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ENGINEERING DEVELOPMENT OF SELECTIVE AGGLOMERATION

FINAL REPORT

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Scope of Work

This report presents the findings of the project entitled "Engineering Development of Selective Agglomeration." In 1989 the U.S. Department of Energy contracted with Southern Company Services, Inc. (DOE Contract No. DE-AC22-89PC88879) to develop selective agglomeration technology to a commercially acceptable level by 1993. This project is part of DOE's program to advance the state of physical coal cleaning technologies in order to accelerate the utilization of high-sulfur coals while complying with environmental regulations. Such projects assume added importance in light of the 1990 Clean Air Act Amendments. Appropriate utilization of the abundant reserves of high-sulfur coal in the United States can make a significant contribution to achieving the goal of energy independence.

This work was conducted by a multi-organization team headed by Southern Company Services, Inc. (SCS) who provided management, detailed design, and cost sharing. The Alberta Research Council (ARC) provided process development and cofunding. Southern Electric International, Inc. (SEI) was responsible for Component Development Test Facility (CDTF) and Proof-of-Concept (POC) facility construction and operations. Praxis Engineers, Inc. (Praxis) provided process engineering. The Electric Power Research Institute (EPRI) provided significant cofunding as well as expertise in coal cleaning and coal markets.

In addition to this final report, the following three companion reports have also been issued:

- A stand-alone "Executive Summary" of this final report
- A "Trace Element Removal Study" which reports on the effectiveness of the selective agglomeration technology in removing certain trace elements from coal prior to combustion that are listed as hazardous

air pollutants in the 1990 Clean Air Act Amendments, Title III

- A "Site Closeout Report" which addresses all state and federal regulations encountered in closing the selective agglomeration testing site in Wilsonville, Alabama

The selective agglomeration process, as applied to coal cleaning, is based on differences in the surface chemistry of coal and its associated impurities. Coal particles are hydrophobic (i.e., repelled from water) while the majority of its impurities are hydrophilic (i.e., stabilized in water). During selective agglomeration, a liquid (the agglomerant) that is immiscible with water is introduced into a coal-water slurry which is then mechanically agitated with sufficient intensity to disperse the agglomerant, thereby allowing it to come in contact with all particles in the slurry. This unit operation is referred to as high-shear agglomeration. The coal particles, due to their hydrophobic nature, are attracted to the agglomerant phase. The hydrophilic mineral impurities remain in the water phase. Continued high-shear agitation of the agglomerant-coated coal particles causes them to coalesce to form microagglomerates.

The size of the microagglomerates formed during this process is primarily a function of the agglomerant concentration utilized and the agglomeration residence time. Generally, as the agglomerant concentration or residence time are increased—with all other parameters remaining constant—the resulting microagglomerates increase in size.

Microagglomerates formed via high-shear agglomeration are then separated from the mineral matter-bearing aqueous phase. The manner in which this separation is achieved primarily depends on the size of the microagglomerates. If large enough, the microagglomerates can be separated by screening; otherwise, froth flotation of the microagglomerates is required to achieve the desired separation.

Following separation of the microagglomerates from the mineral matter-bearing aqueous phase, subsequent processing steps may be required to achieve a final product compatible with conventional coal handling systems. Larger agglomerates (>1 mm diameter) can be formed by adding a finely divided liquid binder, such as an asphalt/diesel blend, followed by continued low-shear mechanical agitation. These larger agglomerates are then mechanically dewatered. In lieu of low-shear agglomeration, the recovered microagglomerates can be mechanically dewatered and then pelletized using the appropriate binder to form a product of the desired size. Typically, the product from either of these final product formation processes is thermally dried to meet product moisture requirements and increase the agglomerate/pellet strength.

