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PROJECT FOR LABORATORY STUDY FOR REMOVAL OF ORGANIC
SULFUR FROM COAL

Quarterly Technical Progress Report

July 15, 1980

Work Performed Under Contract No. AC22-80PC30141

Defense and Space Systems Group
TRW Inc.
Redondo Beach, California

U. S. DEPARTMENT OF ENERGY

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PROJECT FOR

LABORATORY STUDY FOR REMOVAL OF ORGANIC
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U.S. DOE CONTRACT
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QUARTERLY TECHNICAL PROGRESS REPORT

JULY 15, 1980

TRW

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1.0 INTRODUCTION AND SUMMARY

Substantial progress has been made in the development of the Gravimelt Process for removal of organic sulfur from coal during this first quarter of the project.

Three reactors have been fabricated which will be used for both material balanced studies of the desulfurization of coal with caustic and examination of the behavior of model organic and inorganic sulfur-containing compounds with the same mixture. Model organic sulfur compound have been procured and samples of Kentucky No. 9 coal enriched in mineral matter and samples enriched in organic matter have been prepared by float sink techniques for use in determining mechanism and products of the desulfurization reactions.

Initial probing experimentation has been performed aimed at determining the fate of sulfur removed from coal and obtaining semi-quantitative information for future material balanced studies. These studies show near 90% of the sulfur content of the Kentucky No. 9 coal was removed and approximately 3/4 of this removed sulfur was found by chemical analysis to be in the caustic phase. It was further determined that approximately 1% of the coal organic matter dissolves into the caustic phase. These results indicate rough material flows and show that material balanced measurements are feasible.

A preliminary conceptual engineering design for a full scale Gravimelt coal desulfurization plant was prepared in order to guide future laboratory efforts toward obtaining key engineering data. The engineering study indicates that the Gravimelt Process can be designed utilizing state of the art equipment and that likely energy recovery is approximately 90%. It is estimated that coal desulfurization costs will be in the range of \$20 per ton of coal produced, or $70¢/10^6$ Btu, in 1980 dollars.

The results of the laboratory studies are presented in the first section to follow and the results of the engineering and cost estimation studies are presented in the second section. Plans for the next quarter effort are presented in the final section.

2.0 LABORATORY EXPERIMENTATION

Initiation of work for Gravimelt experimentation encompassed:

- 1) Acquisition and preparation of materials for model sulfur removal studies,
- 2) Equipment fabrication, and
- 3) Experiments in support of process design and material balance.

2.1 MODEL STUDIES

Three sulfur containing organic compounds (Table 1) were obtained for future reaction with caustic melt to investigate reactions and byproducts formed during sulfur removal processes. These were selected primarily on the basis of their boiling points and variation of chemical structure. Boiling points in the range of $\sim 300^{\circ}\text{--}370^{\circ}\text{C}$ provide stable compounds within the approximate temperature range of experimental studies envisioned for eventual sulfur removal from coal. Additionally, iron pyrite (FeS_2) was obtained for reaction with a caustic melt. A small sample (20 g) of high mineral content material from Kentucky No. 9 coal was prepared by gravity separation of a 200 g coal sample in 1,2 dibromoethane ($\rho = 2.14$). This sample will, likewise, be reserved for future studies.

2.2 EQUIPMENT FABRICATION FOR MATERIAL BALANCE AND MECHANISM STUDIES

It is intended to determine general chemical classifications and amounts of materials produced as a result of reaction of coal (and model compounds) with a caustic melt. Accordingly, it was necessary to fabricate some small reactors capable of being incorporated into a system which can contain and trap a majority of the reaction products. Previous Gravimelt reactions have been conducted using open tube stainless steel reactors with N_2 blanket to prevent oxidation of the reactant coal. Containment, however, of the volatile products was not attempted.

