United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S7-86/017 Dec. 1986

EPA

Project Summary

Evaluation of Conventional and Advanced Coal Cleaning Techniques

A. B. Onursal, J. Buroff, and J. Strauss

This report assesses the capability, cost, and environmental effects of coal cleaning to reduce sulfur dioxide (SO_2) emissions. It is the culmination of a 4-year program directed by EPA's Air and Energy Engineering Research Laboratory.

The report includes evaluations of SO_2 emission reductions by cleaning coals on a state and regional basis; descriptions of coal cleaning equipment; calculation of environmental tradeoffs; development of algorithms for coal cleaning capital costs, operation and maintenance costs, and cost-benefits; brief descriptions of advanced coal cleaning processes; summaries of coal and utility industry trends relative to coal cleaning; and development of a utility-system-based model for calculating SO_2 emission compliance costs using coal cleaning, blending, and flue gas desulfurization options.

The report notes that 85 percent of the SO_2 emission reductions produced by coal cleaning would be attained from coals in the Northern Appalachian and Eastern Midwest regions. For a given coal, the environmental tradeoff is a reduction of 20 to 50 percent in potential SO_2 emissions and 25 to 85 percent reduction in particulate loadings versus a 50 to 150 percent increase in solid wastes generation. The capital cost of a cleaning plant is quite dependent on the coal, the mining method, and site specific factors. However, a linear relationship can be developed for O&M costs versus cleaning plant feed rate. Most benefits of cleaning were quantified based on the results of a recent study of the Tennessee Valley Authority (TVA) system.

Several chemical and advanced physical coal cleaning processes continue to look promising for production of very low sulfur, low ash coals. Generally, the number of coal preparation plants and amount of coal cleaned can be expected to grow substantially in the next 10 years. This growth rate will depend largely on energy prices and EPA policies affecting SO_2 emissions.

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

In the mid-1970s, EPA's Office of Research and Development began a comprehensive program to determine the sulfur removal capabilities of coal preparation, a technology that has been in commercial use for over 50 years. This report is the culmination of that effort. It contains information concerning the control of SO_2 emissions from coal burning sources using coal preparation.

Coal preparation—also referred to as physical coal cleaning (PCC), coal washing, or coal beneficiation—is a series of mechanical operations that remove mineral matter (ash) from coal. Coal preparation processes are designed to provide ash removal, to enhance energy production, and to standardize the coal product. Sulfur is removed because the pyritic material that is removed comprises sulfur and iron. Preparation plants are not designed to optimize sulfur removal. The utility industry uses cleaned coal in place of raw coal to provide a higher energy content fuel, to meet emission regulations, and to improve boiler performance and availability (less than one-third of utility steam coal is cleaned). There are about 500 coal preparation plants in the U.S., almost all located at the mine site.

Conclusions

The conclusions drawn by this comprehensive study of coal cleaning technology are presented below.