Project performance targets for the selective agglomeration process were to achieve 85% or greater Btu recovery at 85% or greater pyritic sulfur rejection (PSR) on a run-of-mine (ROM) coal basis, while producing a final clean-coal product with an ash content of 6% or less which is handleable by conventional coal handling systems. Engineering development of selective agglomeration included:

- Batch and continuous bench-scale process development testing
- Continuous pilot-scale (3-t/h) component development testing to evaluate the adaptation and/or modification of existing unit operations for selective agglomeration
- Continuous pilot-scale (2-t/h) POC testing to optimize the selective agglomeration process and demonstrate process reliability
- Vendor testing to evaluate pelletization and thermal drying processes as applied to selective agglomeration
- Conceptual design of a commercial-scale (200-t/h) selective agglomeration facility
- Economic analysis of the selective agglomeration process at a commercial (200-t/h) scale

The information obtained from the various modes of testing and analysis, particularly POC operations, resulted in a technical and economic design base sufficient to support construction and operation of a commercial plant.

Phase I Testing Summary

During Phase I of the project, a batch testing program was carried out by ARC and SEI. Various agglomerating liquids, ranging from heavy oils such as Maya crude to light hydrocarbons like hexane, were evaluated in this program. Initial testing indicated that diesel (considered a heavy agglomerant) and heptane (a light agglomerant) were the most appropriate high-shear agglomerants, and they were therefore investigated further in two parallel-path test programs.

The diesel process tested utilized high-shear agglomeration with diesel (approximately 1% on a dry coal basis) followed by two-stage flotation recovery of microagglomerates. The recovered microagglomerates were then either subjected to low-shear agglomeration using various blends of diesel/asphalt as a binder or mechanically dewatered and pelletized using dry-milled flour as a binder and asphalt for weatherproofing. These enlarged products were then thermally dried to produce the final product. Evaluation of these two product formation methods determined that the pelletization process provided a more handleable product at a lower cost, and it was therefore selected for further investigation.

The heptane process tested utilized heptane (approximately 20-30% on a dry coal basis) during high-shear agglomeration. Following high shear, microagglomerates were recovered by screening. These microagglomerates were then processed using low-shear agglomeration with a diesel/asphalt blend as a binder. The low-shear product was then thermally dried to recover the heptane and produce the final product.

During Phase I batch testing, Btu recoveries of approximately 90% at 75-80% PSR were achieved for all three test coals for both the diesel- and heptane-based processes on a ROM basis. Similar results were also achieved in 5-kg/h bench-continuous testing conducted during Phase I. While both the diesel- and heptane-based processes provided similar performance, the diesel/pelletization process was selected for investigation during Phase II of the project since it was ranked as a more mature process with fewer uncertainties. The diesel- and heptane-based processes, however, both possess inherent advantages and disadvantages.

A primary advantage of the diesel process is due to the nature and quantity of the agglomerant used. In the diesel or heavy-oil process, relatively small amounts (<1.0%) of diesel oil, a hydrocarbon of low volatility, are used. As such, the diesel does not have to be recovered

and remains in the final product. In contrast, the heptane or light-oil process utilizes significant concentrations (20-30%) of heptane, a highly volatile hydrocarbon, during high shear. The heptane cannot be allowed to remain in the final product and must be recovered in order to meet product safety and environmental standards. As a result, the entire process from the point of heptane introduction during high shear to heptane recovery by thermal dryers must be sealed and blanketed with an inert gas for safety reasons. This required safety precaution increases capital investment substantially.

During selective agglomeration, the high-shear unit operation is typically conducted at about 20% solids concentration. In the heptane process, no dilution of the high-shear product is required prior to screening to recover microagglomerates. While some wash water is required to assist in the screening separation, the amount of water needed is small compared to that used during the two stages of flotation to recover microagglomerates in the diesel process. For both stages of flotation in the diesel process, the feed is diluted to approximately 6% solids concentration to improve process performance.

An additional advantage of the light-oil process is that the screening operation is simpler, easier to control, and less expensive than froth flotation recovery of microagglomerates. It is also possible that with flotation the overall performance of the selective agglomeration process may be determined primarily by the microagglomerate recovery step rather than by the high-shear agglomeration unit operation.

During heptane agglomeration, final product formation is conducted via low-shear agglomeration using asphalt-based binders blended with additional heptane. While the asphalt is needed to impart strength to the final product, its presence impedes recovery of heptane to the required levels. In fact, Phase I testing indicated that when asphalt was present in the low-shear product, the quantity of heptane remaining on the final product after thermal recovery was environmentally unacceptable. In addition, the final product from the heptane process is not as strong and handleable as that from the diesel/pelletization process.

