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Project Summary

Economic Evaluation of Oil Agglomeration for Recovery of Fine Coal Refuse

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In this project economics of an oil-agglomeration process with and without an oil recovery system were evaluated for recovering coal fines from a fine refuse stream of 105 ton/hr* from a coal preparation plant. The two base case processes studied are an oil-agglomeration process in which heptane is used and recovered and an oil-agglomeration process in which fuel oil is used and blended with the product. The economics for both processes were estimated with and without a pond credit (savings in coal preparation plant investment resulting from the smaller waste disposal pond needed for the oil-agglomeration process). The total capital investments for the recovery and nonrecovery processes without a pond credit are $21 million and $13 million, respectively. With the use of the pond credit, the total capital investment for the recovery process is $9 million, and a capital investment credit of $0.2 million is received for the nonrecovery process. The first-year annual revenue requirements for the recovery and nonrecovery processes are $6.4 million (0.86 $/10⁶ Btu) and $8.0 million (1.10 $/10⁶ Btu) with a pond credit and $8.5 million (1.15 $/10⁶ Btu) and $10.3 million (1.42 $/10⁶ Btu) without a pond credit, respectively. These costs compare quite favorably with an eastern bituminous coal which has a heating value of 11,000 Btu/lb and cost of 1.85 $/10⁶ Btu (40.70 $/ton). Both the recovery and the nonrecovery processes appear to be economically feasible, but the recovery process is more cost-effective for recovering fine coal from refuse streams.

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 this report, the economics of an oil-agglomeration process with and without oil recovery system are evaluated. The two base case processes studied are an oil-agglomeration process using heptane with a heptane recovery system and an oil-agglomeration process using fuel oil that does not have an oil recovery system. The design data for the processes are based on information from vendors and researchers of oil-agglomeration and oil recovery systems. The econmics of both processes are presented and compared, and several case variations are also examined.

Background

Much of the coal lost in the waste from coal-cleaning plants consists of fine coal that is difficult to separate from noncoal minerals with conventional coal-cleaning techniques. The use of highly efficient coal-cleaning processes and cleaning of coal with finely dispersed pyrite, both of which necessitate more extensive use of fine coal-cleaning techniques, can dramatically increase the quantity of coal lost in the fine waste stream and the

*Readers more familiar with metric units may use the conversion factors at the back of this Summary.

volume of fine waste produced. The coal loss represents a substantial potential resource, and the waste itself, which consists of a slurry that is difficult to dewater and must be confined in a pond, poses increasingly serious economic and environmental problems. Consequently, interest in methods of cleaning and recovering fine coal has increased. One of the most effective methods is the oil-agglomeration process developed by the National Research Council of Canada.

The oil-agglomeration process is a means both of cleaning fine coal and of recovering the coal in a more useful form. Fine coal (in the minus 28-mesh range) is dispersed in an agitated vessel with a light oil such as heptane, fuel oil, or kerosene, and in some cases a small quantity of a binder such as asphalt is used. By carefully controlling the degree of agitation, the oil is dispersed in small droplets in which the coal and other oleophilic (oil attracted) minerals collect, forming small spherical particles. Over 90% of the coal in a fine coal slurry can be recovered in this manner. In spite of its effectiveness, the process has not gained commercial acceptance because of the cost of the oil used. The agglomeration process becomes more economically attractive when designed for low oil-to-coal ratios; however, there is also a corresponding decrease in coal recovery efficiency and product quality. Recovery and reuse of the oil would allow the agglomeration process to operate at higher oil consumption levels with greater coal recovery and improved product quality.

The recovery process is ostensibly simple: the mechanically dewatered agglomerate is heated to vaporize the oil and the vapor is condensed to recover the oil. Several companies have investigated aspects of an oil-agglomeration process with an oil recovery system but many technical and practical details remain to be defined. The primary technical challenge is the development of a heating system that provides efficient and controllable heat transfer without thermal and mechanical damage to the particles.

Design and Economic Premises

The design and economic premises used in this study were developed by the Tennessee Valley Authority (TVA) for economic comparisons of processes related to coal-cleaning and emission control in electric utility applications. The conceptual process designs are based on information provided by vendors of oil-agglomeration and oil recovery equipment and systems. The plant is assumed to operate at 5,500 hr/yr for 30 years, with a total operating life of 165,000 hours.

The quantity and composition of the feed to the oil-agglomeration plant for this study are assumed to be similar to the fine coal refuse produced by the Breckenridge Camp No. 11 coal-cleaning plant near Breckenridge, Kentucky. The refuse consists of a 10% solids slurry produced at a rate of 5.8 million ton/yr. The solids have a maximum size of 28 mesh and consist of 47.5% coal, 2.5% pyrite, and 50% other noncoal minerals. The base case design conditions for the oil-agglomeration process (using heptane) with a heptane recovery system (recovery process) and the agglomeration process (using No. 2 fuel oil) without a recovery system (nonrecovery process) are shown in Table 1. Heptane was selected as the oil in the recovery process because of its distinct properties which make it easier to recover than other oils, and No. 2 fuel oil was used in the nonrecovery process mainly because of its lower cost.

