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COMPARISON OF BERC RE-REFINING PROCESS WITH ACID/CLAY/DISTILLATION PROCESS

By

Richard J. Bigda & Associates
Prepared for DOE Under P. O. No. EY-77-X-19-0237

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Bartlesville Energy Research Center
Department of Energy
Bartlesville, Oklahoma

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Engineering and design studies
Prepared for the Department of Energy
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EXECUTIVE SUMMARY

This report compares the economics of acid/clay re-refining with the economics of the BERC solvent re-refining process. The costs of re-refining using the BERC process have been studied in a previous report entitled "Predesign Cost Estimate for Re-refined Lube Oil Plant" prepared for the Bartlesville Energy Research Center. Many of the basic assumptions such as plant size, unit capacities, etc. used in that report have been used in this document.

Part I of this report compares both technologies with vacuum distillation as is anticipated with the BERC process. The cost of processing a gallon of re-refined oil with acid/clay/distillation technology was found to be 48.7 cents per gallon compared to 40.1 cents per gallon using the BERC solvent/distillation process.

Part II of the report compares acid/clay technology as is now commonly used with the BERC solvent system, without using vacuum distillation for either re-refining scheme. Cost for processing a gallon of oil using acid/clay without vacuum distillation was found to be 45.8 cents per gallon compared to 37.9 cents per gallon for the BERC solvent system without vacuum distillation. It should be noted that the BERC process is less expensive than either acid/clay process.

COMPARISON OF BERC RE-REFINING PROCESS WITH ACID/CLAY/DISTILLATION PROCESS

Introduction:

The development of a new process always brings up the fundamental question. Is the new process an improvement over the old? This cannot be absolutely proved until a side-by-side demonstration and comparison can take place. The BERC laboratories have developed a lube oil re-refining process which utilizes solvent extraction to separate the lube oil stock from various sludges and contaminants. The most widely used commercial process for re-refining waste lube oils involves treatment with sulfuric acid followed by clay contacting. This process has been in use for about four decades with little change. The majority of the re-refiners have little technical knowledge and no research facilities to aid them in developing a more efficient process. The present system has evolved through years of secretive trial and error - each refiner discovering and keeping certain process tricks confidential.

Most such re-refineries are small, generally put together with little engineering knowledge with a variety of used equipment. The refineries are frequently labor-intensive and thermally inefficient. It would be wholly unfair to compare these actual re-refineries with a new process on an "as is" basis; therefore, the comparison in this analysis is made by putting both processes on an equivalent basis, that is, a new plant and equipment with similar labor and material costs. Though there will be inaccuracies in such an analyses, it is expected that this type of review will serve to illustrate where economic disparities exist. In the future if new re-refineries are built they will have to invest considerably more money than they have in the past. Undoubtedly many new re-refiners will continue to utilize used equipment which will reduce their capital investment and therefore improve their overall costs. Other than certain efficiencies which might be gained through the use of better equipment, operating costs such as the cost of waste oil, sulfuric acid, clay, solvents, etc. will be similar. Certain plant locations will be favored relative to specific costs. For example, an acid/clay treatment re-refiner located near an inexpensive source of sulfuric acid will have an advantage over one who has to pay the expense of trucking his acid a long distance. Similarly, some areas will be favored by the low cost of their waste oil gathering system. None of these variations are predictable and for the purposes of this analysis, all will be put on the same cost bases. The reader is presented, for the purpose of cost comparison, data from an earlier document prepared for the Bartlesville Energy Research Center, ERDA, entitled "Predesign Cost Estimate for Re-refined Lube Oil Plant" by Richard J. Bigda & Associates, dated July 30, 1976. That report examined in detail the costs associated with the BERC re-refining process. The plant and equipment cost estimates used for that plant will be used for comparison and as a basis for costing the acid/clay treatment plant.

Five acid/clay re-refiners were visited early in 1977 to obtain operating information. Basically their processes were similar, but there were variations in the quantity of acid and clay that was used to treat a batch of waste oil. There is no standard treatment as the quality of the waste oil varies. In some situations the time and temperature of treatment also vary, and a batch is complete based upon the judgment of the operator, rather than on analytical testing. The comparison presented here serves to show the differences between the new solvent/distillation process developed by BERC and the common acid/clay treatments that have been used for many years.

Part I of this report compares the BERC solvent/distillation process with an acid/clay process using vacuum distillation and yielding several base stocks with narrow boiling point ranges, rather than one lube oil cut as is done in most acid/clay re-refining operations. Part II of this report compares the cost of using solvent settling and clay contacting with the acid treating and clay contacting now commonly used to produce one wide range base stock.

The inclusion of vacuum distillation in a re-refining scheme offers several advantages: vacuum distillation provides base stocks of uniform viscosity ranges, reduces the amount of clay necessary in clay contacting, improves the color of base stocks, and eliminates some oxidation products in the residual fuel cut. While recommending the inclusion of vacuum distillation in a re-refinery, it is sometimes helpful in comparing costs to examine both processes without vacuum distillation since few present re-refineries distill their oils. Part II of this report contains this comparison.

PART I

ANALYSIS OF THE ACID/CLAY CONTACTING PROCESS

Early in 1977 five acid/clay contacting re-refiners were visited to learn their methods of operation. The objective was to learn of the operating variables, rather than to determine the operating costs of the individual companies. The companies were very frank in revealing information, but as is understandable, they would not want to have the economics of their process published for their competitors to review. For comparison, their procedures and manufacturing costs were adjusted by using standard values for labor and materials. This illustrates variations and problem areas. Two of the plants visited were undergoing process modification and though vital information was gained, they will not be compared here as their operating conditions were not normal.

Exhibit 1 is a flow sheet illustrating the acid/clay contacting process followed by vacuum distillation of the lube oil mixture. Exhibit 2 shows the BERC re-refining process. The distillation step is not usual with the acid/clay re-refiners, but it is an important element of the BERC process and provides a product consisting of several lube oil fractions which are identical to virgin lube oil blending stocks made by major refineries. This