Pilot-scale (3-t/h) testing to evaluate low-shear agglomeration conditions and agglomerate dewatering methods for the diesel process was carried out during Phase I CDTF testing. It was determined during CDTF testing that a low-shear binder concentration of 13% was required to form 1-mm agglomerates with a 100-mesh topsize coal feed. Screen-bowl centrifuge dewatering of

these agglomerates achieved a product moisture content of about 14%. A similar dewatering performance was also achieved for much smaller agglomerates formed using approximately 6% binder.

A major finding of Phase I testing was that a ROM coal should be cleaned conventionally prior to agglomeration. It was found that better process performance was achieved when the project coals were cleaned prior to agglomeration than when raw coals were agglomerated directly. This conclusion is not unexpected since during conventional precleaning impurities are rejected at coarse sizes by gravity techniques with relatively high separation efficiencies. In contrast, agglomeration, a surface-based process, is carried out at fine coal sizes where separation efficiencies are lower.

Phase II Testing Summary

The primary focus of Phase II of the project centered on POC testing of the selected diesel/pelletization agglomeration process at a 2-t/h scale. In addition to POC testing, supporting bench-scale batch agglomeration tests were also completed. The following four feedstocks were tested during Phase II:

- Precleaned Upper Freeport coal from Jefferson County, Pennsylvania, obtained from P&N Coal Company and precleaned by CQ, Inc.
- Precleaned Pittsburgh No. 8 coal from Greene County, Pennsylvania, obtained from and precleaned by Cyprus Coal Company's Emerald mine preparation plant
- ROM Illinois No. 5 coal from Wabash County, Illinois, provided by AMAX Coal Company from their Wabash mine
- Reclaimed pond fines (minus 60-mesh fraction) from Jefferson County, Alabama, provided by Jim Walter Resources (JWR) from their No. 3 mine tailings pond

A photograph of the POC pilot-plant facility that was located at the SEI site in Wilsonville, Alabama, is shown in Figure 1. Figure 2 provides a simplified unit-operations block diagram of the POC facility.

During Phase II of this project, POC testing with Upper Freeport and Pittsburgh No. 8 coals was conducted using a factorial test plan design. However, determination of the effects of individual high-shear parameters on overall process performance proved to be

Figure 1. POC Facility, Wilsonville, Alabama

Figure 2. POC Facility Block Diagram

difficult since the two sequential unit operations, high shear and flotation, are coupled. Flotation dominates the process because of its sensitivity to process variables such as coal hydrophobicity and agglomerant concentration in addition to flotation equipment variables such as air flow rates and cell water levels.

POC testing showed that strongly hydrophobic coals such as Upper Freeport are sensitive to excess agglomerant addition. Diesel addition levels to high shear of 0.5% and above destabilized the air bubbles in the froth as the bubbles rose toward the surface of the flotation cell. During typical flotation froth migration, air bubbles coalesce into larger bubbles but are retained in the froth, thus assisting in drainage of process water from the flotation product.

During POC testing with Upper Freeport coal, the destabilization of air bubbles resulted in greater carryover of process water to the product and a lower froth product solids content than desired. The net effect of this phenomenon was increased product contamination by refuse particles entrained in the process water and increased difficulty in controlling coal recovery to a constant level.

In contrast, this phenomenon did not occur during testing with coals of decreasing hydrophobicity, such as Pittsburgh No. 8 and Illinois No. 5. These two coals could be agglomerated over a wide range of oil concentrations and still maintain acceptable froth properties, with corresponding improvements in flotation performance. Observations during POC operation indicate that as coal hydrophobicity decreases, the range of agglomerant concentration providing good froth

properties along with good microagglomerate recovery is as follows for each coal:

- Upper Freeport (very hydrophobic): <0.3%
- Pittsburgh No. 8 (hydrophobic): 0.125-0.5%
- Illinois No. 5 (weakly hydrophobic): 0.25-1.2%

These observations indicate that evaluation of coal-specific parameters such as hydrophobicity can help determine the range of high-shear agglomerant concentrations that will provide good froth properties during microagglomerate recovery via flotation.