TABLE 1. MODEL COMPOUNDS FOR SULFUR REMOVAL STUDIES

MODEL COMPOUND	CHEMICAL STRUCTURE	M.W.	B.P. (°C)	SOLUBILITY	
				H ₂ O	BENZENE
THIOXANTHONE [C ₁₃ H ₈ OS]		212	371-3 (Sub.)	Insol.	S
DIPHENYL SULFIDE [(C ₆ H ₅) ₂ S]		186	296	Insol.	S
DIBENZOTHIOPHENE [C ₁₂ H ₈ S]		184	332-3	S	S

Four small identical reactors have been designed and fabricated for use in the Gravimelt program. A schematic representation of the reactor is shown in Figure 1. Basically, a 3-inch diameter stainless steel (316L) tube, 12-inch long, with a flanged cover containing four ports encompasses the basic assembly. A sealed glass stirrer bearing will be provided in the center port for a double-blade stirrer and the three adjacent ports will be used (one each) for a thermocouple well and/or introduction of N_2 flow, gas exit tube and addition tube. It is intended that the gas exit tube will be utilized as the path for volatile products to be sampled for GC analysis or contained in a LN_2 trap for subsequent analysis. Heating of the reactors is accomplished with "clam shell" heaters fitted to encompass the cylindrical pipe section.

2.3 PROCESS DESIGN AND INITIAL MATERIAL BALANCE

In the Gravimelt Process, it is economically desirable to separate caustic from coal as much as possible after reaction and before adding water to the coal for final washing. In order to provide initial engineering data, the physical separation of reacted coal from molten caustic was attempted using two coal sizes after Gravimelt reaction.

The coal samples consisted of float samples of 1/4" x 12 mesh and 14 mesh x 0 obtained after gravity separation of Kentucky No. 9 coal in 1.30 specific gravity KOH/NaOH solution ($\sim 30\%$ w/w caustic in H_2O).

Each of the coal samples (~ 10 g) was added to ~ 80 g of molten (1:1 w/w) KOH/NaOH at $370^\circ C$ and reacted for 20 minutes at atmospheric pressure. Following the reaction, the contents of each tube was emptied onto a pre-heated 40 mesh stainless steel screen. Coal and residual caustic was retained on the screen.

Retention of caustic by the coal was markedly different for the two coal sizes. This was determined as follows:

Each of the recovered coal/caustic residues were weighed and then washed (2 slurry plus 2 cake) with hot water. Dried coal samples were weighed as well as the evaporated residue of an

Figure 1. Schematic Representation of Gravimelt Reactor

TABLE 2. CAUSTIC RETENTION OF GRAVIMELT PROCESSED COAL

Coal Size	(Unwashed-Washed) ⁽¹⁾ Unwashed Coal w/w	(Residue/Unwashed) ⁽²⁾ Coal
1/4" x 12 Mesh	36	27
14 Mesh x 0	83	-

(1) Data obtained from a comparison of unwashed and washed coal samples.

(2) Data obtained from evaporation of an aliquot of caustic washings.

aliquot of caustic solution washed from the 1/4" x 12 sample. It is seen in Table 2 that ~ 30% w/w caustic is retained by 1/4" x 12 mesh coal when separated under the above conditions. Similarly, a sample of recovered 14 mesh x 0 coal contains 87% w/w caustic.

We believe that the caustic retention by the coal will be less in commercial equipment and that these results represent an upper boundary.

The 28.8 g of filtrate from the 14 mesh x 0 experiment was analyzed for sulfur and heat content and the sulfur content of the product coal was obtained. This information, together with a starting coal analysis, allows a rough material balance between the coal and caustic phase to be obtained. The results shown in Table 3 indicate that, to a rough approximation, 1) most if not all of the sulfur removed from the coal is extracted into the caustic phase and 2) on the order of 1% of the coal (in addition to coal sulfur) dissolves into the caustic phase.

These initial results indicate rough material flows and show that material balance measurements are feasible. Future material balance studies will include analysis of off gases and species of sulfur dissolved or volatilized.

