ENERGY REQUIREMENTS IN AN OIL SHALE INDUSTRY: BASED ON PARAHO'S DIRECT COMBUSTION RETORTING PROCESS

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The objective of an oil shale industry is to produce an alternate source of energy to help alleviate dependence on imported hydrocarbons. During the process of mining, crushing, retorting and refining, the industry must consume energy to operate the facility. The purpose of the author is to identify the source, amount, and the net energy balance of an oil shale industry. Energy requirements for coal and natural crude oil, and alternate sources of fossil fuel are also analyzed on a comparable basis as major suppliers of energy, and an overall energy balance is computed. To compare coal, oil shale, and natural crude oil, all have been converted to a common Btu index* of substitute natural gas (SNG), electricity, and liquid fuels (gasoline, jet fuel, etc., for transportation).

Oil shales contain varying amounts of kerogen. This energy content of oil shale is generally defined as so many gal/ton grade. However, total energy present in oil shale is a combination of heating value of the kerogen, gases and other combustible matter present. For example, although low in sulfur, sulfur content of oil shale has a heating value of 4,000 Btu/pound. Heating value varies from grade to grade. A 28 gal/ton oil shale grade has a gross heating value of 2,600 Btu/pound of rock. By comparison, typical Indiana and Illinois coal has a heating value of 10,000 Btu/pound. Lignite in the western states has a heating value of 6,000 to 7,000 Btu/pound.

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*For this comparison, energy is defined in Btu. For example, 1 cubic foot of natural gas contains about 1,000 Btu of energy and 1 barrel of crude contains about 6,000,000 Btu of energy.

MINING

For this study underground mining has been assumed. Preliminary mine design dictates that one mine would be required to support each 50,000 bbl of refinery capacity. It would produce about 70,000 tons/day of rock. Energy required to mine oil shale is in the form of electric power for hoisting converted matter, ventilation and lighting, and diesel fuel for hauling, loading, scaling, and roof bolting equipment, etc. Total energy required in mining represents about 1 to 1.5 percent of the energy extracted or has a thermal efficiency of about 98.5 to 99 percent. This does not include oil shale left (about 40 percent) for roof support which, by comparison, is far less than natural crude oil (about 66 percent of crude oil is left behind in the ground during the production process). A detailed breakdown of the energy required follows:

Electric Power	70,000 tons/day
Production shaft & hoisting	10,500 hp
Men & material shaft	1,100
Mine ventilation	7,950
	19,550 hp
Fuel	
Ventilation heating during winter	12,600 gal/wk
Drilling	4,430
Fuel oil used in blasting mixture	3,885
Roof bolting	4,860
Scaling	2,163
Loading	21,800
Hauling	63,500
	113,238 gal/wk

CRUSHING

Paraho's retorting process requires crushed rock in the range of +⅜ and –3½ inch. Crushing requires energy in the form of electric power for crushers and conveyor belts. Fines produced are in the range of 6 to 10 percent of the material fed to crushers. Thermal efficiency* of this step is in the range of 89.5 to 93.5 percent depending upon fines produced, that is, less than ⅜ inch in size and not usable in the retorting process.

$$\text{*Thermal efficiency} = \frac{\text{total Btu output from the process}}{\text{total Btu input to the process}} \times 100$$

RETORTING

Paraho's direct combustion retort is assumed. In this process raw oil shale is fed cold to the retort. The rock descends by gravity and the oil-gas mixture flows upwards. Retorting heat is supplied by combustion of about 40 percent of the carbon residue in the retorted shale. A part of the gas produced is circulated through the bottom of the retort thus recovering sensible heat from retorted shale.

Two cases using different parameters have been developed. For a 28 gal/ton and a 90 percent Fischer assay liquid yield, the overall thermal efficiency of retorting jumps to about 92 percent.

PREREFINING

Prerefining reduces the pour point and viscosity of shale oil so that it can be transported by pipeline. It usually consists of converting crude shale oil to synthetic crude and removing sulfur and nitrogen. Synthetic crude is a more desirable feed stock to refineries and can readily be converted to motor gasoline, jet fuel or heating oil.

Shale oil can be processed to synthetic crude by using a combination of crude distillation, coking, and hydrotreating. Overall thermal efficiency of such a refinery is estimated to be in the range of 95 percent.

RETORTED SHALE DISPOSAL

Energy required to dispose of retorted shale, including putting a layer of natural cover over it and watering to revegetate (pumping costs, etc.) is estimated to be less than ½ percent of the energy recovered from the oil shale industry.