Considering the high-shear and flotation unit operations as a single process, agglomerant and frother concentrations in combination control coal recovery. At any given agglomerant concentration there is an optimal frother level that will achieve the desired recovery, providing good froth structure is maintained. If the agglomerant concentration is reduced, coal recovery decreases unless frother levels are increased correspondingly. If the agglomerant concentration is increased beyond the ranges previously discussed, the presence of excess oil adversely affects the froth structure regardless of frother concentration.

Optimization of a three-component system in series (high shear followed by two stages of flotation) is difficult and requires a large number of tests to complete a factorial design. Sequential design of experiments appears to be a promising approach for optimization of these types of problems. The use of tools such as Ultramax process optimization software allows determination of the effects of several operating parameters simultaneously. This reduces the total number of experiments required to evaluate the effects of all process variables of interest over the desired ranges. For parametric testing of the Illinois No. 5 coal, EPRI made available a pre-release version of the Ultramax software program to assist in the optimization of the selective agglomeration process. This product is under co-development by EPRI and Ultramax Corporation, an industrial partner.

During Phase II POC operations, parametric testing to determine optimal operating conditions was performed for each of the three primary project coals: Upper Freeport, Pittsburgh No. 8, and Illinois No. 5. Following parametric testing of each coal, an extended demonstration run (approximately four days' duration) was conducted for each coal at selected optimal operating conditions.

Bench-scale batch agglomeration tests were completed in support of POC testing. Comparison of laboratory batch and continuous POC results for all coals tested indicates that similar performance was achieved by both modes of testing. This similarity between batch and continuous test results indicates that a well-planned series of batch agglomeration tests can provide much information to predict the performance of continuous-mode testing.

Based on the analysis of POC and batch testing results, grade/recovery curves characterizing selective agglomeration performance for each coal were developed, as shown in Figure 3. Also shown in Figure 3 are the grade/recovery curves predicted by washability analyses of POC high-shear agglomeration feed samples.

Figure 3. Phase II Testing and Washability Grade/Recovery Curves

Based on the grade/recovery curves presented in Figure 3, the ROM coal-basis PSR at 85% Btu recovery for each coal is characterized in Table 1.

Table 1
Phase II Testing and Washability
PSR at 85% Btu Recovery

Coal	Topsize	Testing PSR, %	Washability PSR, %
Upper Freeport	200 mesh	84	96
Pittsburgh No. 8	200 mesh	68	90
Illinois No. 5	100 mesh	64	80

As is evident in this table, consistently lower PSR levels were achieved in the agglomeration tests than in the centrifuge sink/float washability analyses. Agglomeration grade/recovery curves generally parallel the washability curves, but at lower PSR. At 85% Btu recovery, the differences between washability and test-result PSR are approximately 12, 22, and 16% for the Upper Freeport, Pittsburgh No. 8, and Illinois No. 5 coals, respectively.

These significant differences in PSR between agglomeration and washability results may be attributed to a number of factors. Fine coal washability results are based on gravity separations in which all particles of specific gravity greater than 1.8 report to the refuse and are therefore considered rejected. The centrifuge float/sink washability procedure utilized requires the use of a dispersant and a 20-minute residence time at a centrifuge rpm of 1500 to ensure that a good gravity separation is achieved at a 200-mesh coal topsize. In contrast, during agglomeration testing, a coal surface-based separation is made during flotation recovery of microagglomerates. Since so much care is required to guarantee a good laboratory float/sink separation at these fine coal sizes, it is not unexpected that actual batch and continuous agglomeration test results indicate poorer performance than washability predictions.

During these sink/float separations, many "locked" or unliberated particles, i.e., particles which are part carbon and part mineral matter, report to the refuse based on overall particle specific gravity. During agglomeration, however, locked particles may report to the product since any coal on the particle surface will be coated with agglomerant.

This reporting of unliberated, predominantly mineral matter-bearing particles to the product can be reduced by additional grinding to further liberate impurities from the coal. Finer grinding will, however, affect overall process costs as follows:

- Increased grinding energy costs
- Increased high-shear agglomerant requirements due to the greater coal surface area
- Increased mechanical dewatering costs to achieve the same flotation product moisture content

The use of very low (or starvation) quantities of agglomerant may help curtail the recovery of locked particles by reducing the oil available to coat the carbonaceous portions of these particles.