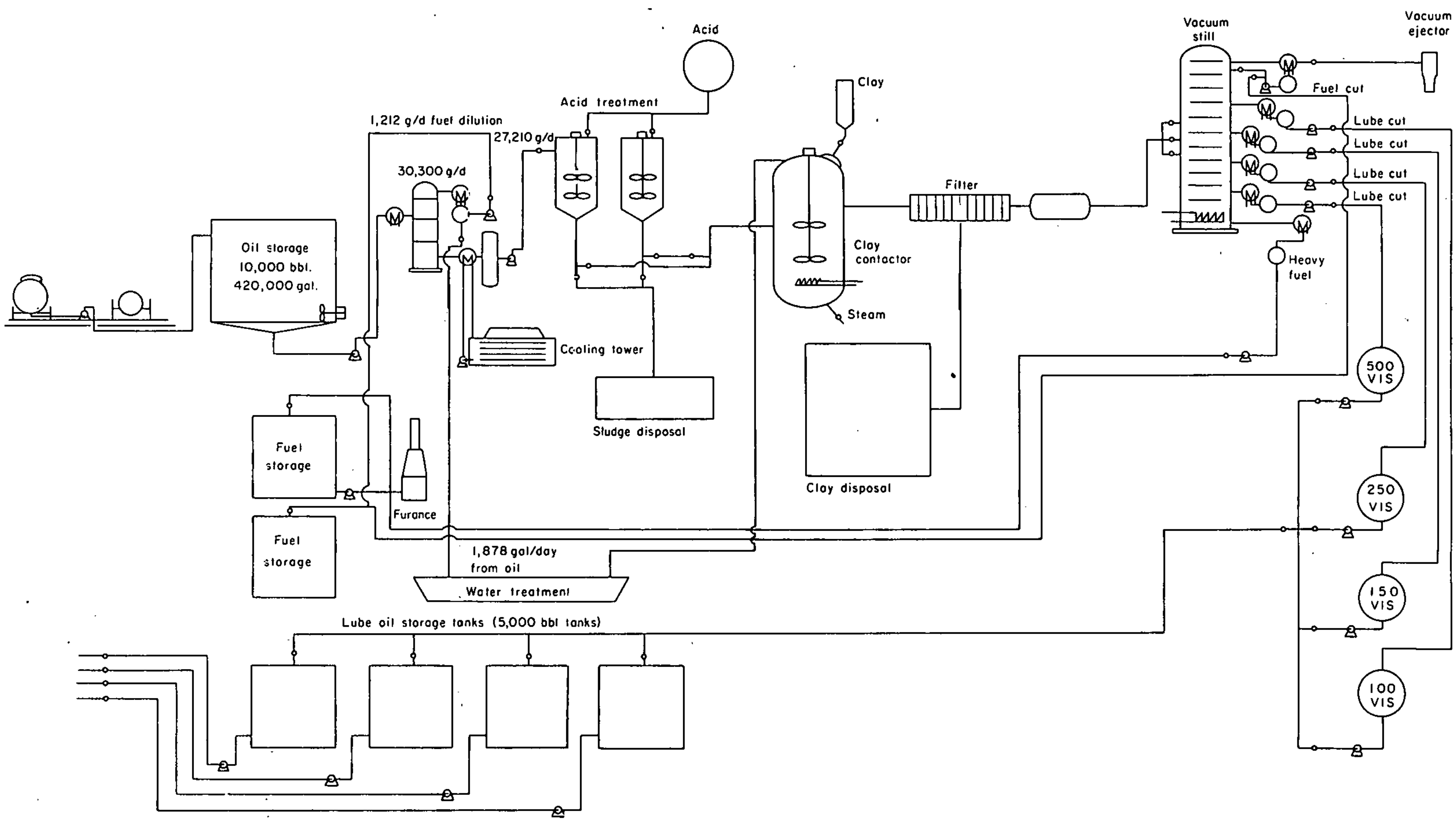

EXHIBIT 1.-Acid/clay re-refining process with vacuum distillation.

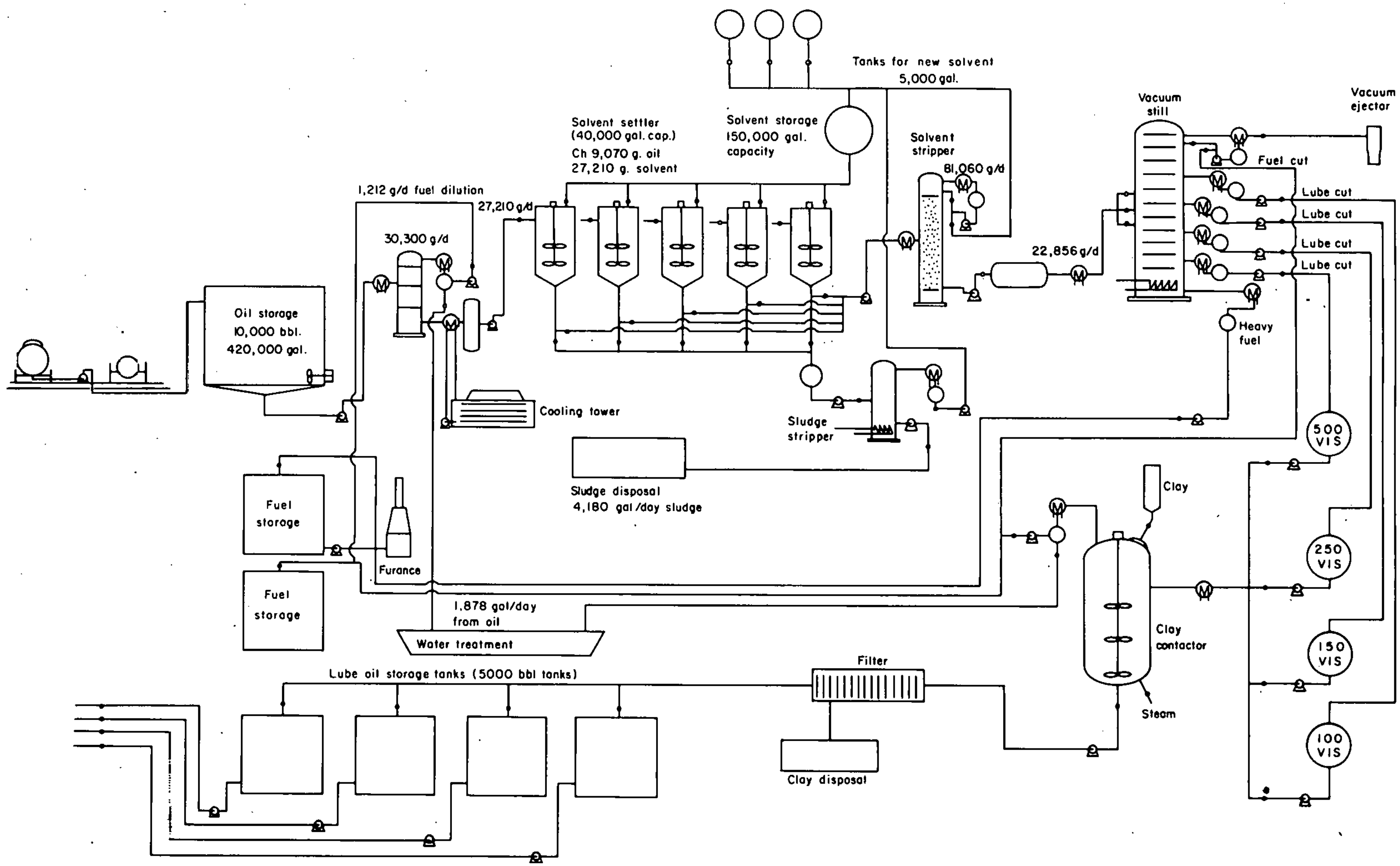

EXHIBIT 2.-BERC re-refining process.

added vacuum distillation, therefore, provides a re-refiner with the same flexibility to blend motor oil that is enjoyed by a major refiner. The difference in this process versus the BERC solvent treating refinement is that instead of treating the dehydrated waste oil with solvent to effect the separation of the sludges and additives, the dehydrated oil is cooled and mixed with 5% to 6% of concentrated sulfuric acid.

