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**THE BERC RE-REFINING PROCESS: COMPARISON OF
HYDROFINISHING VERSUS CLAY CONTACTING**

By

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

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Department of Energy
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Engineering and design studies
Prepared for the Department of Energy
Under Purchase Order No. EY-77-X-19-0237

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EXECUTIVE SUMMARY

To produce high quality lubricating oil from used oil requires the complete removal of all contaminants. The BERC process accomplishes this through a combination of solvent extraction followed by vacuum distillation. The distilled oil may still possess unacceptable levels of color and odor. A final finishing step consisting of either clay contacting or treatment with hydrogen will result in specification grade motor oils. Both hydrofinishing and clay contacting have advantages and operating differences. Handling of solid clay and disposing of an oil-soaked spent clay present processing problems, but its use is easily controlled and little skill is required. Hydrofinishing eliminates the solids handling problems, but introduces a sophisticated high pressure unit operation into the traditionally simple re-refining industry. This paper compares the processing advantages and problems and, by economic analysis, demonstrates that the costs of production of either finishing step are nearly the same - about 40¢ per gallon. Variables such as clay and hydrogen costs and waste clay disposal costs are determining factors. Capital costs for a BERC unit with clay contacting is about \$100,000, or 3% cheaper. More highly skilled labor is required for the high pressure hydrofinishing step. The options presented will aid the re-refiners in designing a new facility.

THE BERC RE-REFINING PROCESS: COMPARISON OF HYDROFINISHING VERSUS CLAY CONTACTING

INTRODUCTION:

Over the past several years re-refining research has developed new techniques for reclaiming used lubricating oils. Independent re-refiners have been operating with acid/clay technology for the most part during the past thirty years, but little effort until now has been applied to this process by major laboratories. Bartlesville Energy Research Center (BERC) has developed a new process to reclaim used lube oils, using a solvent extraction process, followed by vacuum distillation and a final clay contacting or hydrogenation finishing step. Clay contacting was a standard procedure used by major lube oil producers until the 1960's when it was found that by hydrotreating the virgin lube stocks, clay contacting could be eliminated. A ready source of hydrogen existed at the refineries and it was more economical to use their own by-product, hydrogen, than to buy clay, cope with a solids handling problem, and contend with the disposal of the spent clay. To the best of this author's knowledge the hydrofinishing of used lube oils is not now a part of any commercial process in the United States or Europe, although it has been proposed by several in the industry. It has been suggested by such advocates that using hydrogen in place of clay would produce a cheaper finished lube oil with superior quality. The purpose of this report is to explore this contention and to determine the cost factors and operating variables associated with hydrofinishing.

In preparing cost comparisons and analyzing operating variables, it is necessary to put the operations to be compared on the same basis. Therefore, a hypothetical system must be devised to compare the operating process variations and their economic effect. In this case the basis is an earlier report prepared for the Bartlesville Energy Research Center, Department of Energy, entitled "Predesign Cost Estimate for Re-refined Lube Oil Plant"¹. In this earlier document costs associated with the BERC solvent refining process were detailed and equipment and operating cost estimates developed. This predesign report is a comparison between the two possible lube finishing steps, clay contacting or hydrofinishing.

Hydrofinishing is inherently attractive because it eliminates the necessity to purchase clay and the labor intensive steps of charging the clay to the contacting vessel,