An additional explanation for the difference in PSR levels between the agglomeration test and washability data is the contamination of the flotation product by mineral matter carried in the water in the flotation froth. Recovery of microagglomerates by flotation results in a strong froth which can entrap ash and pyrite particles suspended in the water between the air bubbles in the froth.

One method used to prevent mineral-matter entrapment is to reduce the solids concentration in the flotation feed. A reduction in the feed solids concentration produces a corresponding reduction in the mineral-matter concentration in the flotation cells and therefore reduces the amount of impurities carried to the product with each unit of water contained in the froth. A second method practiced in other industries is to apply water to the froth as it forms on top of the flotation cells, thereby replacing the mineral matter-bearing process water in the froth with clean water.

In general, while washability data provide information about the liberation characteristics of a given coal, they cannot be used to predict actual agglomeration performance for the reasons discussed above. Prediction of continuous-mode agglomeration performance at any grind size requires, at a minimum, batch agglomeration testing which can then be extrapolated using available washability data.

Figure 4 presents a comparison of the average performance obtained during the demonstration runs for each of the three primary project coals with the grade/recovery curves presented in Figure 3.

As can be seen in Figure 4, the average POC demonstration run performance approximates the grade/recovery curve for each coal tested. Therefore, for the Upper Freeport and Pittsburgh No. 8 coals, the average demonstration run performance was used as the basis for the commercial-scale (200-t/h) plant design.

In the case of the Illinois No. 5 coal, however, POC results were not used for the commercial plant design since the POC feedstock represented the entire raw coal and the commercial design was completed for the minus 100-mesh natural fines fraction only. This natural fines agglomeration scenario was evaluated because AMAX Coal Company, the supplier of the Illinois No. 5 coal, expressed an interest in using selective agglomeration to clean the minus 100-mesh material which is currently bypassed to tailings in the design of a 1500-t/h cleaning plant now under construction. To evaluate agglomeration for this application, laboratory batch tests were

Figure 4. Characterization of Selective Agglomeration POC Performance

completed on minus 100-mesh natural fines samples of the POC feedstock. The results of these tests, along with washability data for these natural fines, are presented in Figure 5.

Figure 5. Illinois No. 5 Natural Minus 100-Mesh Fines Batch Results

These data show that batch tests using the natural minus 100-mesh fines achieved 79% PSR at 85% Btu recovery. This indicates 15% greater PSR at the same Btu recovery than POC agglomeration of the entire raw coal. This 15% increase in PSR approximates the difference in liberation indicated by washability data for the two Illinois No. 5 coal samples.

The selective agglomeration performance values used for the commercial-scale design for the three project coals are presented in Table 2.

Table 2
Selective Agglomeration Performance for Commercial-Scale Design

Coal	Topsize	Btu Rec, %	PSR, %
Upper Freeport	200 M	89.7	81.0
Pittsburgh No. 8	200 M	88.2	64.4
Illinois No. 5	100 M (natural fines)	85.0	79.0

For the fourth project feedstock tested, reclaimed pond fines from JWR No. 3 mine, both laboratory batch and POC tests achieved approximately 30% yield from the minus 60-mesh fraction while making a 15% ash product. This performance was achieved in batch and continuous testing both with and without the use of high shear prior to flotation. This indicates that for the JWR pond fines no benefit was observed from the use of agglomeration. It should be noted, however, that the benefits of agglomeration appear to be coal-dependent and for many tailings pond materials, especially those that are oxidized, agglomeration could provide superior process performance to recovery by froth flotation alone.