- Washing reduces, by about 30 percent, the heat-specific SO_2 emission parameter for the high sulfur coal regions of Northern Appalachian, Eastern Midwest, and Western Midwest. The percent reduction in the heat specific SO_2 emission parameter for the low sulfur coal regions (i.e., Southern Appalachian, Alabama, and Western) ranges from 13 to 22 percent.
- In the Northern Appalachian and Eastern Midwest regions, coal washing can double or triple the amount of coal able to meet moderate SO_2 emission values.
- Coal washing does not measurably increase the amount of coal able to meet the stringent 1.2 lb $SO_2/10^6$ Btu* emission standard.
- Emission reductions by coal washing are sensitive to both energy or Btu recovery and specific gravity of separation. For example, a 5 percent drop in energy recovery (from 95 to 90 percent), caused by allowing more pyrite and coal to go to the refuse stream, can produce a cleaner product with a 20 percent reduction in SO_2 emissions from the raw high sulfur coals. An additional 10 to 15 percent reduction in potential SO_2 emissions can be obtained by allowing energy recovery to fall to 80 percent for high sulfur coals. Low sulfur coals show a 10 percent drop in SO_2 emissions as energy recovery is reduced from 95 percent to 90 percent. The energy recovery loss may be associated with reducing the specific gravity of separation. For example, lowering the specific gravity of separation in the preparation process from 1.6 to 1.4 will reduce high sulfur coal emissions by 10 to 20 percent. Lowering the specific gravity may have almost no effect on lowering SO_2 emissions from low sulfur coals.
- Current coal preparation equipment is capable of removing only some pyritic sulfur from coal; it is ineffective for the removal of organic sulfur and most fine-grained pyritic sulfur.
- Coal washing reduces SO_2 emissions by 20 to 50 percent and decreases particulate loadings in the flue gas by 25 to 80 percent; it increases solid wastes by 25 to 150 percent. The overall net effect of washing is to partially transfer waste generation from the point of use (i.e., power plant) back to the point of origin (i.e., coal mine and preparation plant). For every ton of SO_2 removed, from 1 to 20 tons of solid waste may be generated.
- Cleaning costs are affected by level of cleaning (i.e., as coal top sizes decrease, both capital and operating costs increase), play yield (i.e., as yield decreases, cleaned coal costs increase), and plant size (i.e., economy of scale is operative). Accurate costing of cleaning plants must be based on the specific coal and the desired end results within specified economic constraints.
- Coal cleaning is becoming more economic as coal and transportation costs rise, as coal quality deteriorates because of less selective mining techniques, as utilities need to increase availability and capacity, and as pollution control requirements become more stringent.
- Barriers to expanded coal cleaning include the need for: better quality control techniques, improved ash separation techniques, more data on the benefits of cleaned coal on boiler operation, and monetary incentives to use or produce cleaned coal.
- The long-term outlook for increased coal preparation may depend on the ability to produce a low ash, low sulfur slurry product for use in (converted) oil-fired boilers.
- The R&D area of greatest short-term emphasis in the preparation industry is improving fine coal washing and dewatering equipment. Long-term R&D will center around development of low ash, low sulfur fuels and chemical cleaning technologies.
- Promising advanced physical coal cleaning processes under development are the AED process (electrostatic separation technique), OTISCA process (fine coal specific gravity separation using an organic liquid), oil agglomeration (surface property separation using oil in a coal/water slurry), and high gradient magnetic separation (removal of weakly magnetic ash materials).
- Promising advanced chemical coal cleaning processes in development are the Gravimelt ($Fe_2(SO_4)_3$ basis) and General Electric (microwave irradiation plus sodium hydroxide treatment) processes.

SO_2 Emission Reductions

Coal cleaning plant design involves a tradeoff between top size, extent of cleaning, and energy recovery. Reducing the top size lowers the potential SO_2 emissions from the coal. Except for western coals, a more significant reduction in SO_2 emissions is attained by decreasing the specific gravity at which coal is cleaned. The emission reduction varies from 20 to over 40 percent.

Analysis of coal deliveries to utilities indicates that the greatest SO_2 reduction from washing (0.8 million tons* of SO_2) could have been achieved in the State of Ohio, where approximately 70 percent of the coal consumed comes from the Northern Appalachian region.

Assuming that mandatory washing were to occur on a regional basis, the midwestern states would experience the greatest reduction of SO_2 emissions and the southeastern states the least; the reduction in emissions in the midwestern states would total 3.2 times that of the southeastern states.

The total absolute reduction for all the states considered, if all the coal had been washed in 1979, would have been approximately 4 million tons. Of this total, 3.5 million tons, or 86 percent, of the reduction would have resulted from the washing of those coals which originated in either Northern Appalachia or the Midwestern state regions. Coals from the Southern Appalachia, Alabama, Western Midwest, and Western regions, which constituted 38 percent of the coals burned, would have accounted for only 14 percent of the absolute SO_2 reductions from washing all coals in 1979. From a user standpoint, most states burn coals originating from three to six coal-producing states, and from several coal producing regions. As a result, any regulations involving coal

*1 short ton × 0.907 = 1 metric ton.

washing or coal use affect each state differently.

The ability of a coal to comply with an emission standard is a function of the variability in the coal characteristics, time frame of the emission regulation, and the amount of coal burned (i.e., lot size). Blending, coal preparation, and coal handling attenuate the variability of the run-of-mine (ROM) coal characteristics. Cleaned coal has less variability than ROM coal, and this difference is greatest for short averaging times and small lot sizes. Conversely, for long averaging times (e.g., 30 days) and large lot sizes, the variability is greatly reduced and thiere is almost no difference between ROM and cleaned coal variability characteristics. The mean coal sulfur values needed for compliance must be determined on a case-by-case basis.

Coal has been found to contain nearly every naturally occurring element. Major portions of many trace and minor elements are associated with the inorganic fraction of the coal as discrete mineral phases. One way to control trace element emissions is to remove the constituents before combustion.