After vigorous mixing the acid-oil mixture is allowed to settle for 12 to 48 hours, depending on the rate of separation. The tarry, acid sludge is drawn off the bottom of the settling units and must be disposed of. As pollution control laws become more strict, it is becoming more difficult and more costly to dispose of these hazardous acid sludges. After separation of the sludge from the oil, the oil is contacted with approximately one pound of clay per gallon of oil. This oil/clay slurry is then reheated to 500-600° F for several hours to neutralize any excess acid and to reduce the color and odor of the oil. Following filtration to remove the clay, the oil would then be subject to vacuum distillation to separate it into its viscosity components. From this point onward, the process is again the same as that built by the BERC laboratories. Should the acid/clay treated oil be subjected to vacuum distillation, it is not certain whether it will have to again be re-clay contacted to improve its color and odor before marketing. For the sake of this comparison it is assumed that this additional clay treatment will not be necessary. If it is, an added cost must be applied to the final product.

Exhibit 3 illustrates a comparison of three operating acid/clay contacting re-refineries with a hypothetical refinery developed by the EPA technical staff, along with a brief comparison of the quantities and conditions employed. It is interesting to note the variation in the quantity of acid used to produce 1,000 gallons of re-refined oil. Note also that the amount of clay can vary by a factor of 100%. Some operations use sodium hydroxide or ammonia to aid in the neutralization of acid waste and vapors which cause corrosion. Most plants are able to utilize the light fuels stripped in the initial dehydration step to provide energy for process heat.

The quantity of electricity used is indeterminate since the new plant, with all of its pumps and equipment, is not operating. Cost-wise, only a negligible amount of water is used. One plant did use some natural gas as a supplement, but as mentioned previously this will probably not be necessary. The labor required to process the daily output of each plant varies considerably and is not necessarily in proportion to the quantity of oil produced. A much larger plant could be made more efficient and, therefore, process much more with less labor. In none of the plants investigated, nor in the theoretical EPA design or the BERC design, is labor utilized to its fullest extent.

The yields of re-refined lube oils relative to the waste oil feed actually varies from batch to batch. Frequently the batches are contaminated with larger amounts of water or other types of oils or solvents which greatly reduce the yield and in many cases consume more acid and clay. Wise operators try to control the waste oil which they purchase by buying only from reliable collectors or by collecting it themselves. Another approach

EXHIBIT 3

COMPARISON OF QUANTITIES AND CONDITIONS PER 1,000 GALLONS RE-REFINED OIL

	A	B	C	EPA	BERC
Capacity, g WO/d	3,000	9,000	16,000	20,000	30,000
Cost of Waste Oil, $	0.12	0.15	0.10-0.15	0.03	0.10
Quantity of Acid, #	1,400	727	938	1,000	0
Cost of Acid, $/T		96	48		0
Quantity of Clay, dlvd. #	357	397	838	400	243
Cost of Clay, $/T	160	160	70		
NaOH, #		274			-
Cost of NaOH, $/T		140			-
NH_3		?			-
Cost of NH_3, $		9.00			-
Electricity, $	7.14	2.86	4.16	3	
Water, $				0.01	
Gas, $	0	0	12.20	0	0
Labor, workers	6	8	5	8	9
Sales re-refined oil, $/gal.	1.00	0.57-1.00	0.84-1.20		
Dehydration, T °F		610			
Acid Treating, T °F		90			
Clay Contacting, T °F		600			
Sludge Disposal, $	17.85	19	6.92	5	5
Caustic Water Disposal, $		4.76			
Refined Oil, g/d	1,680	6,300	13,000		
Yield, %	60	60-75	75	75	70
Estimated Investment, $	1,500,000	800,000	1,500,000	1,061,000	

MANUFACTURING COST USING STANDARD COSTS
$/1,000 gallons Re-refined Oil

	Unit Cost	A	B	C	EPA	Avg. Acid/ Clay	BERC
Used Oil	$0.15/g	150.00	150.00	150.00	150.00	150.00	150.00
Acid, 98% H_2SO_4, 15.27#/g	$48/T	33.60	17.45	22.50	24.00	24.40	-
Clay	$160/T	28.56	31.75	67.00	32.00	39.83	19.44
NaOH	$140/T	-	19.24	-	-	7.00	-
NH_3				9.00	-		-
Solvent	$1.21/G						24.11
Supplies							
Labor	$5/hr	95.24	51.00	15.38	21.33	45.73	17.50
Gas		-	-	12.20	-		-
Water							
Electricity		7.14	2.86	4.16	3.00	4.30	
Maintenance							
Finished Oil, note conv.		60%	68%	75%	75%	68%	70%
Waste Disposal		17.85	23.76	6.92	5.00	16.17	5.00

would be to have a large volume of oil in storage which would tend to reduce variations and provide for a more homogeneous feedstock. The re-refiners claim yields are between 60% and 75%. For purposes of this study, the acid/clay process was considered to give 65% yields and the BERC solvent process 70% yields. This is based on the fact that a mixture of acid and heavy oils is difficult to settle and two to five times more clay is used in the acid/clay contacting process where additional lube oil losses could occur.

Equipment Variations

Relative to the differences in the type of equipment used for both processes, first it can be noted that the beginning of the process is the same for either operation. The waste oil is strained, stored, dehydrated, stripped of light naphthas and gasolines and then sent to the treater for acid or solvent mixing and settling. Similar types of equipment could be used for either process. That is, the use of mild steel tanks in which the concentrated acid or solvent is intimately mixed with the dehydrated waste oil and allowed to settle. The conical bottoms on the tanks would facilitate separation of either the acid or the solvent. Depending upon the time necessary for settling, two or more batch treatment tanks may be desired. Advantage was given to the acid treatment process in this case as only two mixing tanks and separators were included in the equipment list for the acid/clay process; whereas, four have been included for the solvent treatment.

Another plus for the acid/clay system is that no solvent recovery distillation units are needed. Further, no solvent storage or solvent inventory is needed, which should reduce the cost in favor of the acid/clay. However, probably a larger clay contacting system may be needed and as mentioned before, perhaps another clay contactor will be required to finish the oil after distillation. In this predesign the latter has not been included and for the sake of comparison the similar clay contacting systems were used in both cases. If some larger unit is needed for the additional clay, the incremental cost would be relatively small. During the inspection trips of the acid/clay contacting re-refiners, it was noticed that considerable corrosion was evident in tanks and transfer lines. As no corrosive acid will be used in the solvent system, it is expected that the maintenance for the BERC process will be less. Maintenance and supplies for the acid/clay process have arbitrarily been doubled relative to the normal five per cent.

Disposal of the acid sludge is a very critical problem and the difficulty of finding a place to dispose of this material plus the high cost charged for acid disposal is definitely a negative factor. The average cost of disposal approaches $15.00 per thousand gallons of re-refined oil produced. One operator said that just a couple of years ago he paid $8.00 for dumping 3,000 gallons of sludge. Recently he was refused at two dumps and the third and last wanted $1,000 per load. Some research is necessary in this area to alleviate the problems of acid sludge disposal.