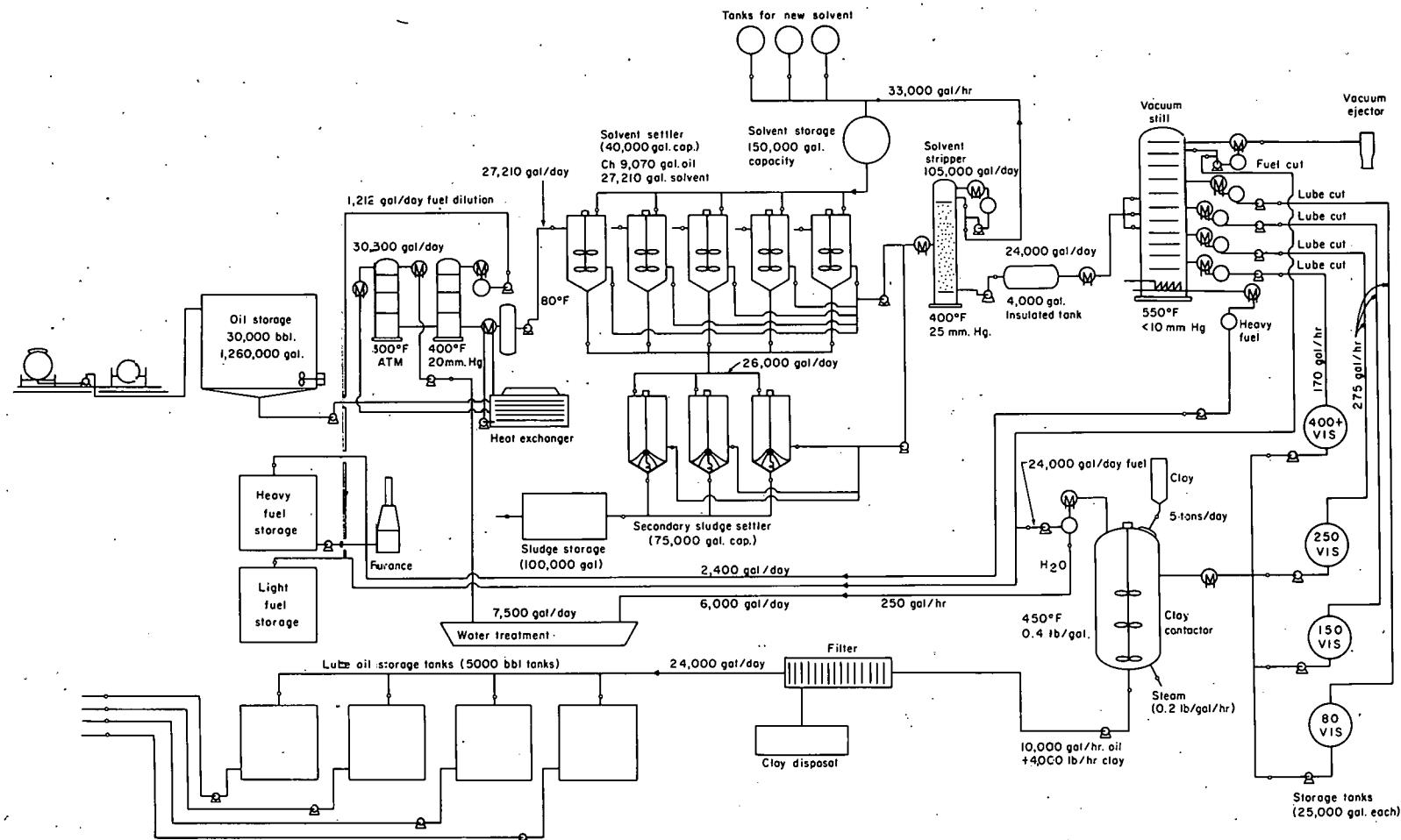
filtering it, and disposing of a solid waste material, the oily spent clay. A messy time-consuming step, that of filtering hot oily clay, is eliminated. Gaseous hydrogen flowing through a catalytic reactor followed by only minor filtration appears at first to be a more desirable finishing step; however, some of the problems associated with hydrogenation will be delineated in this document. This comparison can serve as a starting point for considering the advantages and disadvantages of both processes. No effort is made in this analysis to determine the advantages of hydrotreating raw used motor oils as an alternative process to the BERC solvent re-refining, acid/clay contacting, or other re-refining processes. In this case the raw used oil is solvent extracted first, then vacuum distilled and treated with hydrogen.

ANALYSIS OF THE HYDROFINISHING OF
SOLVENT-TREATED USED LUBE OILS

In the BERC solvent re-refining process used motor oils are first dehydrated and stripped of light hydrocarbons in a packed column. This process is described in the Bureau of Mines Report of Investigations 7925². The dehydrated sludge-containing oil is then treated with a 3:1 mixture of mixed solvents (butyl alcohol, isopropyl alcohol and methyl ethyl ketone). The solvent-used oil mixture is allowed to settle and the sludge is drawn off the bottom of the conical settling tanks or centrifuged to recover oil and solvent. The solvent is then recovered from the lube oil by distillation. In the BERC process the solvent is recycled and the extracted lube oil vacuum distilled to produce specification lube oil blending stocks. These blending stocks are contacted with absorbent clay to remove color bodies and improve odor. After the clay and hot lube oil have been contacted, the mixture must be filtered to produce a finished lube stock having qualities similar to virgin lube stocks.