TABLE 3. PROBING MATERIAL BALANCE

	Percentage w/w	Absolute Amt, wt
Analyzed Input Coal Sulfur Content :	2.3%	0.23 g
Analyzed Desulfurized Coal Sulfur Content:	0.3%	0.03 g
Analyzed Sulfur in Caustic :	0.19%	0.15 g
Calculated Sulfur Removed from Coal Anal.:	87%	0.20 g
Sulfur Balance :	3/4 of sulfur removed is accounted for in caustic	
	<u>Btu</u> <u>lb</u>	Absolute Amt, Btu's
Analyzed Input Coal Heat Content :	13400	295
Analyzed Heat Content of Caustic :	43	7.5
Calculated Heat Content of Sulfide in Caustic Phase :	13300	4.4
Calculated Heat Content of Coal Organic Material in Caustic Phase (by Difference) :	-	3
Calculated % of Coal Heat Content (Other Than Sulfur) Dissolved in Caustic Phase :	-	1%

3. GRAVIMELT CONCEPTUAL DESIGN

The following pages present the preliminary conceptual design for a Gravimelt process producing coal for a 1000 MWe power plant. This preliminary design will serve as a base case for future designs after the assumptions made in this design have been tested in the laboratory. This design will also point out areas where the overall process economics are sensitive to estimated capital costs and operating parameters. The following pages include a design basis, heat and material balance, brief process description, capital cost estimate, and estimated annual operating costs.

3.1 DESIGN BASIS

3.1.1 Feed Coal

The Gravimelt process is designed to provide coal feed to a 1000 MWe power plant assuming a power plant efficiency of 36% based on the higher heating value of the coal feed. Using the 36% efficiency or 9483 Btu/KWe the required coal output from the Gravimelt process is 9483 MM Btu/hr. It is assumed that the coal feed to the Gravimelt process is nominal 1/8 inch X 0, 1.33 sp. gr. float fraction from an Illinois #6 coal. For the purposes of this study it is assumed that the coal feed has been dried to three percent moisture and the coal product from the Gravimelt process will also be dried to three percent moisture. Below is the analysis of the float coal feed used in this study.

Composition (wt. % on a moisture free basis)

Carbon	76.86
Hydrogen	5.42
Nitrogen	1.48
Oxygen	10.35
Sulfur	2.43
Ash	3.46

100.0

Moisture 3%
HHV = 13,850 Btu/lb

3.1.2 Molten Caustic Reactor

The chemical desulfurization of the coal by reaction with an 80% molten caustic mixture with a 1:1 mole ratio of KOH and NaOH occur in a nickel reaction vessel at atmospheric pressure and 715⁰F. Based on laboratory results it is assumed that 90% of the coal sulfur is converted to K₂S and Na₂S. The reactor is sized to provide 30 minutes residence time for the coal slurry which has four parts caustic to one part coal. It is known that a portion of the coal will be volatilized upon heating to the reaction temperature. For the purpose of this study it is assumed that the volatilized gases will contain seven percent of the heat value in the feed coal and this material will have an average heating value of 18,000 Btu/lb. The above assumptions are subject to confirmation by the ongoing laboratory work on this program.

3.1.3 Coal Recovery

It is assumed that the coal slurry from the reactor can be screened to contain 50% coal prior to the addition of water for cooling and washing. It is also assumed that the washing of the coal to recover the caustic and sulfides can be done using two rotary drum filters in series with a counter-current washing arrangement to minimize the wash water requirements. The assumed wash water requirement is one pound water per pound of dry coal. From the filters the coal is further dewatered to 18% moisture prior to thermal drying to a level of three percent moisture. The heating value of the recovered coal is 13,680 Btu/lb after the removal of sulfur and volatiles. As part of the laboratory program, the assumptions made here will be checked to better determine the operating parameters for dewatering and washing of the reacted coal.

3.1.4 Caustic Regeneration

The aqueous caustic solution from the filter is reacted with lime to convert the potassium and sodium salts to calcium sulfide. It is assumed that 75% of lime feed to the regenerator reactor will be utilized in the conversion to sulfide. The reaction occurs in a nickel reactor with a 30 minute residence time at 320⁰F and atmospheric pressure. The insoluble

sulfides and unreacted lime are removed by thickening and filtration and the caustic solution is reconcentrated by evaporation to 80% concentration for recycle to the caustic reactor.

3.1.5 Product Coal

The coal product from the process has a heating value of 13,680 Btu/lb which is slightly less than the feed coal due to the removal of volatile material and the replacement of sulfur by oxygen in the coal by the desulfurization reaction. The sulfur content of the product coal is 0.26% on a dry weight basis plus the small amount of residual sulfide salts remaining on the coal after washing.