A 30-day-capacity holding pond and a 30-year-capacity waste disposal pond are provided for the oil-agglomeration plant as a replacement for the large volume waste disposal pond that would have been required for the coal-cleaning plant if the waste had not been processed. The waste disposal ponds are square earthen-diked impoundments with a median diverter dike and a 12-in. clay lining.

Raw materials consist of a propane precipitated asphalt at 189.2 $/ton and commercial grades of heptane, No. 2 fuel oil, and kerosene at 1.60, 1.09, and 1.32 $/gal., respectively. All raw materials are

Table 1. *Process Design Conditions*

	Process	
	Heptane With Recovery	*Fuel Oil Without Recovery*
Feedstock		
Rate, 10^6 lb/hr	2.1	2.1
Slurry concentration, % solids	10	10
Solids composition, % by wt (dry)		
Coal	47.5	47.5
Noncoal minerals	50	50
Pyrite	2.5	2.5
Operating Conditions		
Time, hr/yr	5,500	5,500
Coal recovery, % of coal feed	92	90
Oil, % of undried product	18[a]	6.1[b]
Asphalt, % of undried product	2	0
Oil recovery, % of oil feed	97.7	0
Product[c]		
Production, ton/yr	289,000	302,000
Solids composition, % by wt (dry)		
Coal	89	83
Noncoal minerals	8	14
Sulfur	3	3
Water	<5	30
Heating value, Btu/lb (dry)	12,900	12,000
Waste		
Rate, 10^6 lb/hr	1.9	1.9
Solids, %	5	5
Coal, % of waste	0.3	0.4

[a] *This number corresponds to 14.1% of oil based on the weight of the feed solids and 21.4% oil based on the dry weight of the agglomerated product (water-free basis).*

[b] *This number corresponds to 5.0% oil based on the weight of the feed solids and 8.7% oil based on the dry weight of the agglomerated product (water-free basis).*

[c] *All product percentages and the heating values are based on the dry weight of the product (coal and all noncoal minerals, including pyrite) and do not include the weights or effects on heating value of residual oil, asphalt, or water (the heating values of the residual oil and asphalt are taken into account in the economics).*

delivered by rail in tank cars and are stored in tanks sized to provide a storage capacity of 30 days.

The economic estimates consist of capital investments and both first-year and levelized annual revenue requirements. Capital investments are based on mid-1982 costs and annual revenue requirements are projected to 1984 and are based on 5,500 hr/yr of operation at full capacity. The capital investments also include pond credits which are determined by subtracting the cost of the 30-day-capacity holding pond and the 30-year-capacity waste disposal pond for the agglomeration plant from the cost of the coal-cleaning plant 30-year-capacity waste disposal pond.

Process Description

Oil Agglomeration with Heptane Recovery

The process consists of four identical trains of agglomeration and heptane recovery equipment, supplied by a single feed tank and raw material storage and supply system. The flow diagram is shown in Figure 1. The agglomeration plant is designed to process a 10% solids slurry at a rate of 2 x 10^6 lb/hr (about 4,000 gal./min of slurry) for 5,500 hr/yr for 30 years. The 10% solids slurry is recovered from the coal-cleaning plant holding pond and pumped to a scalping screen that removes particles over 0.5 mm in size. The slurry that passes through the screen is stored in an agitated tank from which it is pumped to the high-shear mix tank. Along with the slurry, 18% heptane and 2% asphalt (both based on agglomerated product from the screen) are added to the mix tank. The high degree of agitation produces very fine droplets of heptane and asphalt in which the coal and other oleophilic minerals agglomerate. The slurry flows to the low-shear mix tank which has a lesser degree of agitation and allows the small agglomerates formed in the high-shear mix tank to coalesce into particles 2 to 3 mm in diameter (an adequate size particle for thermal drying).

The slurry flows by gravity from the low-shear mix tank to a vibrating screen which removes agglomerated particles. The unagglomerated particles (mostly noncoal minerals) and liquid drain to a refuse tank. The agglomerated particles are transferred by belt conveyor to the heptane recovery system. The agglomeration plant is designed to recover 92% of the coal in the waste and produce 289,000 ton/yr of product containing 89% coal, 8.0% mineral matter, and 3.0% sulfur with a heating value of 12,900 Btu/lb (not including residual heptane and the asphalt binder).