In this report economic and technical comparison is made with the BERC process as it has been developed and by substituting hydrofinishing for the clay contacting step. Our concept of the BERC process is presented in the flow sheet of Exhibit 1. If hydrofinishing were substituted for clay contacting, some equipment would be eliminated and new items added. The clay contacting apparatus and the larger more expensive filtering apparatus would be removed, but in their place a high pressure catalytic reactor would be added for mild hydrotreating of lubricating oils. A mixture of the oil and hydrogen is passed through a heater, probably a direct fired furnace, to bring it up to an operating temperature of 480° to 600° F. Depending on the process chosen, the operating pressures would be between 400 and 1,000 psig. Generally a nickel-molybdenum or cobalt-molybdenum type catalyst would be used to promote the hydrogenation reaction. After passing through the furnace or heater the high pressure fluid is pumped into the reactor at the top allowing a downward flow through the catalyst bed.^{3,4,5,6} Hydrogenation promotes color and odor improvement, neutralization and desulfurization.

After reaction the oil is separated from the gas in two stages. The offgas can be recycled or used as a fuel gas. Following gas separation the oil is then steam stripped and dried in a vacuum column to remove water and light distillates. The catalyst is required to be regenerated on occasion and this can usually be accomplished by a simple in situ burn off with a steam-air mixture. The advantages of this mild hydrotreating are the elimination of the clay treatment, a



BERL RE-REFINING PROCESS - CLAY CONTACTING

comparatively simple and continuous operation, and reduction of manual labor required to charge the clay contactor and operate the filter press. Product yields may be improved and the clay disposal problem is eliminated. A filtering step may still be involved, but this merely involves polishing the product and would employ only a small, inexpensive type filter. Exhibit 2 is a flow sheet showing the BERC process with mild hydrotreating substituted for the clay contacting operation.

PREDESIGN PROCESS EQUIPMENT COSTS:

An equipment list is included in Exhibit 3. It indicates the remaining equipment is identical to that in the 10-million-gallon-per-year plant described in the original pre-design study (Exhibit 1), except for a larger furnace since additional heat will be required for the hydrogenation. Naturally the hydrogenation equipment including another steam stripper and vacuum dryer is substituted for the clay contacting and heavy duty filtering apparatus. The difference in capital costs is estimated to be approximately \$116,000 more for the hydrotreating process versus the clay contacting operation. The clay contacting plant is estimated to cost \$1,963,000, while the hydrogenation system may cost \$2,079,000 (note Exhibit 4). If a cheaper batch type filter were used instead of the rotary filter provided for in the original BERC design, the BERC capital costs with clay contacting could be considerably less.

MANUFACTURING COSTS:

Because of the increased sophistication of the operation, it is suggested that an additional skilled man be added to operate the hydrogenation section of the plant. More careful attention will have to be paid to this high pressure operation than for the relatively simple clay contacting. Labor cost estimates are shown at \$226,400 per year in Exhibit 5. Most references suggest that labor requirements will be reduced, but this will be true only for much larger plants (10 to 20 times larger). Almost \$660 worth of clay per day was used in the original process, and hydrogen, the replacement for the clay, is estimated to cost only \$116 a day, but an additional charge of \$1,050 per month is made by the hydrogen supplier to defray the costs of on-site hydrogen storage, either cryogenic or steel cylinders. This amounts to \$36 a day, applied to indirect manufacturing costs. Based on a 20,570-gallon-per-day production of finished lube oils, the cost per gallon for the hydrotreated oils would approximate 40¢, which is competitive with clay contacting at an estimated cost of 41¢, as noted in Exhibit 6. With the capital and operating costs so nearly the same for either option,

