:*
*National Technical Information Service*
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