The recovery system consists of a fluidized-bed dryer; a particle purge vessel; and associated gas circulating, solids collecting, and condensing equipment. The particles are transported from the feed bin in a screw conveyor and fed to the dryer through an air lock. The particles are fluidized with a heated mixture of 60% heptane and 40% water vapors which vaporizes 95% of the heptane and water in the particles.

The gas from the dryer passes through a cyclone and filter to remove entrained solids. Two-thirds of the gas is recycled through a compressor and heated to 465°F before entering the dryer and one-third is passed through a water-cooled shell-and-tube heat exchanger that condenses and cools the heptane and water to 100°F. The condensate drains to a condensate tank in which the heptane and water separate. The heptane is returned to the agglomeration system and the water is pumped to the waste pond. Approximately 97.7% of the heptane is recovered.

Oil-Agglomeration Without Oil Recovery

The nonrecovery process used No. 2 fuel oil and is based on conditions typical

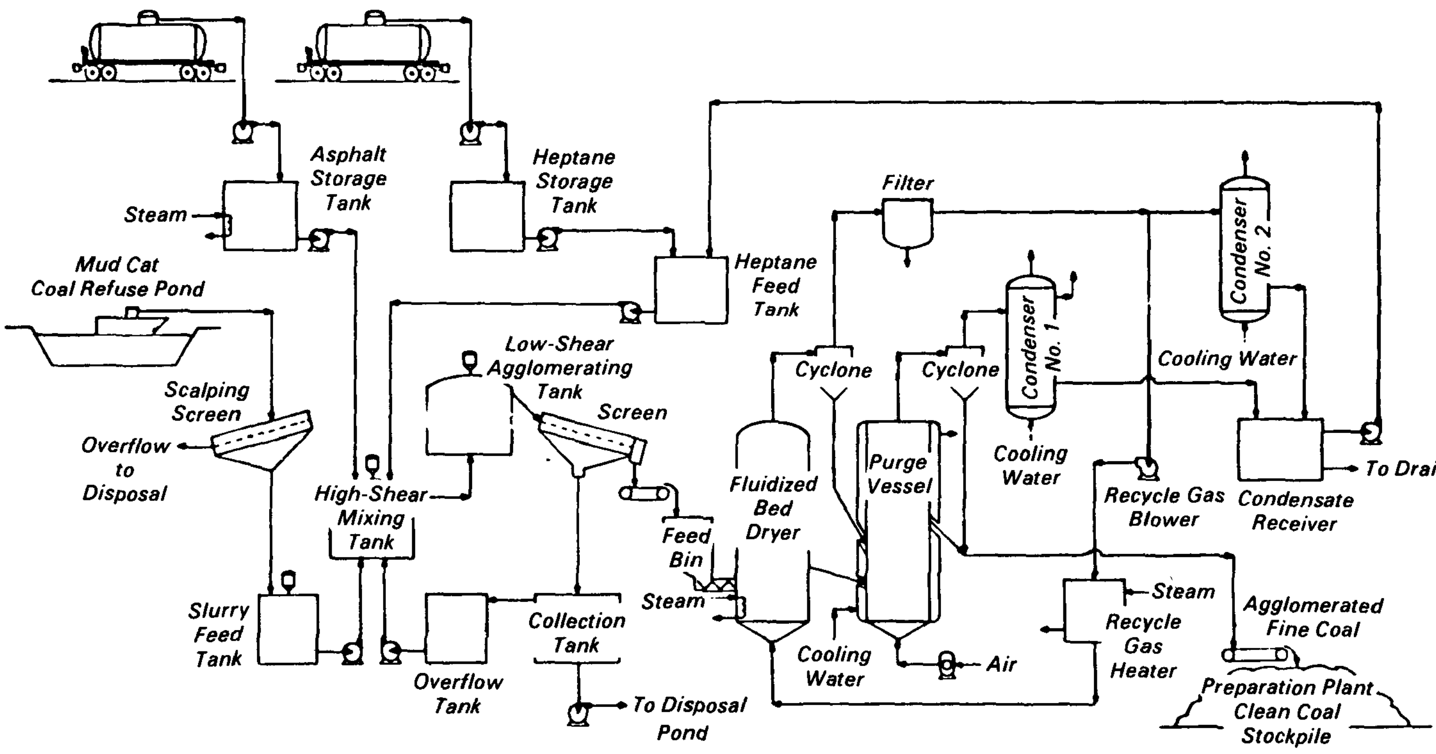

Figure 1. *Oil-agglomeration process with heptane recovery.*

of those conventional oil-agglomeration processes in which the quantity of oil used is minimized to reduce cost. The nonrecovery process differs from the recovery process by the use of a less expensive oil and a much lower oil content in the agglomerated product (6.1% fuel oil based on the agglomerated product from the screen—see Table 1) and the absence of the oil recovery system. As a result of the lower oil content, the coal recovery is somewhat lower (90%) and the product particle size is smaller (+100 mesh). [The quantity of oil used in the agglomeration process has the greatest effect on the product particle size and coal recovery rate. The physical properties of the oil (e.g., density, viscosity) will have a slight effect, but were not evaluated in this study since their effect was considered to be very minor when compared to the effect of the oil level.] The flow diagram for the nonrecovery process is shown in Figure 2. The equipment and process descriptions for the nonrecovery process are similar to the agglomeration circuit in the recovery process except for the deletion of the asphalt binder for the agglomerated coal which is not needed since the nonrecovery product is not thermally dried.