Pelletization of dewatered selective agglomeration products was shown to provide a "green" (wet) pellet approximately 6 mm in diameter which had sufficient strength to withstand transfer via belt conveyors. These pellets were formed using approximately 2-2.5% starch binder for strength and 0.5% asphalt binder for weatherproofing. Optimal feed moistures to achieve these results were approximately 25% and 27% for 100- and 200-mesh topsizes, respectively. Thermal drying of "green" pellets was completed in a vibrating fluidized-bed dryer at residence times of 2 to 2-1/2 minutes to achieve a moisture content of less than 4%. The resulting dried pellets are considered satisfactory for conventional coal handling facilities. Combustion testing of both mechanically dewatered agglomerates and dried pelletized products was conducted by DOE for each of the three primary project feedstocks. The results of these combustion tests were unavailable at the time of publication.

The pelletized and thermally dried product agglomerates produced from each of the three primary project test coals were characterized. The characterization data are presented in Table 3. These data show that the final thermally dried agglomerated product is low in both moisture and ash content, which indicates potential

savings during transportation of this fuel. Additional savings would be realized during power plant pulverization due to the very high grindabilities of these products. This savings would help offset the initial cost of fine grinding prior to agglomeration.

Table 3
Final Product Analysis (Dry Basis)

	Upper Freeport	Pittsburgh No. 8	Illinois No. 5
<u>Proximate Analysis</u>			
Moisture, % (as is)	0.95	1.90	2.53
Ash, %	5.56	5.28	4.72
Volatile matter, %	33.22	38.74	39.19
Fixed carbon, %	61.22	55.98	56.09
<u>Forms of Sulfur</u>			
Total sulfur, %	1.08	1.75	1.38
Pyritic sulfur, %	0.05	0.60	0.48
Sulfate sulfur, %	0.39	0.12	0.17
Inorganic sulfur, %	0.44	0.72	0.65
Organic sulfur, %	0.64	1.03	0.73
lb SO ₂ /MBtu	1.51	2.46	2.03
Btu/lb	14274	14209	13618
Hardgrove index	177	197	150

Commercial-Scale Conceptual Design

Selective agglomeration performance throughout this project has been defined by process Btu recovery and PSR calculated on a ROM basis. For POC feedstocks which were precleaned prior to agglomeration, ROM performance is based on conventional cleaning performance and subsequent agglomeration results. Thus, the conceptual design for the commercial-scale 200-t/h plant based on the Upper Freeport and Pittsburgh No. 8 coals includes conventional cleaning of the ROM coal followed by selective agglomeration of the precleaned product. This plant has been scheduled to operate 24 hours per day, 7 days per week, and 50 weeks per year. To meet this operating schedule of 8400 hours per year, excess capacity has been included in the design where necessary, along with all required spare parts.

The 200-t/h commercial agglomeration plant conceptual design for the Upper Freeport and Pittsburgh No. 8 coals is based on the average POC demonstration run performance as presented previously in Figure 4 and Table 2. A conceptual design of the same plant at a 20-t/h semiworks scale was also completed.

For the Illinois No. 5 coal, the commercial plant design is for a retrofit application to agglomerate the minus 100-mesh natural fines which are currently bypassed to plant tailings in the design of a 1500-t/h coal cleaning facility now under construction by AMAX Coal Company. In this design, the agglomerated natural fines are mechanically dewatered and blended with the conventionally cleaned coarse coal fractions. Scheduled operating hours for the design of this retrofit circuit are 5400 hours per year.

For the Illinois No. 5 coal, the commercial-scale 1500-t/h plant design for the plus 100-mesh coal is based on washability data provided by AMAX Coal Company. Commercial-scale design for the natural minus 100-mesh ROM coal fraction is based on the Phase II batch testing performance at 85% Btu recovery achieved using this natural fines fraction and presented previously in Figure 5 and Table 2.

Commercial-Scale Plant Reliability Analysis

The reliability analysis for both the 200- and 20-t/h plant designs is based on the following three criteria:

- Availability Factor (AF): The expected percentage of scheduled operating hours that the plant is in service
- Equivalent Availability Factor (EAF): The expected percentage of the design coal processing rate at which the plant will operate
- Full Load Operation Factor (FLOF): The expected percentage of scheduled operating hours at which the plant operates at the designed capacity

Table 4 presents the availability factors and expected operating rates for the conceptual designs of both the 20- and 200-t/h selective agglomeration plants.