3.2 PROCESS DESCRIPTION

For the purpose of discussion, the Graymelt process design has been divided into three functional sections: Caustic reaction, coal recovery, and caustic regeneration. A process flow diagram for the preliminary design is presented in Figure-2. The process material balance is given in Table 4.

3.2.1 Caustic Reaction Section

The caustic reaction section consists of equipment necessary to feed dried coal to the caustic reactor, react the coal with the molten caustic, heat the recycle caustic to the reactor and recover the volatile fuels evolved from the coal during the reaction. A dried float coal which has been recovered from an Illinois No. 6 Coal cleaned to a 1.33 specific gravity is fed from coal silos to the reactors by conveyors at the rate of about 382 TPH. The feed coal is assumed to be 1/8 inch X 0 and represents about 40 wt. % of the ROM Illinois No. 6 Coal. For the feeding of coal, the caustic reaction, and the coal screening, the plant has been divided into five trains. Each train is provided with coal feed silos which have the capacity to store 24 hours of feed coal. The coal is fed from the silos to the reactors using conveyors where the coal is contacted with the molten caustic solution at 715°F and atmospheric pressure in an agitated nickel reactor. Each of the five reactors sized to provide 30 minute residence

Figure 2. Process Flow Diagram

TABLE 4. MATERIAL BALANCE

STREAM	1 COAL FEED	2 VOLATILE VENT	3 REACTOR EFFLUENT	4 FEED CAUSTIC	5 RECYCLE CAUSTIC	6 COAL SLURRY	7 SLURRY DRUM REFLUX	8 FILTER FEED SLURRY
COAL, TPH								
MAF	348.78	-	332.88	-	-	332.88	-	332.88
S	9.01	-	0.90	-	-	0.90	-	0.90
ASH	12.82	-	12.82	-	-	12.82	-	12.82
VOLATILE	-	19.96	-	-	-	-	-	-
H ₂ O	11.46	16.03	-	-	-	-	-	-
TOTAL	382.08	35.99	346.60	-	-	346.60	-	346.60
CAUSTIC, TPH								
KOH	-	-	602.91	617.12	452.18	150.73	-	200.42
NaOH	-	-	429.90	440.03	322.42	107.47	-	142.90
K ₂ S	-	-	55.86	41.89	41.89	13.96	-	18.57
Na ₂ S	-	-	39.54	29.65	29.65	9.88	-	13.14
H ₂ O	-	-	258.20	258.22	193.65	64.55	80.71	318.17
TOTAL	-	-	1386.40	1386.91	1039.80	346.60	80.71	318.17
TOTAL TPH	382.08	35.99	1733.00	1386.91	1039.80	693.20	80.71	1039.80
(CONTINUED)								

TABLE 4. (CONTINUED)

STREAM	9 WASH FILTRATE	10 WASH WATER	11 FILTER CAKE	12 CENTRATE	13 CENTRIFUGE CAKE	14 DRIED COAL	15 REGENERATOR FEED	16 LIME FEED	17 REGENERATOR EFFLUENT
COAL, 1991									
MAF			332.88		332.88	332.88			
S			0.90		0.90	0.90			
ASH			12.82		12.82	12.82			
VOLATILE H ₂ O									
TOTAL			346.60		346.60	346.60			
CAUSTIC, TPH									
KOH	49.69		0.42	.234	.183	.193	150.31		164.48
NaOH	35.43		0.30	.167	.131	.131	107.18		117.28
K ₂ S	4.60		.04	.022	.017	.017	13.93		
Na ₂ S	3.26		.03	.015	.012	.012	9.86		
H ₂ O	253.63	346.60	172.51	96.78	75.74	10.40	238.63		232.57
CaO								18.89	
Ca(OH) ₂									6.24
CaS									18.22
TOTAL	346.60	346.60	173.30	97.22	76.08	10.74	519.91	18.89	538.79
TOTAL	346.60	346.60	519.90	97.22	422.68	357.34	519.91	18.89	538.79
(CONTINUED)									

TABLE 4. (CONTINUED)