Results

Capital investments and first-year and levelized annual revenue requirements are developed for the base case processes just described. Several case variations and sensitivities are examined for the base cases, and the alternative of using kerosene or heptane instead of fuel oil is evaluated for the nonrecovery process.

Capital Investment

The summary of the capital investment estimates for the base case processes is shown in Table 2. The total capital investment for the recovery process is $9 million with the pond credit and $21 million without the pond credit. The total capital investment for the nonrecovery process using fuel oil is almost $13 million without the pond credit and a capital investment credit of $0.2 million is received with the pond credit. The major capital investment difference for the base case processes is in the total process capital. The total process capital for the nonrecovery process is approximately 43% less than the recovery process. The smaller process capital cost for the nonrecovery process is due to the exclusion of the heptane recovery system, which accounts for approximately 43% of the total process capital for the recovery process.

The pond credit for the nonrecovery process is approximately 6% higher than the recovery process. This is a result of the nonrecovery process using a lower oil-to-coal ratio, and thus having lower coal but higher ash recoveries, which subsequently decrease the quantity of waste solids and require a smaller refuse pond for the nonrecovery process.

The pond credit has a very large effect on the capital investments and the difference is illustrative of the large cost associated with pond disposal of large volumes of waste. The pond credit reduces the total capital investments for the recovery process by approximately 57% and the nonrecovery process by more than 100%.