FINAL REFINING OF SYNTHETIC CRUDE TO LIQUID FUELS

Studies compiled by various oil companies indicate overall thermal efficiency of a typical sweet crude based refinery is in the range of 93 percent. Synthetic crude is a more desirable feed stock since it has already been partially refined. A refinery based on synthetic crude as feed stock is expected to have an overall thermal efficiency of about 95 percent.

OVERALL THERMAL EFFICIENCIES

For an oil shale complex starting with mining and producing synthetic crude, the overall thermal efficiency is in the range of 67 to 78 percent, depending upon the shale grade, fines loss, and liquid yield.

In figures 1 and 2, we summarize the energy requirement for a nominal 100,000 barrel per day synthetic crude oil shale complex. In Case A (fig. 1), we assume a conservative approach, namely:

(1) A 28 gal/ton oil shale grade;
(2) 10 percent of oil shale extracted is in fine gravel and is used to cover retorted shale;
(3) 90 percent Fischer assay liquid yield.

In Case B (fig. 2), we assume a more optimistic approach, namely:

(1) A 35 gal/ton oil shale grade;
(2) 6 percent of oil shale extracted is in fine gravel and is used to cover retorted shale;
(3) 100 percent Fischer assay liquid yield.

COMPARISON WITH OTHER FOSSIL FUELS

In tables 1 through 3, we summarize conversion of oil shale, coal and natural crude to transportation liquid fuels (motor gasoline, jet fuels, etc.), substitute natural gas, and electricity, respectively.

CONCLUSION

In converting to liquid fuels, the oil shale industry is expected to use 25 to 35 percent of the energy it produces. Coal requires about 35 percent or more. As the technology progresses and experience is gained, there is a good probability of improving these overall thermal efficiencies. There are already some designs on the drawing board (such as steam and oxygen injection) which have a potential of cutting down the energy requirements in retorting oil shale.

In coverting oil shale to substitute natural gas, 30 to 40 percent of the energy is consumed compared to 35 to 45 percent for coal, owing to the much greater amount of hydrogenation required to convert coal to methane (CH_4), since coal has less hydrogen than oil shale kerogen.

In converting oil shale or high sulfur coal to electricity via the clean fuels route, about 75 percent of the energy available is consumed because the thermal efficiency of producing electricity by burning fuel under a boiler is only 35 percent.

OBSERVATIONS

Conservation of energy is of ever-increasing importance. Economic and technical viability are continuing essentials. Natural crude oil and natural gas, while ideal sources of liquid fuels for transportation and home heating, respectively, are declining in the United States. Low sulfur