STREAM	18 THICKNER OVERFLOW	19 THICKNER UNDERFLOW	20 WASH WATER	21 FILTRATE	22 SOLIDS TO DISPOSAL	23 EVAPORATOR FEED	24 MAKE UP KOH/NaOH	25 EVAPORATOR WATER	26 EVAPORATOR BOTTOMS
CAUSTIC, TPH									
KOH	156.66	7.82		7.79	.032	164.45	0.49		164.94
NaOH	111.70	5.58		5.56	.023	117.26	0.35		117.61
K ₂ S									
Na ₂ S									
H ₂ O	221.50	11.06	24.46	23.35	12.18	244.85	.21	180.49	64.57
CaO									
Ca(OH) ₂		6.24			6.24				
CaS		18.22			18.22				
TOTAL	489.86	48.93	24.46	36.70	36.70	526.56	1.05	180.49	347.11

time for the coal are 15 feet diameter by 22.5 feet high. The caustic feed rate to the reactor is 1387 TPH which allows a 4:1 ratio of caustic to coal. The feed caustic enters the reactor at 755°F providing enough heat to raise the temperature of the feed coal to 715°F and volatilize the water present in the coal and hydrocarbons equal to seven percent of the heat content of the feed coal. Water is removed from the vent gas using a 275 ft² condenser on each reactor. The vent gases are then compressed to 100 psig in a single 3500 HP compressor where more water is removed and the gaseous and liquid fuels are recovered for process use. It is not known at this time the quantity of fuel which will be recovered as liquid. An analysis of the volatile material will be included as part of the ongoing laboratory program.

The desulfurization of the coal forming sulfide salts is accomplished by the following reactions:

The reacted coal slurry from the reactors overflows to five nickel screens where the liquid material is removed to leave a coal containing 50% caustic solution. The caustic solution is recycled to the reactor after reheating in the recycle caustic heater where both the recycle caustic and the re-generated caustic from the evaporator are heated to 755°F. The caustic heater with a fired duty of 177 MM Btu/hr, assuming a 70% efficiency, uses fuel recovered from the volatile vent stream at the reactor. For this analysis it has been assumed that all equipment contacting the caustic solution will be constructed from nickel. The possibility of using less noble and less expensive material will be studied as part of the laboratory program.

3.2.2 Coal Recovery Section

The coal slurry from the screens containing 50 wt. % coal is fed to a slurry tank where it is combined with the wash filtrate from the filter/washing operation. The slurry tank is an 18,500 gallon agitated nickel vessel which is sized to provide 10 minutes residence time for the coal

slurry. The slurry is cooled by the 180°F wash water from the filters and a reflux condenser which condenses and cools the vapor boiled off from the slurry to 175°F before recycle back to the tank which is operating at about 320°F. The assumed 320°F boiling temperature for the solution is subject to confirmation in the laboratory. The overhead condenser duty is 171 MM Btu/hr requiring approximately 6100 ft² of surface area. The cooled slurry containing about 33 wt. % coal is fed to two trains of two rotary drum vacuum filters in series for dewatering and washing. The four filters require a total of 1700 BHP for the filter drives and vacuum systems. The filters are arranged to wash the coal countercurrently using one ton of water per ton of dry coal with the fresh wash water used as feed for the 2nd stage filter. The wash filtrate from the second stage filter is used to reslurry the coal cake from the first stage filter and the filtrate from the second stage filter is used as the wash water for the first stage filter. The wash filtrate from the first stage filter is used to make up the coal slurry in the slurry tank. The filtrate from the first stage filter, approximately a 50% caustic solution containing most of the sulfide salts, is fed to the regenerator for the reaction with lime. It is assumed that in all stages of filtration the coal will be dewatered to contain 0.5 lb solution per pound of coal. The washed coal cake from the filter containing 33% moisture is further dewatered to 18% moisture content using four 350 hp solid bowl centrifuges. The coal cake from the centrifuges contains 347 TPH coal with about 76 TPH moisture. The moisture on the coal cake at this point has been washed to contain about 370 lb/hr KOH, 260 lb/hr NaOH, and about 60 lb/hr sulfide salts. The coal cake from the centrifuges is then dried in a fine coal drier requiring about 635 MM Btu/hr of fuel assuming a 65% thermal efficiency. The drier will use coal and recovered volatiles as fuel to dry the product coal to three percent moisture. The overall sulfur content of the coal product including the residual sulfide salts is 0.26 wt. %.