PREDESIGN PROCESS EQUIPMENT COSTS

It will be noted that there are only a few changes from the predesign process equipment costs presented in the Bigda,[1] July 1976, report. Predesign cost estimates for the acid/clay distillation process are shown in Exhibit 4; comparative costs for the BERC process are seen in Exhibit 5. The solvent treatment system has been reduced by two units and converted to an acid treatment system. The solvent strippers have been eliminated including the sludge stripper. The vacuum distillation units are intact as are the intermediate lube storage, the clay contactor, filter and finished lube storage. Of course, the solvent storage tanks have been deleted. Relative to heating capacity in the acid/clay process, the thermal load of the solvent recovery system has been deleted, but in its place additional duty for the prolonged high-temperature clay contacting process has been added. For these capacity changes the equipment costs for either a slightly smaller or slightly larger unit would be approximately the same. The total cost of equipment is then estimated at $1,476,600 as compared to the BERC/ERDA solvent system which would cost $1,963,000. This is reflected in Exhibit 6 entitled "Capital Investment Comparison".

Working Capital

Working capital has also been compared and the obvious differences are for solvent and acid inventory, and twice as much clay is needed for the acid/clay process. The total capital for the acid/clay process is approximately $500,000 less. Based on the size of the plant (30,000 gallons a day or 10,000,000 gallons a year), the manpower requirements would be the same (see Exhibit 7); therefore, the payroll for either process would be comparable.

Manufacturing Costs

The manufacturing costs for the acid/clay/distillation and the solvent extraction/distillation process are compared (Exhibit 8), using the same costs for the waste oil (15 cents/gal) and other similar costs where the process is nearly the same. Note that maintenance costs for the acid system have been increased to 10% of fixed capital versus 5% for the solvent distillation process. An analysis of these costs is revealing. Solvent loss is expected to add about $496 a day, but sulfuric acid costs will be $732. Clay costs will be about three times as high for the acid/clay contact system as for the BERC process. The disposal of oily clay presents no particular problem. It can be dumped in landfills; however, the acid sludge will add about $315 a day. No cost has been given for the

[1] BERC/RI-77/11 - "Predesign Cost Estimate for Re-Refined Lube Oil Plant" by Richard J. Bigda and Associates. Prepared for ERDA Under Contract No. BE-60-P-2688. ERDA, 1977, 17 pp.

EXHIBIT 4

ACID/CLAY/DISTILLATION PREDESIGN PROCESS EQUIPMENT COSTS

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Oil Unloading			
Oil Storage Tank, 2	200,000 g	$ 45,000	$ 90,000
Side Mixers, 2	5 hp	3,000	6,000
Unloading Pump	100 gpm, 1.5 hp	2,600	2,600
			$ 98,600
Fuel Flash			
Oil Feed Pump	25 gpm	1,900	$ 1,900
Fuel Flash Heat Exchanger	330 ft^2	15,800	15,800
Fuel Flash Drum	3' x 5'	5,000	5,000
Condenser	40 ft^2	2,500	2,500
Accumulator	100 g	1,000	1,000
Lt. Fuel Pump	3 gpm	800	800
Crude Lube Cooler	511 ft^2	21,300	21,300
			$ 48,300
Acid Treatment			
Oil to Treater Pump	20 gpm	1,900	$ 1,900
Acid Pump to Treater	60 gpm	2,500	2,500
Acid Treaters, 2	40,000 g	20,000	40,000
Agitators, 2	3 hp	3,200	6,400
			$ 50,800
Clay Contactor			
Clay Contactor	20,000 g	15,000	$ 15,000
Agitator	3 hp	3,200	3,200
Clay Hopper	50 ft^2	800	800
Lube Heater	788 ft^2	30,000	30,000
Condenser		500	500
Pump - Water	2 gpm	600	600
Product Pump	90 gpm	2,600	2,600
			$ 52,700
Filter			
Filter, Rotary	10' dia. x 16' + aux. equipment	200,000	$ 200,000
			$ 200,000

EXHIBIT 4 (Continued)

ACID/CLAY/DISTILLATION
PREDESIGN PROCESS EQUIPMENT COSTS

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Vacuum Distillation			
Vac. Still Feed HX	75 ft^2	$ 4,800	$ 4,800
Vacuum Ejector	1#/hr, 5.0 mm	3,500	3,500
Feed Pump	20 gpm	1,900	1,900
Vac. Still	4' dia. x 40' + 24 trays	82,000	82,000
Reboiler	2000 ft^2	51,000	51,000
Reflux Cond., Lt Oil	26 ft^2	1,500	1,500
Accumulator	100 g	1,000	1,000
Reflux Pump	2 gpm	800	800
Lube Condenser, 100 V	55 ft^2	3,500	3,500
Accumulator	100 g	1,000	1,000
Pump	5 gpm	800	800
Lube Condenser, 150 V	53 ft^2	3,500	3,500
Accumulator	100 g	1,000	1,000
Pump	5 gpm	800	800
Condenser, 250 V	73 ft^2	4,800	4,800
Accumulator	100 g	1,000	1,000
Pump	6 gpm	800	800
Condenser, 600 V	22 ft^2	1,500	1,500
Accumulator	100 g	1,000	1,000
Pump	2 gpm	1,000	1,000
Hvy Gas Oil Condenser	14 ft^2	700	700
Accumulator	100 g	1,000	1,000
Pump	2 gpm	1,200	1,200
			$ 170,100
Intermediate Lube Storage			
Storage Tank, 100 V	25,000 g	8,000	$ 8,000
Pump	90 gpm	2,600	2,600
Storage Tank, 150 V	25,000 g	8,000	8,000
Pump	90 gpm	2,800	2,800
Storage Tank, 250 V	25,000 g	8,000	8,000
Pump	90 gpm	2,800	2,800
Storage Tank, 600 V	25,000 g	8,000	8,000
Pump	90 gpm	2,800	2,800
			$ 43,000

EXHIBIT 4 (Continued)

ACID/CLAY/DISTILLATION
PREDESIGN PROCESS EQUIPMENT COSTS

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Finished Lube and Solvent Storage			
Lube Storage Tanks, 4	200,000 g	$ 39,000	$ 156,000
Pumps, 4	100 gpm	2,600	10,400
Fuel Storage, 3	40,000 g	9,000	27,000
Pump Loading	100 gpm	2,600	2,600
Acid Storage	50,000 g	11,000	11,000
Pump	60 gpm	2,400	2,400
			$ 209,400
Each Separate			
Boiler, Complete	200 psi, 10,000 #/hr.	$ 77,000	$ 77,000
Hot Oil Furnace, Complete Direct (Dow Therm X 1.3)	20 M Btu/hr, 700° F	$ 277,000	$ 277,000
Cooling Water, Complete	1400 gpm, 4,000,000 Btu/hr.	$ 95,500	$ 95,500
Water Treatment			
Clay Disposal			
Sludge Disposal			
TOTAL EQUIPMENT COST			$1,322,400

EXHIBIT 5

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PREDESIGN PROCESS EQUIPMENT COSTS