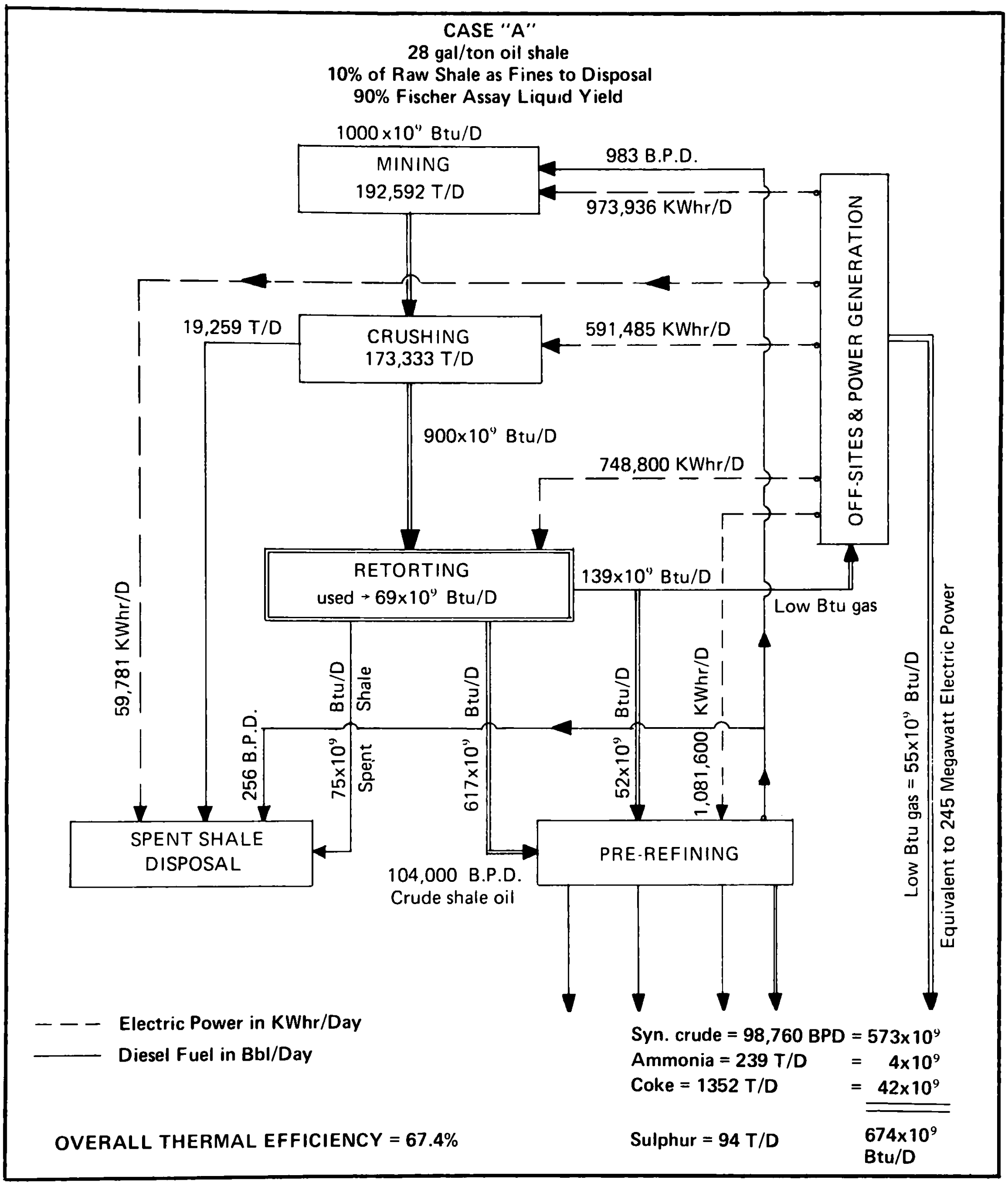

FIGURE 1.—Case A: energy requirement for an oil shale complex at 28 gal/ton oil shale grade.

western coal is most efficiently used as boiler fuel to generate electricity but it is located great distances from markets, making transportation or transmission expensive. To minimize our dependence upon foreign oil, all available energy sources will need to be tapped and converted to various forms of fuel to meet our needs. Oil shale is a promising and thermally efficient source for supplying a small but important percentage of our liquid fuel requirements. By-products in the form of ammonia for fertilizer and low Btu gas for electric power generation will represent added benefits to oil shale country.