3.2.3 Caustic Regeneration Section

In the caustic regeneration section the filtrate from the coal recovery section is reacted with slaked lime to precipitate the sulfide salts and regenerate NaOH and KOH via the following reactions:

The regeneration is carried out in two 25,000 gallon nickel reactors which provide 30 minute residence time for the slurry of lime and caustic. The overall heats reaction are exothermic, heating the slurry to about 330°F. Lime is fed to the reactors at the rate of 18.9 TPH from lime silos using conveyors and feeders. The slurry effluent from the reactors, containing unreacted $Ca(OH)_2$ and CaS, are fed to a 60 ft diameter thickener where the underflow is concentrated to a slurry which is 50 wt. % solids. The thickener overflow goes to the evaporator for concentration to 80 wt. % caustic. The thickener underflow is pumped to a two stage countercurrent vacuum filter system for dewatering and washing. The filter arrangement is similar to that used for the coal washing and requires about 250 HP for the filter drums and vacuum system. The system requires one ton of wash water per ton of solids and the solid cake from the system contains 35 wt. % moisture. The filtrate and wash filtrate from the system is collected and pumped to the evaporator with the thickener overflow. The solids from the system containing CaS and $Ca(OH)_2$ are sent to a disposal site. The ability to recover the sulfide salts in the manner described about will be tested in the laboratory, as there is some question as to the stability of the calcium sulfide under these conditions.

The diluted caustic solution from the filter and thickner are fed to a double effect nickel evaporator for concentration to 80 wt. % before recycle back to the caustic reactor. Each effect of the evaporator system will require about 7000 ft² of heat transfer surface and the overall steam requirement is estimated at 265,000 lb/hr. A package steam generator is provided to produce about 300,000 lb/hr of 600 psig steam at 680°F. The fired duty is estimated at 320 MM Btu/hr using fuel recovered from the reactor vent.

3.2.4 Heat Balance

The heat input to the plant as coal feed is equal to 10,266 MM Btu/hr based on 13,850 Btu/lb coal (moisture free). The heat output as product coal is equal to 9483 MM Btu/hr based 13,680 Btu/lb (moisture free). The difference of 783 MM Btu/hr is used in process and charged to the process. From the 783 MM Btu/hr the value of recovered volatile fuel is 718.6 MM Btu/hr; the remaining heat is evolved in the coal/caustic reaction and is consumed for heating purposes in the reactor. Table 5 below outlines the overall fuel requirements using the 718.6 MM Btu/hr recovered from the volatiles.

TABLE 5. FUEL REQUIREMENTS

<u>Heat Available</u>	MM Btu/hr
Volatiles	<u>718.6</u>
Total	718.6
<u>Heat Required</u>	
Caustic Heater	177
Coal Dryer	634
Steam Generator	<u>320</u>
	1,131
Additional Fuel Required	412.4

The additional fuel required will be provided by burning coal in the coal dryer in addition to the fuel recovered from the reactor vent.

3.3 EQUIPMENT LIST/CAPITAL COSTS

The capital equipment required for the Gravimelt process are listed along with estimated 1980 costs in Table 6. The following references are used as a basis for equipment sizing and costing information.

- Perry, "Chemical Engineers Handbook", 5th edition
- Guthrie, K.M., Process Plant Estimating, Evaluation, and Control; 1974
- Internal TRW Costing Data

All costs were escalated to mid 1980 using the Marshall and Swift cost index provided in Chemical Engineering publications. The costs listed in Table 6 are installed equipment costs which include the F.O.B. equipment cost, foundations, supports, piping, instrumentation, other miscellaneous equipment, and construction labor. The total installed cost for the Gravimelt process is \$50.6 MM. Using this number for installed cost the total invested capital is presented in Table 7. The total capital investment is equal to \$73.5 MM which is equivalent to \$73.50/KWe for the 1000 MWe power plant.

3.4 OPERATING COSTS

Table 8 presents the operating costs for the Gravimelt process based on 330 operating days per year. The costs are presented as annual costs and dollars per ton of product coal produced. An operating cost of coal at \$2/MM Btu is taken for the coal feed to the Gravimelt process which is in excess of the coal required for the 1000 MWe power plant. This excess coal is volatilized in the caustic reactor and recovered as fuel gas and liquid fuels which is used in the Gravimelt process for heating purposes.