Table 4
200-t/h Conceptual Design Availability Results

	20 t/h	200 t/h
Availability factor (AF)	95.4%	97.2%
Expected operating hours per year	8010	8164
Equivalent availability factor (EAF)	95.0%	95.2%
Expected coal processing rate (t/h)	19	190
Full load operating factor (FLOF)	93.4%	90.0%
Hours per year at design capacity	7843	7475

For reliability analyses completed on the Illinois No. 5 coal plant design, the EAF of the conventional coal cleaning portion of the plant was assumed to be 90%.

Using this assumption and reliability analysis of the natural fines agglomeration circuit, reliability results for this commercial-scale (1500-t/h feed) plant design are presented in Table 5.

Table 5
Natural Fines and Overall Plant Reliability

Equipment	EAF	Product t/h
Conventional coal cleaning only	90.0%	1083
Agglomeration process only	98.5%	69
Overall plant	90.5%	1152

Commercial-Scale Plant Economic Analysis

Economic analyses completed on the commercial-scale agglomeration plant for the Upper Freeport and Illinois No. 5 coals were based on the assumptions presented in Table 6.

Table 6
Commercial Plant (200 t/h) Economic Assumptions

Actual operating hours	7,560
Plant availability	90%
Production rate	200 t/h product
Plant life	20 years
Royalties	None
Financing	100% equity
Inflation rate	4.0%
Corporate tax rate	38.0%
Rate of return	10.0%

Based on these assumptions and the actual plant design, the annualized product costs for both coals are presented in Table 7. These costs represent total plant processing costs including capital investment, operation and maintenance costs, and Btu losses incurred during processing. However, these annualized product costs do not include the cost of the ROM coal. In this table, costs are presented for a pelletized and thermally dried product containing 4% moisture, a nonpelletized product thermally dried to 8% moisture, and a nonpelletized mechanically dewatered product containing approximately 25% moisture.

Sensitivity analyses varying the rate of return, operating hours, and plant size were performed for this 200-t/h product commercial plant design. These analyses reveal that:

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- An increase in the rate of return from 10% to 20% increases product costs by 20%.
- A decrease in the actual annual operating hours from 7560 to 5400 increases product costs by 16%.
- An increase in plant size from 200 t/h to 500 t/h decreases product costs by 10%.

Table 7
Commercial Agglomeration Annualized Product Cost Summary

	Upper Freeport	Pittsburgh No. 8
Pelletized Product, 4% Moisture		
\$/ton product	24.73	25.32
\$/million Btu	0.84	0.87
\$/ton SO ₂ removed	333.56	488.08
Nonpelletized Product, 8% Moisture		
\$/ton product	17.70	18.28
\$/million Btu	0.60	0.63
\$/ton SO ₂ removed	238.66	352.41
Nonpelletized Product, 25% Moisture		
\$/ton product	14.08	14.72
\$/million Btu	0.48	0.51
\$/ton SO ₂ removed	189.95	283.79

The cost of cleaning minus 100-mesh natural fines using an agglomeration circuit retrofit in a conventional cleaning plant is shown in Table 8. The natural fines circuit costs represent total processing costs including capital investment and operation and maintenance costs. Added cost for Btu losses incurred during natural fines

processing are not included since this circuit is a retrofit application to a plant which bypasses the fines to tailings. Annualized product costs for the entire plant are based on natural fines circuit product costs and an assumed value of \$2/ton product for the plant conventional cleaning circuits.

Table 8
Natural Fines Annualized Product Cost Summary

Fines Circuit	
\$/ton product	\$12.62
\$/million Btu	\$0.49
\$/ton SO ₂ removed	\$243.24
Entire Plant	
\$/ton product	\$2.58
\$/million Btu	\$0.10
\$/ton SO ₂ removed	\$74.68

The retrofit selective agglomeration fines recovery circuit produces approximately 378,000 tons/year of product generating additional revenue. Assuming an energy value of \$0.80 per million Btu, an after-tax profit of \$2.35 million per year is realized. This annual profit does not include credit for refuse handling cost savings such as reduced capital equipment investment, reduced operating costs, and lower ponding capital and operating costs.

Based on these revenue projections, the rate of return for the retrofit selective agglomeration fines circuit is 14.5% with a payback period of 6.5 years from startup.

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