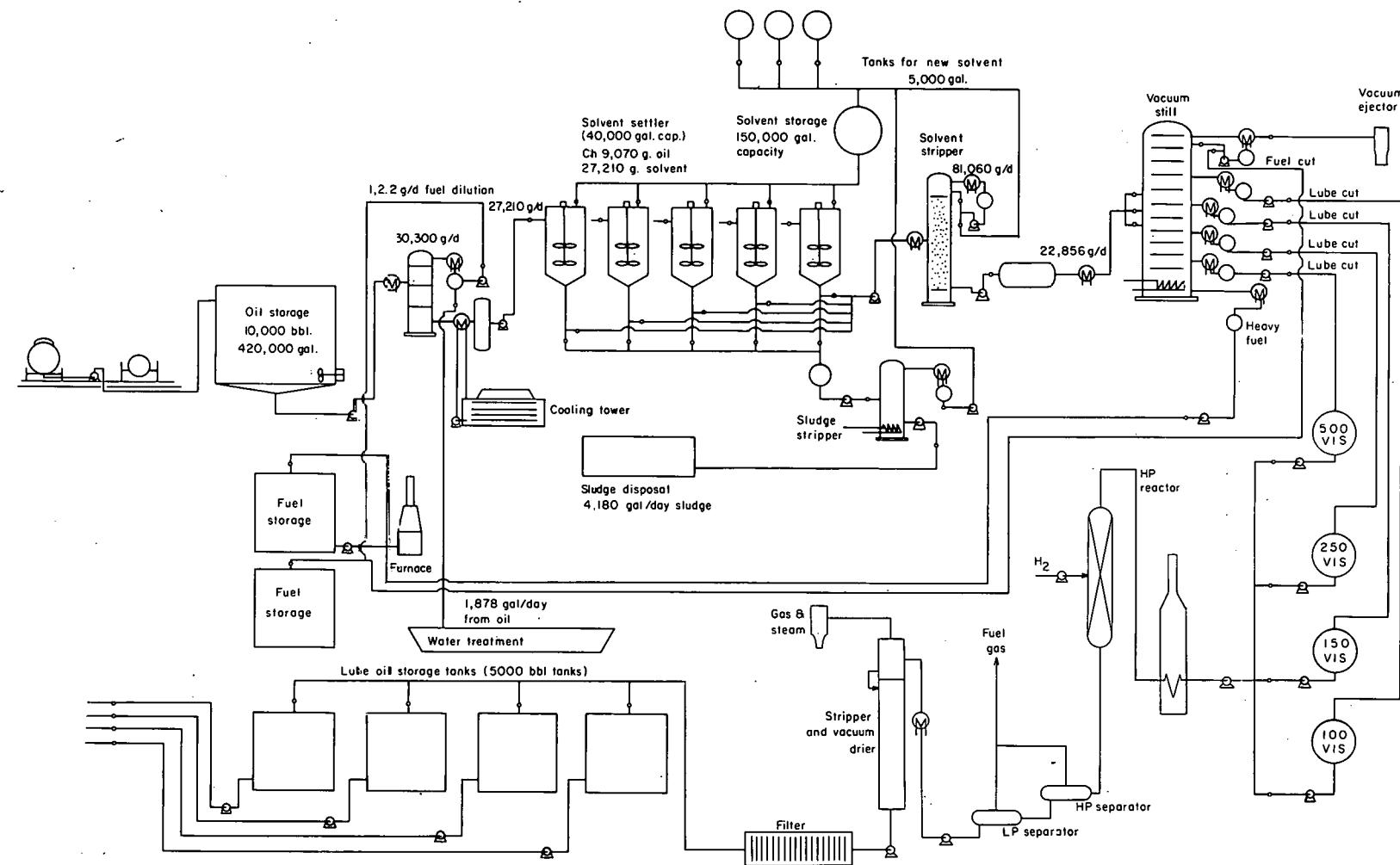


EXHIBIT 3

BERC PROCESS WITH HYDROTREATING
PREDESIGN PROCESS EQUIPMENT COSTS

<u>Item of Equipment</u>	<u>Specifications</u>	<u>Estimated Erected Cost, Each</u>	<u>Total Cost</u>
<u>Oil Unloading</u>			
Oil Storage Tank, 2	200,000	\$ 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
<u>Fuel Flash</u>			
Oil Feed Pump	25 gpm	1,900	\$ 1,900
Fuel Flash Heat Exchanger	330 ft ²	15,800	15,800
Fuel Flash Drum	3 ft x 5 ft	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	21,300	21,300
			\$ 48,300
<u>Solvent Treatment</u>			
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, 5	3 hp	3,200	16,000
			\$ 100,400
<u>Solvent Stripper</u>			
Pump Solvent Stripper	80 gpm	2,600	\$ 2,600
Feed Heater - Sol. St.	790 ft ²	30,300	30,300
Solvent Stripper	4 ft dia. x 30 ft 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 3 (Continued)