Washability and Preparation

The potential for improving the quality of a coal by separating mineral components from the coal matrix using differences in specific gravity is called the washability of the coal. A washability analysis evaluates coal characteristics that indicate how easy or how difficult it is to improve the quality of the coal by specific gravity separation. Washability test results are used by coal preparation engineers to estimate the yield and properties of the cleaned coal, to design coal cleaning circuits, and to select coal cleaning equipment. The washability test procedure consists of a screen analysis followed by a float-and-sink test and a chemical analysis. The washability results can be plotted in a number of ways to produce a set of curves which are characteristic of the coal.

The washability data provide information on how well various coal cleaning circuits may perform. The selection of the proper cleaning circuit(s) is dictated by the design objective and by a set of constraints. A typical design objective might be the minimization of coal cleaning costs. On the other hand, constraints can be dictated by product specifications, environmental regulations, or process requirements. After the operating characteristics for each circuit are determined, various pieces of coal preparation equipment within each circuit are selected.

Coal preparation operations can be classified as comminution, sizing, cleaning, and dewatering. The major objective of comminution in preparation plants is to reduce the ROM coal to sizes suitable for cleaning. Coal can be sized by air or hydraulic classifiers or by screens. Cleaning is the step in which coal is separated from its impurities. The separation takes place in water, in a dense medium, or in air. Mechanisms for physical cleaning are based either on the specific gravity or on the surface property differences between coal and its impurities. Cleaned coal and refuse streams from wet cleaning need dewatering to meet the product specifications and refuse landfill disposal requirements. Excessive moisture in the cleaned coal and refuse is undesirable because it creates handling problems and increases transportation costs. In addition, moisture reduces the heating value of the cleaned coal, increasing the boiler fuel requirement.

There are four major levels of cleaning:

No Cleaning (Level 1).
Partial Washing (Level 2: Coarse Cleaning Plant).
Coarse Washing with Partial Washing of Fines (Level 3: Coarse- and Intermediate-Size Cleaning Plant).
Total Washing (Level 4: All Size Ranges Cleaned).

There is no universal approach to producing clean coal by physical preparation techniques. Therefore, a given preparation process that is effective on a coal from one seam may be ineffective on coal from another seam in achieving a comparable level of cleaning. For this reason, the coal cleaning approach must be designed around the specific coal and the desired end results within the economic constraints of the situation.

Two or more coals can be blended as an alternative to, or in conjunction with, coal washing. Normally, a coal with a sulfur content that exceeds a given SO_2 emission standard is blended with a lower sulfur coal. For very high sulfur coals, coarse washing can be combined with blending to produce a marketable coal. Blending permits an increase in the amount of potential compliance coal and a resultant increase in marketable coals.

Environmental Impacts From Washing

Many factors influence the amount and form of pollutants emitted from coal cleaning facilities to the surrounding environment. Among these factors are: type of coal, mining methods, siting and geographical location, cleaning process, and level of preparation.

Air

From 1972 to 1974, EPA sampled and analyzed particulates and off-gas emissions from scrubbers associated with thermal dryers at coal preparation plants. Results from EPA's environmental assessment program indicate that fugitive dust is not a problem at preparation plant boundaries. Based on this study, particulate emissions standards were promulgated.

Water

The final regulations for coal preparation plants, as printed in the October 13, 1982, Federal Register, established NSPS for coal preparation plants at zero discharge of pollutants. However, in August 1983, EPA signed an agreement with several parties, including the National Coal Association, stating that the regulations would be changed to eliminate the zero discharge requirement. The presence of trace metals in liquid waste streams is not unexpected since they are found in the coal. Wastewater treatment for the control of pH and suspended solids generally reduces the trace element concentration in treated effluents to acceptable levels.

Solids

Present controls for solid wastes from coal cleaning are in the Surface Mining Control and Reclamation Act (SMCRA) regulations. These regulations relate mostly to reclaimed area stability, burning, and pollutants leached from the waste and discharged to water. Control technologies are mainly construction and operating standards, which are designed to prevent environmental degradation. Pond sediments and fine waste solids contain heavy metals and other elements at concentrations that produce potential environmental effects. These elements originate in the coal, not the cleaning process which is intended to remove incombustibles as refuse from the coal. The high metal concentrations in the refuse create the problem of their ultimate disposal. Those concentrations also make it evident that precautions must be taken to prevent the migration of these chemicals to groundwater.

Coal preparation involves a tradeoff between widespread air pollution at power plants and additional solid and slurry wastes at preparation plants/mine sites. For every ton of SO_2 removed, from 1 to 20 tons of solid waste is generated. These quantities vary with such factors as ash content of the coal, product specifications, type or level of washing employed, the method of mining, coal washability, and plant yield.