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Oil Unloading			
Oil Storage Tank, 2	200,000 g	$ 45,000	$ 90,000
Side Mixers, 2	5 hp	3,000	6,000
Unloading Pump	100 gpm, 1.5 hp	2,600	2,600
			$ 98,600
Fuel Flash			
Oil Feed Pump	25 gpm	1,900	$ 1,900
Fuel Flash Heat Exchanger	330 ft^2	15,800	15,800
Fuel Flash Drum	3' x 5'	5,000	5,000
Condenser	40 ft^2	2,500	2,500
Accumulator	100 g	1,000	1,000
Lt. Fuel Pump	3 gpm	800	800
Crude Lube Cooler	511 ft^2	21,300	21,300
			$ 48,300
Solvent Treatment			
Oil to Treater Pump	20 gpm	1,900	1,900
Solvent Pump to Treater	60 gpm	2,500	2,500
Solvent Settler, 4	40,000 g	20,000	80,000
Agitators	3 hp	3,200	16,000
			$ 100,400
Solvent Stripper			
Pump Solvent Stripper	80 gpm	$ 2,600	$ 2,600
Feed Heater - Sol. St.	790 ft^2	30,300	30,300
Solvent Stripper	4' dia. x 30' packed Berl saddles	30,000	30,000
Reflux Condenser	400 ft^2	16,500	16,500
Accumulator	100 g	1,000	1,000
Reboiler	2700 ft^2	70,000	70,000
Pump Reflux	90 gpm	2,600	2,600
Pump Stripper Bottoms	20 gpm	1,900	1,900
			$ 154,900

EXHIBIT 5 (Continued)
BERC
PREDESIGN PROCESS EQUIPMENT COSTS Continued)

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Sludge Stripper			
Sludge Accumulator	5000 g	$ 3,000	$ 3,000
Sludge Pump to Stripper	80 gpm	3,000	3,000
Sludge Pump	80 gpm	3,000	3,000
Sludge Overhead Condenser	6 ft^2	500	500
Accumulator	100 g	1,000	1,000
Sludge-Solvent Pump	3 gpm	800	800
Reboiler	107 ft^2	6,800	6,800
Sludge Cooler		7,300	7,300
Sludge Stripper	2' x 5' packed	2,900	2,900
			$ 28,300
Vacuum Distillation			
Vac. Still Feed HX	75 ft^2	4,800	$ 4,800
Vacuum Ejector	1#/hr, 5.0 mm	3,500	3,500
Feed Pump	20 gpm	1,900	1,900
Vac. Still	4' dia. x 40' + 24 trays	82,000	82,000
Reboiler	2000 ft^2	51,000	51,000
Reflux Cond., Lt Oil	26 ft^2	1,500	1,500
Accumulator	100 g	1,000	1,000
Reflux Pump	2 gpm	800	800
Lube Condenser, 100 V	55 ft^2	3,500	3,500
Accumulator	100 g	1,000	1,000
Pump	5 gpm	800	800
Lube Condenser, 150 V	53 ft^2	3,500	3,500
Accumulator	100 g	1,000	1,000
Pump	5 gpm	800	800
Condenser, 250 V	73 ft^2	4,800	4,800
Accumulator	100 g	1,000	1,000
Pump	6 gpm	800	800
Condenser, 600 V	22 ft^2	1,500	1,500
Accumulator	100 g	1,000	1,000
Pump	2 gpm	1,000	1,000
Hvy Gas Oil Condenser	14 ft2	700	700
Accumulator	100 g	1,000	1,000
Pump	2 gpm	1,200	1,200
			$ 170,100

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Intermediate Lube Storage			
Storage Tank, 100 V	25,000 g	$ 8,000	$ 8,000
Pump	90 gpm	2,600	2,600
Storage Tank, 150 V	25,000 g	8,000	8,000
Pump	90 gpm	2,800	2,800
Storage Tank, 250 V	25,000 g	8,000	8,000
Pump	90 gpm	2,800	2,800
Storage Tank, 600 V	25,000 g	8,000	8,000
Pump	90 gpm	2,800	2,800
			$ 43,000
Clay Contactor			
Clay Contactor	20,000 g	15,000	$ 15,000
Agitator	3 hp	3,200	3,200
Clay Hopper	50 ft^2	800	800
Lube Heater	788 ft^2	30,000	30,000
Condenser		500	500
Pump - Water	2 gpm	600	600
Product Pump	90 gpm	2,600	2,600
			$ 52,700
Filter			
Filter, Rotary Vacuum Drum	10' dia. x 16' + aux. equipment	200,000	$ 200,000
			$ 200,000
Finished Lube and Solvent Storage			
Lube Storage Tanks, 4	200,000 g	39,000	$ 156,000
Pumps, 4	100 gpm	2,600	10,400
Fuel Storage, 3	40,000 g	9,000	27,000
Pump Loading	100 gpm	2,600	2,600
Solvent Storage	150,000 g	28,000	28,000
Separate Solvents, 3	10,000 g	3,500	10,500
Pump	60 gpm	2,400	2,400
			$ 236,900

EXHIBIT 5 (Continued)
BERC
PREDESIGN PROCESS EQUIPMENT COSTS (Continued)

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Each Separate			
Boiler, Complete	200 psi, 22,000 #/hr.	$ 134,000	$ 134,000
Hot Oil Furnace, Complete Direct (Dow Therm X 1.3)	20 M Btu/hr, 700° F	277,000	$ 277,000
Cooling Water, Complete	1400 gpm, 14,000,000 BTU/hr.	221,000	$ 221,000
Water Treatment			
Clay Disposal			
Sludge Disposal			
TOTAL EQUIPMENT COST			$1,765,200

EXHIBIT 6

CAPITAL INVESTMENT COMPARISON

	Acid/Clay/ Distillation	Solvent/ Distillation
Installed Equipment	$1,322,400	$1,765,200
Building $20/ft^2 x 1,000 ft^2	20,000	20,000
Land & Improvements	Unknown	Unknown
Utilities	Unknown	Unknown
TOTAL	$1,342,400	$1,785,200
Engineering & Construction, 10%	134,200	178,000
TOTAL FIXED COST	$1,476,600	$1,963,000

Working Capital:

	Acid/Clay/ Distillation	Solvent/ Distillation
Waste Oil Inventory, one mo. @ $0.15/g	$ 135,000	$ 135,000
Solvent Inventory	-	215,800
Acid Inventory	14,600	-
Clay Inventory	24,000	12,000
Re-refined Oil Inventory, one mo. @ $0.40/g	240,000	240,000
Extended Credit, one mo. sales @ cost	240,000	240,000
Available Cash, one mo. mfg. expense	75,000	75,000
TOTAL WORKING CAPITAL	$ 728,600	$ 917,800
TOTAL CAPITAL REQUIRED	$ 2,205,200	$ 2,880,800

EXHIBIT 7

LABOR REQUIREMENTS

	Men
Day:	
Shipping, receiving and utilities	1
Operator: Acid treatment + stills	1
Operator: Clay contactor + filter	1
Maintenance	2
Supervisor	1
	6
Night:	
Operators - 2 (Three Shifts)	6
Administration:	
Manager	1
Clerk	1
Sales	1
	3

Total Personnel:

12 Hourly x 40 hr/week x $5 x 52 weeks	$124,800/year
3 Salary x $20,000/y	$ 60,000/year

EXHIBIT 8

MANUFACTURING COST PER DAY
350 d/y

	Acid/Clay/ Distillation	Solvent/ Distillation	
Used Oil @ $0.15/g, 30,000 g	$4,500	$4,500	
Solvent @ $1.21/g	-	496	
Sulfuric Acid, 98% @ $48/T	732	-	
Clay @ $160/T	1,181	400	
NaOH @ $140/T	210	0	
Sludge Disposal	315	100	
Supplies, 15% of Maintenance Costs	63	42	
Labor @ $5/hr	357	357	
Supervision: See Administration			
Utilities, estimated	150	150	
Maintenance, 10% of Fixed Capital	422	280	5%
DIRECT MANUFACTURING COST	$7,930	$6,325	
Overhead, 50% of Labor	$ 178	$ 178	
Laboratory, 10% of Labor	36	36	
Shipping - unknown	-	-	
INDIRECT MANUFACTURING COST	$ 214	$ 214	
Depreciation, 10% of Fixed Capital	$ 422	$ 561	
Property Taxes, 2% of Fixed Capital	84	112	
Insurance, 1% of Fixed Capital	42	56	
FIXED MANUFACTURING COST	$ 548	$ 729	
Administration & Sales	$ 171	$ 171	
Expense: See Overhead	-	-	
Finance, 10% Total Capital	630	823	
GENERAL EXPENSE	$ 801	$ 994	
TOTAL MANUFACTURING COST/DAY	$9,493	$8,263	
19,500 g/d, 65% conversion, cost/gallon	$ 0.487		
20,570 g/d, 70% conversion, cost/gallon		$ 0.401	

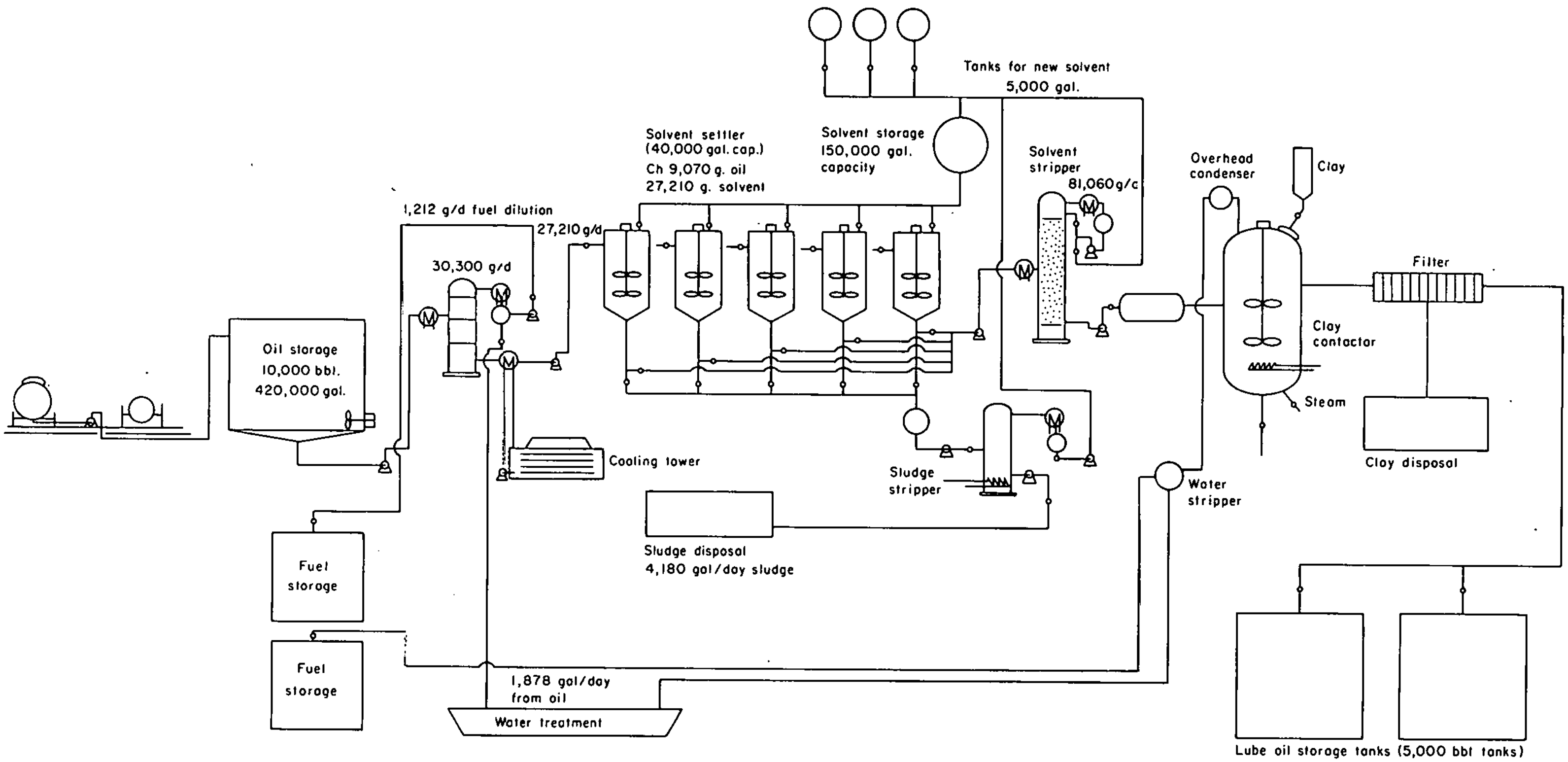

EXHIBIT 9.-Acid/clay re-refining without distillation.