Annual Revenue Requirements

The first-year annual revenue requirements for the recovery process are $6.4

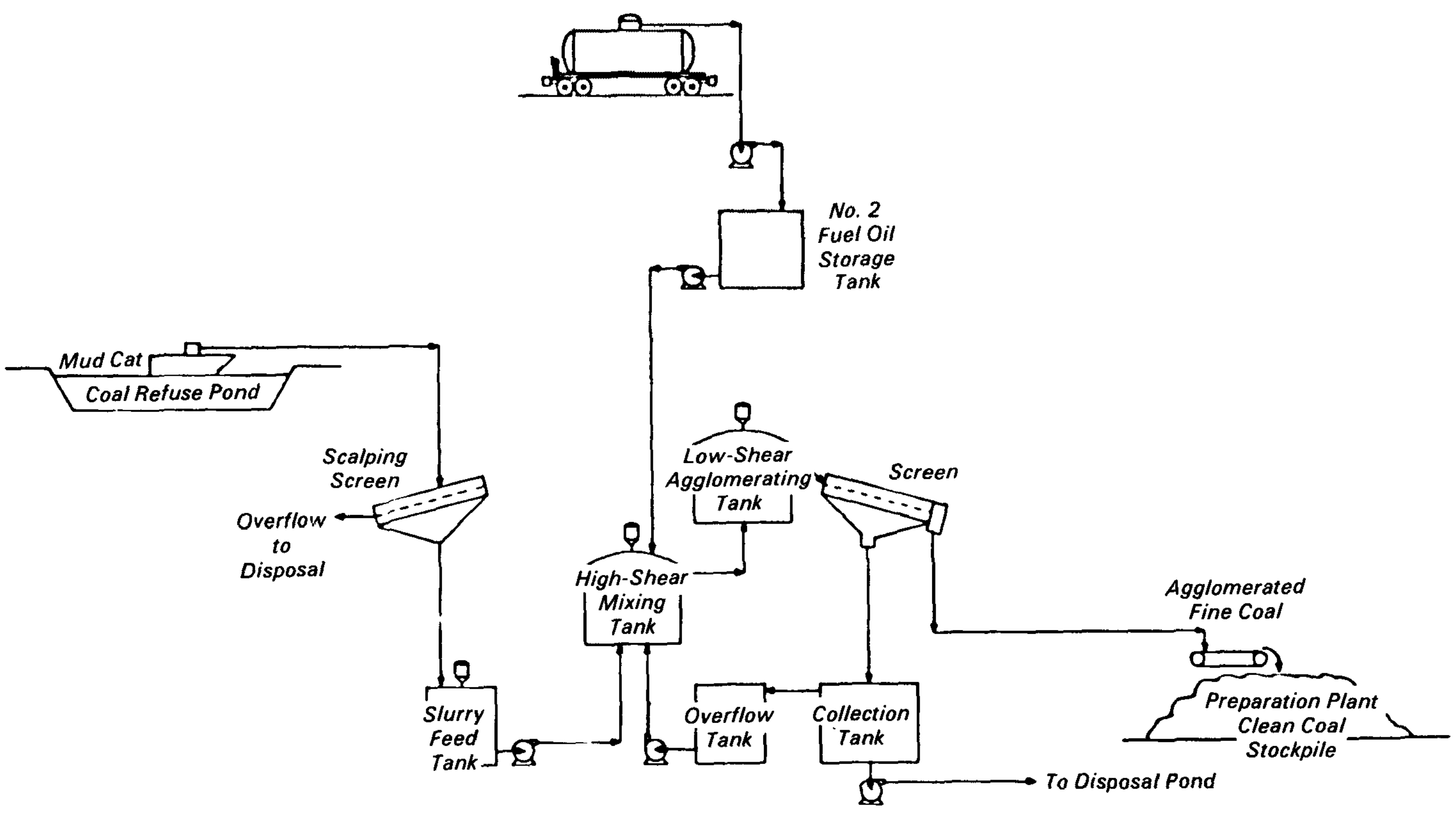

Figure 2. *Oil-agglomeration nonrecovery process with fuel oil.*

Table 2. Summary of Capital Investments

Investment Area	*Total Cost, $1000s*	
	Recovery Process	*Nonrecovery Process With No. 2 Fuel Oil*
Total process capital	*10,015*	*5,668*
Total indirect investment	*6,546*	*3,704*
Working capital	*909*	*1,109*
Other capital charges	*4,029*	*2,279*
Total capital investment excluding pond credit	*21,499*	*12,760*
Pond credit	*(12,168)*	*(12,926)*
Total capital investment	*9,331*	*(166)*

million, as compared with $8.0 million for the nonrecovery process with fuel oil, including the pond credit in both cases. The difference in annual revenue requirements between the two processes is due mainly to the larger quantity of oil consumed by the nonrecovery process, which replaces that lost in the coal agglomerates. Even though a heat credit is applied for the oil, it is not enough to offset the difference between the cost of the two processes. The first-year unit revenue requirements are 0.86 $\$/10^6$ Btu (22 $/ton) for the recovery process and 1.10 $\$/10^6$ Btu (27 $/ton) for the nonrecovery process, including the pond credit in both cases. Without the pond credit, the unit costs are 1.15 $\$/10^6$ Btu (30 $/ton) for the recovery process and 1.42 $\$/10^6$ Btu (34 $/ton) for the nonrecovery process. These costs compare quite favorably with an eastern bituminous coal which has a heating value of 11,000 Btu/lb and cost of 1.85 $\$/10^6$ Btu (40.70 $/ton).

Case Variations

Since the design data for the processes are based on laboratory tests, several case variations and sensitivities are examined, as shown in Table 3, for different pond credits, raw material costs, asphalt contents, and coal recoveries for the recovery process and the nonrecovery process with fuel oil. Different heptane recoveries and purge gases are also evaluated for the recovery process, along with the effects of including a pelletizing system for the product. The effects of using alternate agglomerating agents (oils) and of using a centrifuge to separate the liquid from the coal agglomerates are also evaluated for the nonrecovery process.

The pond credit has a major effect on both the capital investment and annual revenue requirements of both processes. With the pond credit, the capital investments for the recovery and nonrecovery processes are 57% and over 100% lower, respectively, than capital investments without pond credits. The first-year annual revenue requirements for the recovery and nonrecovery processes are increased 34% and 28% without the pond credit. The smaller percentage increase for the nonrecovery process results from the greater importance of the raw material cost, which is the predominant factor in its annual revenue requirements. The recovery and nonrecovery processes are also sensitive to raw material price, asphalt content, and coal recovery rates. The recovery process is also sensitive to heptane recovery rates and slightly sensitive to the type of purge gas selected. The addition of a pelletizing area to the recovery process increases the capital investments and annual revenue requirements by 13% and 23%, respectively, and the use of a centrifuge in the nonrecovery process increases its capital investment and annual revenue requirements by 150% and 10%, respectively. However, the cost for adding the pelletizing area to the recovery process (first-year annual revenue requirements of 1.06 $\$/10^6$ Btu with the pond credit) and using a centrifuge in the nonrecovery process (first-year annual revenue requirements of 1.21 $\$/10^6$ Btu with the pond credit) is still less than the cost of the premise coal at 1.85 $\$/10^6$ Btu.