The additional fuel required is listed as a utility cost for the 412.6 MM Btu/hr required as coal for the thermal dryer. The total non-capitalized operating cost for the Gravimelt process is \$37.6 million per year which is equal to \$13.70/ton of coal product. Using a capital charge

TABLE 6. CAPITAL COST ESTIMATES

	\$1,000 (1980)
<u>Reaction Section</u>	
Reactor w/mixers	6,083
Coal Silos	2,426
Conveyors	326
Feeders	111
Solid Separators	3,452
Pumps	278
Vent Compressor	898
Vent Condenser	351
Recycle Heater	3,280
Total Reactor Section	17,205
<u>Coal Recovery Section</u>	
Slurry Tank w/mixer	752
Overhead Condenser	437
Condensate Drum	70
2 Stage Filter System	3,900
Centrifuge	6,060
Coal Dryer	10,000
Interstage Slurry Tank w/mixer	279
Slurry Pumps	261
	21,759
<u>Caustic Regeneration Section</u>	
Lime Silos	474
Lime Conveyors	450
Lime Feeder	276
Regenerator	1,969
Thickner	1,240
Filter System	925

(CONTINUED)

TABLE 6. (CONTINUED)

<u>Caustic Recovery Section</u>	
Evaporator	4,275
Steam Generator	1,631
Pumps	388
	<u>11,628</u>
Total Installed Cost	\$50,592

TABLE 7. CAPITAL COST SUMMARY

	<u>\$ 10⁶</u>
Installed Equipment	50.59
Engineering & Design @ 10% of Capital Equipment	5.06
Contractors Overhead and Profit @ 22% of Capital Equipment	11.13
Contingency @ 10% of Installed Equipment & Engineering & Design & Overhead & Profit	6.68
	<u>—</u>
Total Invested Capital	73.46

equal to 20% of the total plant investment for depreciation and cost of capital the total amortized annual operating cost is \$52.3 million or \$19.05/ton of coal product.

TABLE 8. OPERATING COSTS

BASIS 330 Operating days/year	Annual Cost	
	\$ Million	\$/Ton Coal Product
Raw Materials		
Coal @ \$2/MM Btu	12.40	4.52
KOH @ \$378/ton	1.47	.54
NaOH @ \$160/ton	0.44	.16
Lime @ \$32/ton	4.79	1.74
Solids Disposal	2.62	.95
Utilities		
Power @ 2.5¢/KW	1.71	.62
Fuel @ \$2/MM Btu	6.53	2.38
Boiler Feedwater @ 65¢/1000 lb	0.08	.03
Process Water @ 40¢/1000 gal	0.13	.05
Cooling Water @ 4.5¢/1000 gal	0.72	.26
Labor 15 positions @ \$8/hr	1.05	.38
Supervision @ 15% of operating labor	0.16	.06
General Overheads @ 60% of Labor & Supervision	0.73	.27
Maintenance	2.20	.80
@ 3% of Total Plant Investment		
Taxes and Insurance	2.20	.80
@ 3% of Total Plant Investment		
Operating Supplies	0.39	.14
@ 20% of Operating Labor		
Total Non-Capitalized Operating Cost	37.62	13.70
Capital Charges @ 20% Total Plant Investment	14.69	5.35
Total Amortized Operating Cost	52.31	19.05

4.0 WORK TO BE UNDERTAKEN DURING THE NEXT REPORTING PERIOD

The following experimentation is scheduled for the July through September quarter:

- 1) Reaction of molten caustic with model organic and inorganic compounds to identify likely desulfurization product species,
- 2) Initial material balanced runs for the desulfurization of float and sink coal fractions, and
- 3) Measurement of key missing conceptual engineering design information including the effect of caustic and coal water content on desulfurization.

The following engineering studies will be undertaken during this reporting period:

- 1) Refining of equipment cost information for a subsequent revised engineering case, and
- 2) Consultation on the laboratory effort regarding engineering interpretation material balanced and mechanism data.