Cost of Cleaning

A capital cost methodology was developed based on specific plant circuits, on their associated capacities, and on a standard EPA methodology for cost analysis of air pollution control systems. The capital cost methodology was based on the cost of the major plant items, plus the installed cost of items outside the basic plant such as silos, external conveyors, and thermal dryers. Capital costs, as a function of size, were developed for major preparation plant unit operations using estimates provided by suppliers of the cleaning plant equipment.

Coal cleaning plant operation and maintenance (O&M) cost estimates were based on 10 detailed cost estimates obtained from previous studies, information obtained from a large coal company, a TVA study, and the Bureau of Labor Statistics; and on data from an equipment manufacturer. The overall O&M costs for a coal cleaning plant include labor, overhead, supplies, maintenance, contracted services, fuel and power, thermal dryer heat fuel, and miscellaneous expense. Other factors being equal, larger plants cost less per ton per hour input capacity because of economy of scale. Similarly, operating labor does not generally increase proportionately with plant size. As coal is cleaned at smaller top sizes, both labor and capital cost generally increase. As yield decreases, a given size plant has less throughput with resulting higher cost. Cost estimates generated by this approach agreed (i.e., within ±20 percent) with O&M costs obtained from operators of existing coal preparation facilities.

Cost Benefits of Coal Preparation

A procedure was established for identifying and estimating the relative costs and benefits to a specific utility associated with their selection of alternative sources of coal. The costs and benefits included:

1. Cleaned Coal Costs
   a) ROM Coal Costs
   b) Coal Cleaning Plant Operating and Maintenance Cost
   c) Coal Cleaning Plant Capital Amortization
   d) Cost of Mined and Discarded Material
   e) Crushing and Screening Cost
   f) Payment to UMW Trust Funds for Union Mines
2. Transportation Cost
3. Ash Disposal Cost
4. Pulverization Cost
5. Utility Plant Maintenance Cost
6. Boiler Efficiency
7. Boiler Availability
8. Emission Control Cost

The boiler related benefits were derived from a study of TVA plants performed jointly for DOE and TVA. The universality of the relationships in the TVA report has not been tested, and the report states that the relationships may not be directly applicable to eastern and midwestern boilers. However, this study represents the most extensive effort to date to document and quantify power plant performance measures. The relationships developed for maintenance cost, boiler efficiency, and boiler availability use coal ash, sulfur, and moisture content, and boiler age as input variables. Both linear and logarithmic relationships were developed, depending on the performance measure studied. The emission control cost dealt with the cost of flue gas desulfurization. The capital cost of an FGD system may be less when using a cleaned coal with lower sulfur content than the raw coal. Lower FGD system annualized costs can also result from a lower capital amortization burden and lower O&M cost. When cleaned coal is burned, the lower SO_2 content in the flue gas may allow some bypassing around the scrubber section, reducing reagent requirements, fuels for reheat, and sludge generation and disposal requirements.

Fuel Options Model

On this program, a model was developed that evaluates the effects of changes in the SO_2 emission regulations on the optimum fuel distribution network and the overall cost of electric power generation for a utility system. The model includes the entire coal-fuel cycle including power plant components (e.g., cyclone and pulverized coal boilers; primary, F.D. and I.D. fans; pulverizers, hammermills, and granulators; electrostatic precipitators; flue gas scrubbers; and solid waste disposal options), coal mining, coal washing, and transportation systems. The model was run for a midwestern utility with 6 power plants and 12 coal sources (4 of which included the raw coal and associated clean coal). The results showed that, for up to a 40 percent overall SO_2 reduction for the system, cleaned coal should be used along with increased use of low sulfur western coals. Past a 40 percent reduction requirement, flue gas desulfurization from burning high sulfur raw coals is the preferred SO_2 control strategy.

Trends in the Coal Preparation Industry

At present, only 20 to 30 percent of the nearly 600 million tons of coal consumed annually by electric utilities is cleaned, a drop of almost 15 percent in the past 10 years, while the number of operational cleaning plants has remained constant. Developing circumstances, however, are making coal cleaning more desirable or necessary. These include: higher coal prices and transportation costs; diminishing coal quality due to less selective mining techniques and increased production of low quality coals; the need to increase availability and capacity factors at existing boilers; stringent air quality standards; lower costs for improving fuel quality versus investing in extra pollution control equipment; and a projected 20 percent increase of coal consumption by eastern and midwestern utilities in the next 10 years.