The first-year annual revenue requirements of the nonrecovery process are projected for two other agglomerating agents (heptane and kerosene). The other nonrecovery processes in which the weight of heptane and kerosene in the product is the same as for the fuel oil process have substantially higher annual revenue requirements—$10.5 million for the kerosene process and $15.3 million for the heptane process, as compared with $8.0 million for the fuel oil process. The predominant difference is the oil costs—1.09, 1.32, and 1.60 $/gal. for fuel oil, kerosene, and heptane, respectively.

Effect of Oil Consumption on Annual Revenue Requirements

The effect of the quantity of oil used on the cost of the nonrecovery processes is shown in Figures 3 and 4 in comparison with the recovery process at different oil recovery efficiencies. The recovery process has the same oil and asphalt content in the agglomerated product as the base case processes—18% oil and 2% asphalt in the agglomerated coal.

The nonrecovery process annual revenue requirements increase rapidly with increasing oil consumption. This is primarily due to the higher consumption of fuel oil which is the predominant cost factor in the first-year annual revenue requirements. The cost of the nonrecovery product with the pond credit exceeds the cost of the premise coal (1.85 $\$/10^6$ Btu) at oil levels of 11% or higher (9% without the pond credit) as shown in Figure 4.

The recovery process annual revenue requirements are not related to oil content in the agglomerated coal but to the efficiency of the oil recovery system. As the recovery efficiency decreases (percent oil loss increases), the annual revenue requirements increase rapidly as shown in Figures 3 and 4. At an 18% to 20% oil loss in the recovery process, the cost of the product with the pond credit exceeds that of the premise coal at 1.85 $\$/10^6$ Btu. With no pond credit, the cost of the recovery product exceeds the premise coal at an oil loss of approximately 13.5%.

At the base case conditions evaluated in this study, the recovery process is less expensive to operate than the nonrecovery process. Also, a poorer quality of product is produced in the nonrecovery process, and there may be greater uncertainty concerning the capability of the nonrecovery process (at the low oil levels) to actually yield a product suitable for use in a pulverized-coal-fired boiler. However, the nonrecovery process could be economically competitive if lower than base

Table 3. Case Variation Cost Sensitivities

Variation	Oil Agglomeration With Heptane Recovery: Capital Investment[a] $10^6	Change, %	Annual Revenue Requirements[b] $/10^6 Btu	Change, %	Oil Agglomeration With Fuel Oil: Capital Investment[a] $10^6	Change, %	Annual Revenue Requirements[b] $/10^6 Btu	Change, %
Pond credit								
Base case	9.3		0.86		(0.2)		1.10	
50% of base case	15.4	+66	1.00	+16	6.3	+3,250	1.26	+15
No pond credit	21.5	+131	1.15	+34	12.8	+6,500	1.42	+29
Raw materials price[c]								
80% of base case	9.29	−0.1	0.79	−8	(0.3)	−50	0.86	−22
Base case	9.3		0.86		(0.2)		1.10	
140% of base case	9.4	+1	1.01	+17	0.1	+150	1.60	+45
Asphalt used[d]								
50% of base case	9.1	−2	0.78	−9				
Base case	9.3		0.86		(0.2)		1.10	
150% of base case	9.6	+3	0.94	+9	1.0	+600	1.41	+28
Coal Recovery[e]								
90% of base case	9.5	+2	0.95	+10	1.5	+850	1.27	+15
Base case	9.3		0.86		(0.2)		1.10	
105% of base case	9.1	−2	0.82	−5	(1.2)	−500	1.02	−7
Heptane recovery								
80%	10.0	+8	1.96	+128				
90%	9.6	+3	1.34	+56				
95%	9.4	+1	1.03	+20				
Base case (97.7%)	9.3		0.86					
99.7%	9.2	−1	0.74	−14				
Purge gas								
Base case (air)	9.3		0.86					
Inert gas	9.2	−1	0.74	−14				
Nitrogen	9.8	+5	0.75	−13				
Pelletization								
Base case	9.3		0.86					
Base case with pelletization	10.5	+13	1.06	+23				
Centrifuge								
Base case					(0.2)		1.10	
Base case with centrifuge					0.1	+150	1.21	+10
Oils								
Base case (fuel oil)					(0.2)		1.10	
Kerosene					0.1	+150	1.45	+32
Heptane					0.5	+350	2.11	+92

[a] 1982 dollars.
[b] First-year annual revenue requirements in 1984 dollars.
[c] Asphalt and heptane or fuel oil.
[d] 1%, 2%, and 3% of undried product for the recovery process; 0% and 3% for the nonrecovery process.
[e] 83%, 92%, and 97% for the recovery process; 81%, 90%, and 95% for the nonrecovery process.

case oil recoveries are achieved in the recovery process. As shown in Figure 3, the first-year annual revenue requirement with pond credits for the recovery process with only 2.3% oil loss (base case) is equivalent to the revenue requirements for the nonrecovey process at an oil level of 4.5% in the product, but at oil losses greater than 6.5% (recoveries less than 93.5%), the first-year annual revenue requirements for the base case nonrecovery process (oil level of 6.1% in the product) with pond credits are less than for the recovery process.