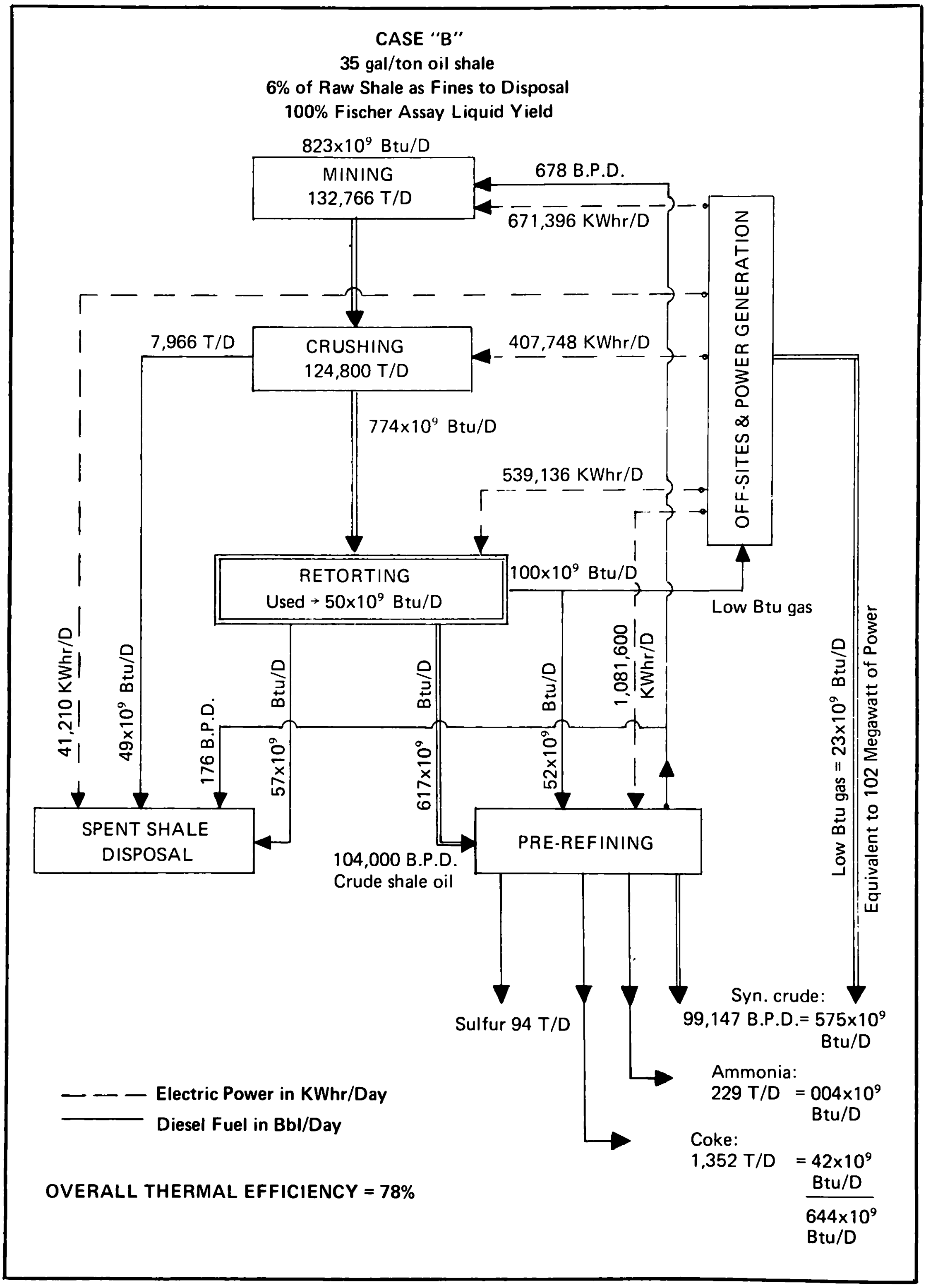

FIGURE 2.—Case B: energy requirement for an oil shale complex at 35 gal/ton oil shale grade.

TABLE 1.—*Fossil fuel to transportation liquid fuels* (% energy required for each of the following steps)

	Oil Shale		Coal		Crude Oil	
	Case A	Case B	Eastern (Sub-bitu)	Western (Lignite)	Sour	Sweet
Mining or Pumping	1.5	1.1	0.5	0.1	0.1	0.1
Crushing and/or Transportation	10.5	6.5	2.5	3.0	1	1
Retorting and/or Liquification	16	8	30	33	—	
Pre-refining to get Syn. Crude	9	9				
Refining	5	5	5	5	12	7
Overall Thermal Efficiency	64%	74%	65%	62%	87%	92%

TABLE 2.—*Fossil fuel to synthetic natural gas (SNG)* (% energy required for each of the following steps)

	Oil Shale		Coal		Crude Oil	
	Case A	Case B	Sub-bitu	Lignite	Sour	Sweet
Mining or Pumping	1.5	1.1	0.5	0.1	0.1	0.1
Crushing and/or Transportation	10.5	6.5	2.5	3.0	1	1
Retorting	16	8				
			45	35	17	15
Gasification	18					
Overall Thermal Efficiency	61%	70%	53%	63%	82%	84%

TABLE 3.—*Fossil fuel to electric power* (% energy required for each of the following steps)

<table>
<tr><th rowspan="2"></th><th colspan="2">Oil Shale</th><th>Coal</th><th colspan="2">Crude Oil</th></tr>
<tr><th>Case A</th><th>Case B</th><th>High Sulfur Coal</th><th>Sweet</th><th>Sour</th></tr>
<tr><td>Mining or Pumping</td><td>1.5</td><td>1.1</td><td>0.5</td><td>0.1</td><td>0.1</td></tr>
<tr><td>Crushing and/or Transportation</td><td>10.5</td><td>6.5</td><td>2.5</td><td>1</td><td>1</td></tr>
<tr><td>Retorting</td><td>16</td><td>8</td><td rowspan="2">22</td><td rowspan="2">2</td><td rowspan="2">5</td></tr>
<tr><td>Clean Boiler Fuel Production</td><td>8</td><td>8</td></tr>
<tr><td>Fuel to Electric Power</td><td>65</td><td>65</td><td>65</td><td>65</td><td>65</td></tr>
<tr><td>Overall Thermal Efficiency</td><td>24%</td><td>27%</td><td>26%</td><td>34%</td><td>33%</td></tr>
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