Discussions with coal and utility industry personnel support the relatively optimistic outlook for coal preparation. They believe the increase in its use is likely because:

- High ash contents in ROM coal are pushing utilities toward cleaning to meet boiler specifications.
- Current research on the benefits of cleaning is expected to indicate considerable savings to utilities.
- Tight markets are forcing coal companies to offer better quality coals to be competitive.

Arguments against increased cleaning are based on continuation of current conditions including increased availability of western coals, stable oil prices, and slow orders for new coal-fired units.

To compete in today's coal market, most large coal companies are cleaning high and medium sulfur coals and improving mining techniques. Several industry representatives stated that they are investigating modifications at all their preparation plants to offer better products to their customers. Blending the good quality and poorer quality coal at the preparation plant is becoming common practice to produce an average coal blend that meets product specifications.

Improvements that would encourage expanded use of coal cleaning include:

- Better quality control in cleaning
- Improved techniques for separation of fine pyrite
- Data on the benefits accruing to boilers
- Better control of leachate from solid wastes
- More information on sulfur removal potential
- Monetary incentives to use or produce coal (i.e., tax considerations).

Utilities are not opposed to using cleaned coal; but they are not fully aware of its advantages (nor are state regulatory agenices). The Electrical Power Research Institute (EPRI) is critically testing the premise that the lowest cost coal produces the lowest cost electricity.

Because customers (e.g., utilities) are generally unfamiliar with the coal cleaning process, little incentive has existed for coal companies to improve preparation plant design and operation. Three areas that have seen recent research activity are (1) preparation circuits, (2) process controls, and (3) productivity improvements.

The research and development area of greatest emphasis in the preparation industry is improvement of washing equipment, particularly fine coal cleaning and dewatering. This is a direct result of the high cost of coal, that penalizes coal losses to refuse, and increased fines production from continuous mining equipment.

The long-term outlook for increased coal preparation by coal companies may depend on the ability to produce a low ash (i.e., less than 3 percent) and low sulfur (i.e., less than 0.5 percent) coal suitable for use with coal/water mixtures in converted oil-fired boilers and in synthetic fuel facilities. Current physical cleaning alone cannot reduce the sulfur to 0.5 percent for most coals. The problems are that large-scale research is needed to produce this type of fuel, but the research funds are limited.

Advanced Coal Cleaning Processes

To overcome the limitations and shortcomings of the coal preparation technology, various advanced coal cleaning processes have been developed. These processes can be classified as (1) those that remove sulfur by reaction with a chemical agent and (2) those that use alternative concepts for improved removal of pyritic sulfur from fine coal.

DOE has selected the Gravimelt and the General Electric processes as the most promising chemical coal cleaning processes; therefore this report describes these two processes in detail.

Various concepts have been proposed and tested to improve pyritic sulfur removal from fine coal. Four physical concepts for the removal of pyritic sulfur are discussed: (1) the OTISCA process uses specific gravity separation in an organic liquid; (2) the AED process separates pyritic sulfur and ash by means of electrostatic forces; (3) the high gradient magnetic separation processes use magnetic forces to remove coal impurities; and (4) the oil agglomeration processes separate ash and pyrite from coal using the principle of surface property difference.

Current Research in Coal Preparation

A significant amount of research and development activities in the 1980s will be associated with the EPRI Coal Cleaning Technology Development Program, including the Coal Cleaning Test Facility. The stated objectives of the program are to: (1) develop engineering data to improve cleaning plant operation; (2) develop/demonstrate new and improved coal cleaning equipment; and (3) develop/demonstrate low ash coal (less than 0.2 percent ash) cleaning processes for production of coal/water slurries.

The Department of Energy continues to support work on ultra-fine coal characterization and cleaning techniques and coal washability determinations for major coal seams. For the late 1980s DOE research is expected to center around equipment and circuits that produce very low ash, low sulfur coal to be used in coal/water slurries (CWM) or coal/oil mixtures (COM). The extent and development of these technologies may depend on the position EPA takes relative to gaseous pollutant emissions from converted boilers.

EPA is sponsoring considerable work in evaluating coal preparation plant equipment at the MCCS in Homer City, Pennsylvania. EPA is also conducting a number of programs to evaluate the economics of coal cleaning in combination with other technologies for controlling SO_2 emissions.

A. B. Onursal, J. Buroff, and J. Strauss are with Versar, Inc., Springfield, VA 22151.
***James D. Kilgroe** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation of Conventional and Advanced Coal Cleaning Techniques," (Order No. PB 87-104 535/AS; Cost: $28.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S7-86/017