BERC PROCESS WITH HYDROTREATING
PREDESIGN PROCESS EQUIPMENT COSTS

Page 2

<u>Item of Equipment</u>	<u>Specifications</u>	<u>Estimated Erected Cost, Each</u>	<u>Total Cost</u>
<u>Sludge Stripper</u>			
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 ft x 5 ft packed	2,900	<u>2,900</u>
			\$ 28,300
<u>Vacuum Distillation</u>			
Vac. Still Feed HX	75 ft ²	4,800	\$ 4,800
Vacuum Ejector	1 lb/hr, 5.0 mm	3,500	3,500
Feed Pump	20 gpm	1,900	1,900
Vac. Still	4 ft dia. x 40 ft x 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	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	<u>1,200</u>
			\$ 170,100

EXHIBIT 3 (Continued)

BERC PROCESS WITH HYDROTREATING
PREDESIGN PROCESS EQUIPMENT COSTS
 Page 3

<u>Item of Equipment</u>	<u>Specifications</u>	<u>Estimated Erected Cost, Each</u>	<u>Total Cost</u>
<u>Intermediate Lube Storage</u>			
Storage tank, 100 V	25,000 gal	\$ 8,000	\$ 8,000
Pump	90 gpm	2,600	2,600
Storage Tank, 150 V	25,000 gal	8,000	8,000
Pump	90 gpm	2,800	2,800
Storage Tank, 250 V	25,000	8,000	8,000
Pump	90 gpm	2,800	2,800
Storage Tank, 600 V	25,000 gal	8,000	8,000
Pump	90 gpm	2,800	2,800
			<u>\$ 43,000</u>
<u>Reactor</u>			
Catalyst		\$ 3,400	\$ 3,400
Pump	1000 psi, 15 gpm	10,200	10,200
H ₂ Compressor	50 hp, 2 stage, 208 scf/in.	60,000	60,000
Reactor	4 ft x 10 ft vertical, 1000 psi	43,000	<u>43,000</u>
			<u>\$ 116,600</u>
<u>HP and LP Separators</u>			
HP	1000 psi, 500 gal	25,440	\$ 25,440
LP	500 psi, 500 gal	14,755	<u>14,775</u>
			<u>\$ 40,200</u>
<u>Stripper and Vac. Drier</u>			
Tower	3 ft x 20 ft	35,800	\$ 35,800
Vac. Ejector		3,500	3,500
Feed Heater	75 ft ²	4,800	4,800
Stripper Feed Pump	20 gpm	1,900	1,900
Filter	100 ft ²	17,000	17,000
Filter Pump	20 gpm	1,900	<u>1,900</u>
			<u>\$ 64,900</u>

EXHIBIT 3 (Continued)

**BERC PROCESS WITH HYDROTREATING
PREDESIGN PROCESS EQUIPMENT COSTS**
Page 4

<u>Item of Equipment</u>	<u>Specifications</u>	<u>Estimated Erected Cost, Each</u>	<u>Total Cost</u>
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	9,600	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
Each Separate			
Boiler, Complete	200 psi, 22,000 lb/hr	134,000	\$ 134,000
Hot Oil Furnace, Complete Direct	30 M Btu/hr, 700° F	410,300	\$ 410,300
Cooling Water, Complete	1400 gpm, 14,000,000 Btu/hr	221,000	\$ 221,000
Water Treatment			
Clay Disposal			
Sludge Disposal			
TOTAL EQUIPMENT COST			\$1,870,000

EXHIBIT 4

CAPITAL INVESTMENT COMPARISON

	<u>Hydrogenation</u>	<u>Clay Contacting</u>
Installed Equipment	\$1,870,000	\$1,765,200
Piping		
Building, \$20/ft ² x 1000 ft ²	20,000	20,000
Land & Improvements	Unknown	Unknown
Utilities	Unknown	Unknown
TOTAL	\$1,890,000	\$1,785,200
Engineering & Construction, 10%	<u>189,000</u>	<u>178,000</u>
TOTAL FIXED COST	\$2,079,000	\$1,963,000

Working Capital:

Raw Material Inventory, one mo. @ \$0.15/g	\$ 135,000	\$ 135,000
Solvent Inventory, full tanks	215,800	215,800
Clay Inventory	-	20,000
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	<u>75,000</u>	<u>75,000</u>
TOTAL WORKING CAPITAL	\$ 905,800	\$ 925,800
TOTAL CAPITAL REQUIRED	\$2,984,800	\$2,888,800

EXHIBIT 5

LABOR REQUIREMENTS

	<u>Men</u>
Day:	
Shipping, receiving and utilities	1
Operator: Solvent settlers, stripper	
dehydrator, solvent treatment and	
distillation	1
Operator: Hydrogenation reactor and	
vacuum stripper	1
Operator: Vacuum distillation and	
filter	1
Maintenance	2
Supervisor	<u>1</u>
	7
Night:	
Operators - 3 (Three Shifts)	9
Administration:	
Manager	1
Clerk	1
Sales	<u>1</u>
	3
Total Personnel:	
16 Hourly x 40 hr/week x \$5 x 52 weeks	\$166,400/year
3 Salary x \$20,000/year	\$ 60,000/year
TOTAL PAYROLL	\$226,400/year

EXHIBIT 6

MANUFACTURING COST PER DAY
350 days per year

	<u>Hydrogenation</u>	<u>Clay Contacting</u>
Used Oil @ \$0.15/g, 30,000 g	\$4,500	\$4,500
Solvent, 410 g/d loss @ \$1.21/g	496	496
H ₂ , 0.6 SCF/g	116	-
Clay @ \$160/T, 0.4 lb/g	-	658
Catalyst, 1¢/B	5	-
Sludge Disposal	-	100
Supplies, 15% of Maintenance Costs	44	42
Labor @ \$5/hr	475	357
Supervision: See Administration		
Utilities, estimated	225	150
Maintenance, 5% of Fixed Capital	297	280
DIRECT MANUFACTURING COST	\$6,158	\$6,583
Overhead, 50% of Labor	238	178
Laboratory, 10% of Labor	48	36
Shipping - unknown	-	-
H ₂ Equipment Rental and Maintenance*	36	-
INDIRECT MANUFACTURING COST	\$ 322	\$ 214
Depreciation, 10% of Fixed Capital	595	561
Property Taxes, 2% of Fixed Capital	119	112
Insurance, 1% of Fixed Capital	59	56
FIXED MANUFACTURING COST	\$ 773	\$ 729
Administration & Sales	171	171
Expense: See Overhead	-	-
Finance, 10% Total Capital	854	823
GENERAL EXPENSE	\$1,025	\$ 994
TOTAL MANUFACTURING COST/DAY	\$8,278	\$8,520
20,570 g/d, 70% conversion, cost/gallon	\$ 0.402	\$ 0.414

*In the most economical method of H₂ handling, the equipment remains the property of the vendor, and the vendor has responsibility for maintenance of the equipment. For this service, there is a standard fee of \$1,050 per month, regardless of the volume of H₂ used. This charge is uniform throughout the industry.

one has to consider carefully the advantages and disadvantages of each mode of operation and determine what would suit them best.

ADVANTAGES AND PROBLEMS ASSOCIATED WITH HYDROTREATING VERSUS CLAY CONTACTING:

Since the capital and operating costs are very similar for the two types of manufacturing schemes, careful attention should be given to the advantages and problems associated with each of the techniques. The advantages and disadvantages to using hydrotreating are noted with attention called to certain unresolved problems which may not be demonstrated one way or another until a commercial unit is in actual operation.

Advantages

- ° Elimination of oily clay disposal problems.
- ° Reduced solids handling - clay in and out.
- ° Filtration problems minimized.

Disadvantages

- ° Slightly higher capital costs for hydrogenation equipment.
- ° Advanced technology required.
- ° Elevated temperatures and pressures pose dangerous operating conditions.
- ° Explosive hydrogen stored on plant site.
- ° Cryogenic or high pressure steel storage cylinders required.
- ° Cryogenic hydrogen storage requires additional attention.
- ° Plant shutdowns may result in excessive hydrogen losses from cryogenic storage unit at approximately 89¢ per 100 standard cubic feet.
- ° Additional energy will be required to maintain the high temperatures and high pressures involved in hydrogenation versus lower temperature atmospheric clay contacting. This is reflected in higher utility costs.

- Increased maintenance costs due to the required care of high pressure equipment.
- Additional stripper and drying tower operation.
- Decreased operating flexibility, i.e., flow rates must be relatively constant, which calls for smoother operation of the entire plant.