Conclusions

Based on typical costs for coal, the oil-agglomeration process appears to be an

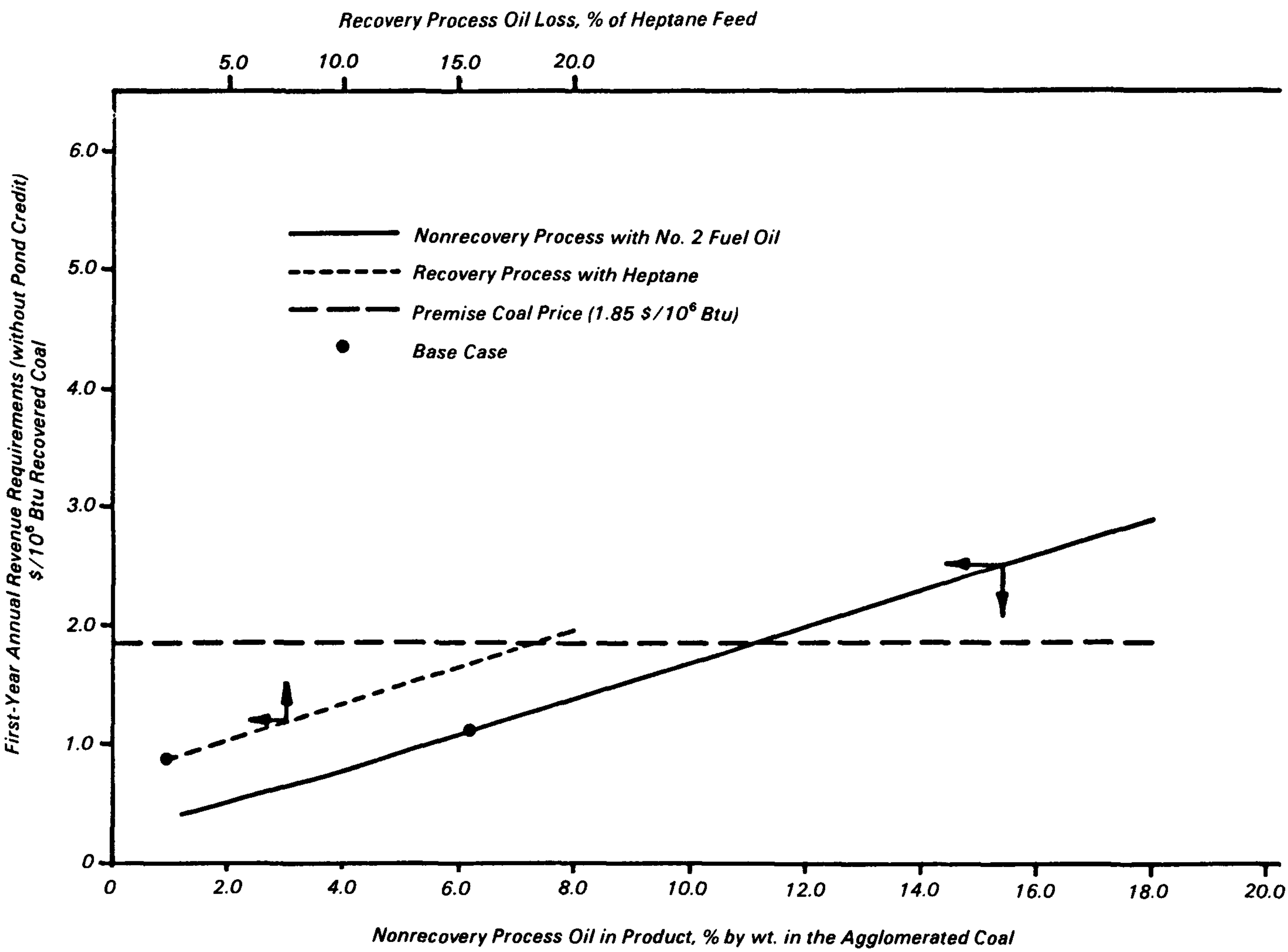

Figure 3. *First-year annual revenue requirements (with pond credit) for the recovery and nonrecovery processes.*

effective method for recovering coal fines from coal-cleaning plant refuse. Both the recovery and the nonrecovery processes appear to be economically feasible methods but, depending on the base case amounts of oil used in the two processes and the efficiency of the oil recovery in the recovery system, the recovery process is more cost effective. As a result of the more favorable economics for the recovery process at the higher oil recovery efficiencies (greater than 93%), it is recommended that this technology be tested to determine if the recovery system can be operated with the desired efficiency. If the recovery system cannot operate at the higher oil recovery efficiencies (greater than 93%), examination of the nonrecovery process may be advisable.