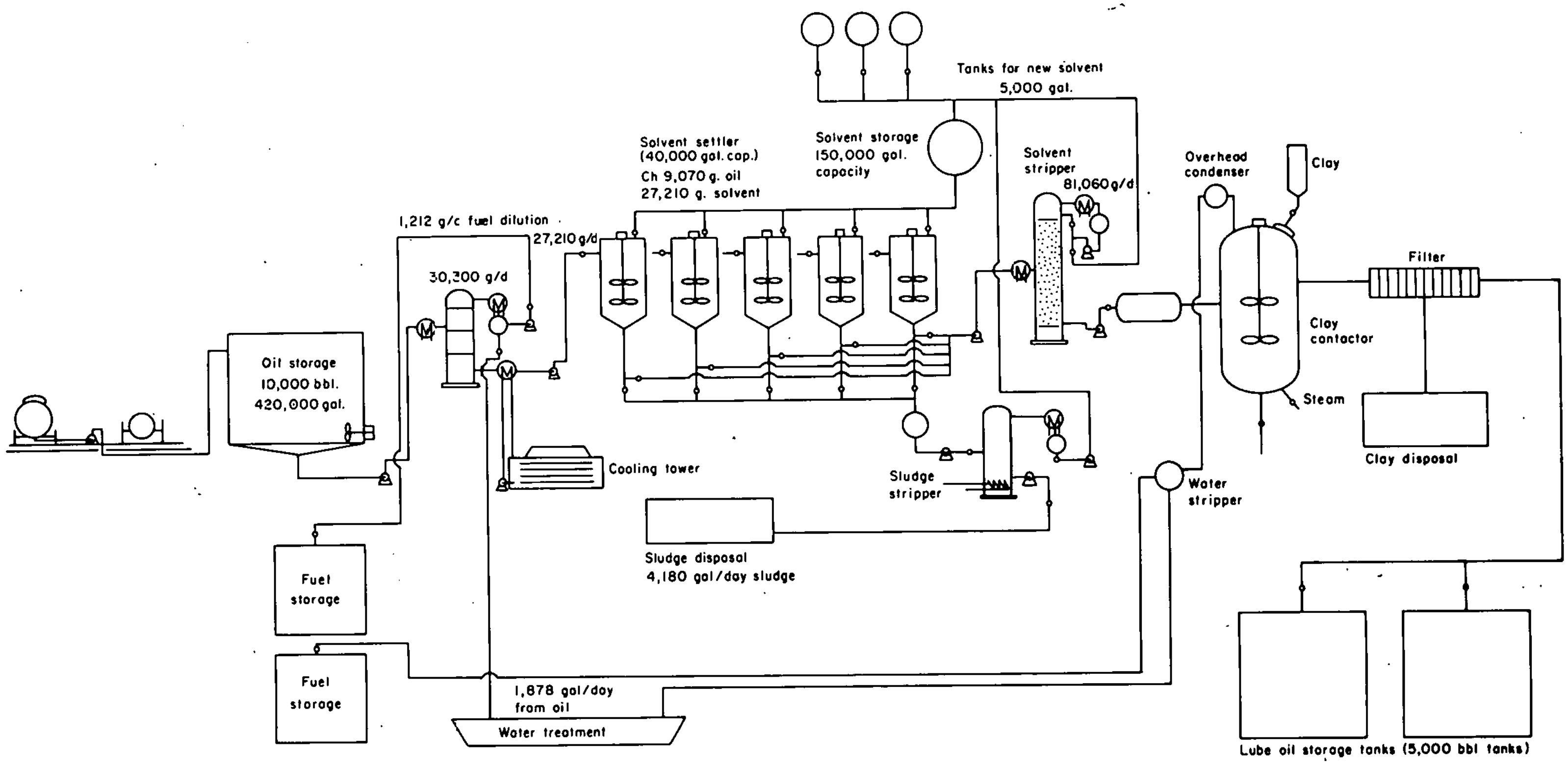

EXHIBIT 10.-BERC process without distillation.

disposal of the clay, but it will always be several times higher than for the solvent system. Maintenance will be $142 higher for the acid system even though the solvent process has more costly equipment. Naturally, depreciation, property taxes and insurance, which are functions of fixed capital, will be lower for the acid process. The finance charge on the higher cost solvent/distillation equipment will add $193 to solvent refining.

The total manufacturing cost per day is estimated $1,231 higher for the acid/clay system. When considering the lower conversion, it was found that total cost would approximate 49 cents a gallon for the acid/clay and 40 cents a gallon for the solvent/distillation process. This 22% difference in operating costs is, of course, extremely significant and indicates that the BERC process has a considerable advantage over the old acid/clay re-refining system. The increased capital investment will more than pay for itself through improved process economics. Although these cost estimates are preliminary, they indicate the probable economic superiority of the solvent refining process. This, coupled with the environmental pluses, should encourage continued research and development of the solvent distillation system developed by BERC/ERDA.

PART II

COMPARISON OF ACID/CLAY AND THE BERC SOLVENT SETTLING PROCESS WITHOUT VACUUM DISTILLATION

Several changes are necessitated by the removal of vacuum distillation from a processing scheme. These can be seen in Exhibits 9 and 10. When the vacuum distillation unit is removed the hot oil furnace can also be removed and replaced with a small direct fired heater for use in clay contacting. A larger condenser and oil separator must be added to remove a light gas-oil product which will be brought overhead by steam in the contactor. It is assumed that higher temperature will be necessary during clay contacting to make a product with acceptable color and other physical properties. Less tankage is required for the finished product because the base stocks produced previously have been combined into one product, cooling water requirements have been reduced, and minor adjustments in utility costs, etc. can be expected with the vacuum distillation unit removed.

The total fixed cost for equipment and installation has been lowered substantially, from $1,476,600 for the acid/clay process with distillation to $899,700 when distillation is removed. Total fixed cost for the BERC process was lowered from $1,963,000 to $1,416,700 by removing vacuum distillation. A detailed list of the equipment necessary for each re-refining method is shown in Exhibits 11 and 12, where possible equipment similar to that used in Part I of this report was utilized. Exhibit 13 summarizes the total capital required for both the acid/clay and BERC plan without vacuum distillation.

EXHIBIT 11

ACID/CLAY PROCESS WITHOUT VACUUM DISTILLATION
PREDESIGN PROCESS EQUIPMENT COSTS

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Oil Unloading			
Oil Storage Tank, 2	200,000 g	$ 45,000	$ 90,000
Side Mixers, 2	5 hp	3,000	6,000
Unloading Pump	100 gpm, 1.5 hp	2,600	2,600
			$ 98,600
Fuel Flash			
Oil Feed Pump	25 gpm	1,900	$ 1,900
Fuel Flash Heat Exchanger	330 ft^2	15,800	15,800
Fuel Flash Drum	3' x 5'	5,000	5,000
Condenser	40 ft^2	2,500	2,500
Accumulator	100 g	1,000	1,000
Lt. Fuel Pump	3 gpm	800	800
Crude Lube Cooler	511 ft^2	21,300	21,300
			$ 48,300
Acid Treatment			
Oil to Treater Pump	20 gpm	1,900	$ 1,900
Acid Pump to Treater	60 gpm	2,500	2,500
Acid Treaters, 2	40,000 g	20,000	40,000
Agitators, 2	3 hp	3,200	6,400
			$ 50,800
Clay Contactor			
Clay Contactor	20,000 g	15,000	$ 15,000
Agitator	3 hp	3,200	3,200
Clay Hopper	50 ft^2	800	800
Lube Heater (diesel fuel)	8,000,000 Btu/hr	80,000	80,000
Condenser		5,000	5,000
Product Pump	90 gpm	2,600	2,600
Separator	100 g	1,000	1,000
Pump - Fuel Oil	10 gpm	1,000	1,000
Vapor Afterburner		1,900	1,900
			$ 110,500
Filter			
Filter, Rotary Vacuum Drum	10' dia. x 16' + aux. equipment	200,000	$ 200,000
			$ 200,000

EXHIBIT 11 (Continued)

ACID/CLAY PROCESS WITHOUT VACUUM DISTILLATION
PREDESIGN PROCESS EQUIPMENT COSTS

Page 2

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Finished Lube and Solvent Storage			
Lube Storage Tanks, 2	200,000 g	$ 39,000	$ 78,000
Pumps, 2	100 gpm	2,600	5,200
Fuel Storage, 2	40,000 g	9,000	18,000
Pump Loading	100 gpm	2,600	2,600
Acid Storage	50,000 g	11,000	11,000
Pump	60 gpm	2,400	2,400
			$ 117,200
Each Separate			
Boiler, Complete	200 psi, 10,000 #/hr.	77,000	$ 77,000
Cooling Water, Complete	800 gpm, 4,000,000 Btu/hr.	95,500	95,500
Water Treatment			
Clay Disposal			
Sludge Disposal			
TOTAL EQUIPMENT COST			$ 797,900