Unresolved Problems

Since used lube oils contain heavy metals and uncontrollable contaminants, it may be that such materials will poison the catalyst. The nickel-molybdenum catalyst sells for approximately \$2.00 a pound and should the catalyst be poisoned, recharging would cost approximately \$3,400 for the catalyst plus the cost of recharging the reactor. Further, it has been demonstrated that hydrofinishing will in fact efficiently improve the color, odor, stability and overall quality of the used oil. Clay has been used commercially to achieve this product quality and it is easily controlled. For example, the quality of the finished oil is adjusted by the temperature, quantity and quality of the clay and time of contacting. Simple physical tests can be performed during the batching of the oil to determine when it has reached the appropriate quality. Hydrogenation is a continuous process which would have to be constantly monitored to insure that a quality product was being produced. If it does not function properly the entire stream must be recycled back to the hydrogenation preheat furnace, which will cause operating difficulties for the stripper and vacuum distillation units.

For small operators, those interested in employing used process equipment, the probability of finding a suitable secondhand hydrogen reaction system is very low; therefore, should such a unit be installed it would likely have to be engineered and fabricated specifically to fit the characteristics of the plant. It is strongly urged that a skilled refinery operator be employed for the operation of the hydrogenation unit. Additional instrumentation and safeguards must be considered. Finally, availability of hydrogen may be a problem as there are few hydrogen-producing facilities producing for the merchant market. Should the re-refiner be located near a crude oil refinery, hydrogen or hydrogen-rich gas may be available via pipeline at a more attractive price.

Merchant hydrogen is available from only a few locations in the U.S. and prices will be f.o.b. shipping point. Therefore, some areas would be disadvantaged by having to

use H₂. A plant located near a hydrogen generator such as a refinery could purchase H₂ via pipeline on demand at very reasonable prices compared to the plant that had to buy liquid H₂. High quality clay, too, will vary in cost depending upon distance. The costs in this report are based upon prices quoted Bartlesville, Oklahoma. Estimating that \$192 per day has been allotted for clay costs and \$116 H₂ + \$36 storage + \$5 catalyst = \$157 per day for hydrogenation, it will not take too much (\$35) refinement to change the advantage in favor of clay contacting. Yields may be slightly improved if hydrofinishing is employed since oil will not be lost by absorption on the clay. An improved yield would lower the processing cost per gallon. A 1% yield variation would change the cost by 0.5¢ per gallon.

COMPARISON OF ACID/CLAY, BERC HYDROGENATION
AND BERC CLAY CONTACTING METHODS OF LUBE OIL RE-REFINING

Exhibit 7 indicates the major operating costs of the process, acid/clay contacting, with the BERC clay contacting and the BERC hydrogenation processes. It can be noted that on the same basis as described in a comparison report issued by BERC⁷ which shows that because of the cost of the acid and clay that this process does appear to be the most costly on a cents-per-gallon basis, even though the capital costs are less. The solvent process developed by BERC with or without hydrogenation is about 20% cheaper than the acid/clay process. Careful consideration should be given by the potential re-refiner to the advantages, disadvantages and problems inherent in each process, and these series of papers may aid in planning the best re-refining process for a particular organization or locality.

EXHIBIT 7

COMPARISON OF BER C CLAY CONTACTING, HYDROFINISHING
AND ACID/CLAY METHODS OF LUBE OIL RE-REFINING

	<u>Acid/Clay</u>	<u>BERC Hydrofinishing</u>	<u>BERC Clay Contacting</u>
Predesign Process Equipment Costs	\$1,322,400	\$1,890,000	\$1,765,200
Total Fixed Cost	1,476,600	2,079,000	1,963,000
Working Capital	728,600	905,800	925,800
Total Capital Required	2,205,200	2,984,800	2,888,800
Total Payroll	184,800	226,400	184,800
Solvent Costs	215,800	215,800	215,800
Direct Manufacturing Cost/Day	7,930	6,158	6,583
Indirect Manufacturing Cost/Day	214	322	214
Fixed Manufacturing Cost	548	773	729
General Expense	801	1,025	994
Total Manufacturing Cost/Day	9,493	8,278	8,520
Cost, \$/gallon, 20,570 gal/day	0.49	0.40	0.41

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