Metric Conversions

Readers more familiar with metric units may use the following metric conversion factors:

Nonmetric	Times	Yields Metric
Btu	1.055	J
°F	5/9 (°F - 32)	°C
gal.	3.785	l
in.	2.54	cm
lb	0.454	kg
ton	907.2	kg

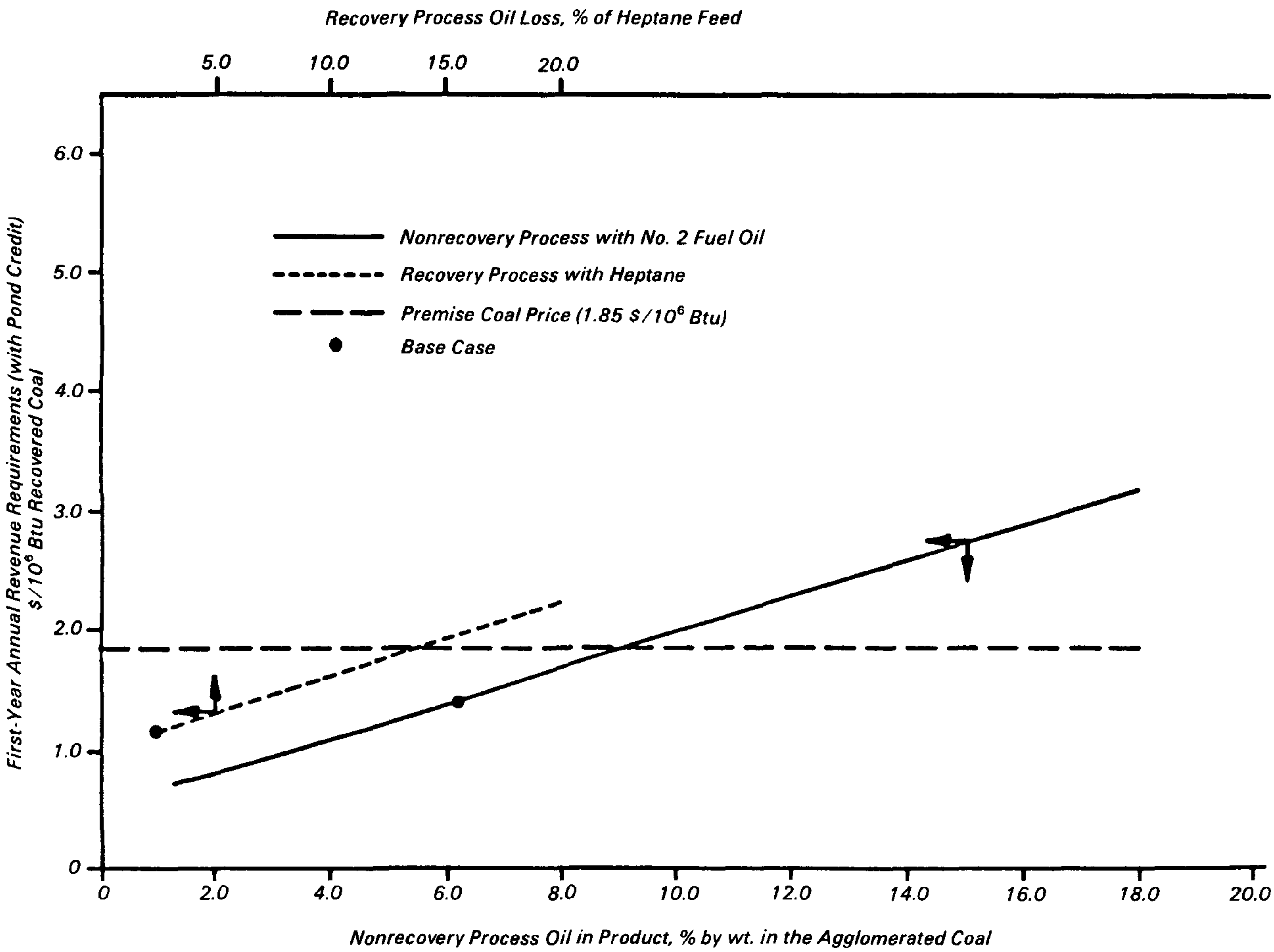

Figure 4. *First-year annual revenue requirements (without pond credit) for the recovery and nonrecovery processes.*

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***Julian W. Jones** is the EPA Project Officer (see below).*

The complete report, entitled "Economic Evaluation of Oil Agglomeration for Recovery of Fine Coal Refuse," (Order No. PB 86-161 304/AS; Cost: $11.95, subject to change) will be available only from:

National Technical Information Service
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