EXHIBIT 12

BERC PREDESIGN PROCESS EQUIPMENT COSTS
WITHOUT VACUUM DISTILLATION

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Oil Unloading			
Oil Storage Tank, 2	200,000 g	$ 45,000	$ 90,000
Side Mixers, 2	5 hp	3,000	6,000
Unloading Pump	100 gpm, 1.5 hp	2,600	2,600
			$ 98,600
Fuel Flash			
Oil Feed Pump	25 gpm	1,900	$ 1,900
Fuel Flash Heat Exchanger	330 ft^2	15,800	15,800
Fuel Flash Drum	3' x 5'	5,000	5,000
Condenser	40 ft^2	2,500	2,500
Accumulator	100 g	1,000	1,000
Lt. Fuel Pump	3 gpm	800	800
Crude Lube Cooler	511 ft^2	21,300	21,300
			$ 48,300
Solvent Treatment			
Oil to Treater Pump	20 gpm	1,900	1,900
Solvent Pump to Treater	60 gpm	2,500	2,500
Solvent Settler, 4	40,000 g	20,000	80,000
Agitators	3 hp	3,200	16,000
			$ 100,400
Solvent Stripper			
Pump Solvent Stripper	80 gpm	2,600	$ 2,600
Feed Heater - Sol. St.	790 ft^2	30,300	30,300
Solvent Stripper	4' dia. x 30' packed Berl saddles	30,000	30,000
Reflux Condenser	400 ft^2	16,500	16,500
Accumulator	100 g	1,000	1,000
Reboiler	2700 ft^2	70,000	70,000
Pump Reflux	90 gpm	2,600	2,600
Pump Stripper Bottoms	20 gpm	1,900	1,900
			$ 154,900

EXHIBIT 12 (Continued)

BERC PREDESIGN PROCESS EQUIPMENT COSTS WITHOUT VACUUM DISTILLATION

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Sludge Stripper			
Sludge Accumulator	5000 g	$ 3,000	$ 3,000
Sludge Pump to Stripper	80 gpm	3,000	3,000
Sludge Pump	80 gpm	3,000	3,000
Sludge Overhead Condenser	6 ft^2	500	500
Accumulator	100 g	1,000	1,000
Sludge-Solvent Pump	3 gpm	800	800
Reboiler	107 ft^2	6,800	6,800
Sludge Cooler		7,300	7,300
Sludge Stripper	2' x 5' packed	2,900	2,900
			$ 28,300
Intermediate Lube Storage			
Storage Tank	100,000 g		22,000
Pump	90 gpm	2,600	2,600
			$ 24,600
Clay Contactor			
Clay Contactor	20,000 g	15,000	$ 15,000
Agitator	3 hp	3,200	3,200
Clay Hopper	50 ft^2	800	800
Lube Direct Fired Heater	8,000,000 Btu/hr	80,000	80,000
Condenser	75 ft^2	5,000	5,000
Separator	100 g	1,000	1,000
Pump - Fuel Oil	10 gpm	1,000	1,000
Product Pump	90 gpm	2,600	2,600
Vapor Afterburner and Stack		1,900	1,900
			$ 110,500
Filter			
Filter, Rotary Vacuum Drum	10' dia. x 16' + aux. equipment	200,000	$ 200,000

EXHIBIT 12 (Continued)

BERC PREDESIGN PROCESS EQUIPMENT COSTS
WITHOUT VACUUM DISTILLATION
Page 3

Item of Equipment	Specifications	Estimated Erected Cost, Each	Total Cost
Finished Lube and Fuel Storage			
Lube Storage Tanks, 2	200,000 g	$ 39,000	$ 78,000
Pumps, 2	100 gpm	2,600	5,200
Fuel Storage, 2	40,000 g	9,000	18,000
Pump Loading, 2	100 gpm	2,600	5,200
Solvent Storage	150,000 g	28,000	28,000
Separate Solvent Tanks, 3	10,000 g	3,500	10,500
Pump	60 gpm	2,400	2,400
			$ 147,300
Each Separate			
Boiler, Complete	200 psi, 22,000 #/hr.	$134,000	$ 134,000
Cooling Water, Complete	1400 gpm, 12,000,000 Btu/hr.	221,000	$ 221,000
Water Treatment			
Clay Disposal			
Sludge Disposal			
TOTAL EQUIPMENT COST			$1,267,900

EXHIBIT 13

CAPITAL INVESTMENT COMPARISON

	Acid/Clay Without Vacuum Distillation	BERC Solvent Without Vacuum Distillation
Installed Equipment	$ 797,900	$1,267,900
Building $20/ft^2 x 1,000 ft^2	20,000	20,000
Land & Improvements	Unknown	Unknown
Utilities	Unknown	Unknown
TOTAL	$ 817,900	$1,287,900
Engineering & Construction, 10%	81,800	128,800
TOTAL FIXED COST	$ 899,700	$1,416,700
Working Capital:		
Waste Oil Inventory, one mo. @ $0.15/g	$ 135,000	$ 135,000
Solvent Inventory		215,800
Acid Inventory	14,600	
Clay Inventory	24,000	12,000
Re-refined Oil Inventory, one mo. @ $0.40/g	240,000	240,000
Extended Credit, one mo. sales @ cost	240,000	240,000
Available Cash, one mo. mfg. expense	75,000	75,000
TOTAL WORKING CAPITAL	$ 728,600	$ 917,800
TOTAL CAPITAL REQUIRED	$ 1,628,300	$ 2,335,025

Assuming that the cost and amount of acid, solvents and clay used will be the same, the manufacturing cost of both processes is compared in Exhibit 14. The same labor requirements are used that was used in Part I of this report and the same yield of finished product is assumed, although this depends on the temperature used in clay contacting and the amount of gas-oil brought overhead. A total cost of 45.8 cents/gallon is arrived at for the acid/clay process and a cost of 37.9 cents/gallon for the solvent system, or a reduction of approximately 2.5 cents/gallon in cost when vacuum distillation is removed.

EXHIBIT 14

MANUFACTURING COST PER DAY
350 d/y

	Acid/Clay	Solvent/Clay	
Used Oil @ $0.15/g, 30,000 g	$4,500	$4,500	
Solvent @ $1.21/g	-	496	
Sulfuric Acid, 98% @ $48/T	732	-	
Clay @ $160/T	1,181	400	
NaOH @ $140/T	210	0	
Sludge Disposal	315	100	
Supplies 15% of Maintenance Costs	41	30	
Labor @ $5/hr	357	357	
Supervision: See Administration			
Utilities, estimated	150	150	
Maintenance, 10% of Fixed Capital	257	202	5%
DIRECT MANUFACTURING COST	$7,743	$6,235	
Overhead, 50% of Labor	$ 178	$ 178	
Laboratory, 10% of Labor	36	36	
Shipping - unknown	-	-	
INDIRECT MANUFACTURING COST	$ 214	$ 214	
Depreciation, 10% of Fixed Capital	$ 257	$ 404	
Property Taxes, 2% of Fixed Capital	51	81	
Insurance, 1% of Fixed Capital	26	40	
FIXED MANUFACTURING COST	$ 334	$ 525	
Administration & Sales	$ 171	$ 171	
Expense: See Overhead	-	-	
Finance, 10% Total Capital	465	660	
GENERAL EXPENSE	$ 636	$ 831	
TOTAL MANUFACTURING COST/DAY	$8,927	$7,805	
19,500 g/d, 65% conversion, cost/gallon	$ 0.458		
20,570 g/d, 70% conversion, cost/gallon		$ 0.379	