

OIL SHALE RETORTING - MEASURING PROCESS YIELDS

M. T. Atwood
J and A Associates
Golden, Colorado

S. W. Tyson
Tosco Corporation
Golden, Colorado

INTRODUCTION

For more than sixty years the rich oil shale formations of Colorado, Utah and Wyoming have been evaluated as a future source of petroleum. After many false starts, including the recent problems due to the economic conditions, the commercial production of shale oil will commence with the 1984 start-up of the Union Oil project near Parachute, Colorado. Other companies continue their interest and await only better economic conditions to become active again.

This paper will review some of the major elements involved in the production of shale oil with emphasis on means available to express the efficiency of production of pyrolysis liquids from oil shale rock.

What Oil Shale Is and Is Not

Oil shale is a generally used but inaccurate name for various combinations of kerogen and host rock. Kerogen is a high molecular weight, three dimensional organic polymer which is not soluble in organic solvents. The unfortunate term "oil shale" evokes an erroneous image of liquid petroleum mixed with clay minerals and quartz.

Most current oil shale interest lies in the Green River formation of Colorado, Utah and Wyoming. Kerogen composition is fairly uniform in this formation. A typical chemical analysis of the associated kerogen is given in Table 1 (J. W. Smith 1961).

The inorganic component or host rock may vary widely in composition but

always contains dolomite, calcite and quartz along with clay minerals. A typical analysis of the mineral component is provided in Table 2 (J. W. Smith 1969).

The inorganic chemistry of oil shale plays a significant role in thermal processing. Dolomite and calcite decompositions in oil shale occur at 565°C (1050°F) and 620°C (1150°F), respectively, and the decompositions are endothermic. These decompositions will be important in direct retorting (see below) where such temperatures may be encountered. Pyrite (FeS₂) decomposition and reaction with kerogen accounts for much of the H₂S produced in pyrolysis gas. (A. K. Burnham 1981). The quartz present may react exothermically with calcite in direct retorting processes (J. H. Campbell, 1978). A discussion of the effect of inorganic minerals on the enthalpy of retorting shows unexpected, wide variations (D. R. Johnson 1979).

FUNDAMENTALS OF OIL SHALE PROCESSING

Since kerogen is not a flowable or soluble substance only thermal decomposition steps are useful in processing to recover hydrocarbons. Thermal decomposition produces oil vapors and gas. As indicated, minimum disturbance of the inorganic matrix is desired.

Thermal decomposition is usually referred to as pyrolysis or retorting. The means for conveying heat to the oil shale to effect decomposition represent a wide variety of engineering approaches which have been under development for the

past century. A simplified classification of retort types is helpful:

Direct Retorting - heat is supplied by combustion in the retorting vessel.

Examples:

N.T.U. (Nevada, Texas, Utah)
Gas Combustion
Paraho (direct)
Union (type A)

Indirect Retorting - heat is produced externally to the retort vessel and conveyed to the retort vessel.

Examples:

Heat supplied by hot gases
Paraho (indirect)
Petrosix
Union (type B)
Heat supplied by hot solids
TOSCO II
Lurgi
Chevron

The nature of the gas and oil products produced from retorting depends greatly on whether direct or indirect heating methods are used. Direct heating by adding air to a combustion zone results in the production of combustion derived carbon dioxide which, along with nitrogen, dilutes the product gas. Generally, gas produced by direct heating has a heating value of around 3726 Joules/Liter (100 Btu/SCF) or less while gas from indirect heating has heating values ranging from 26,000 to 33,500 Joules/Liter (700-900 Btu/SCF). In addition, oil produced by direct heating methods generally contains less of the desirable low boiling point liquid fraction.

Indirect retorting produces a spent shale which may contain 20 percent or more of the organic carbon originally found in the feed raw shale. The substantial process heat represented by this carbon may be recovered by combustion in an external vessel such as a fluid bed. An advantage of direct retorting is the

recovery of much of this same combustion energy in the retort itself.

A typical product slate produced by direct retorting of Colorado (Anvil Points) oil shale is given in Table 3 (C. H. Prien 1979).

For comparison, Table 4 illustrates the products produced by TOSCO II retorting (indirect) of Piceance Basin (Colorado) oil shale. Heat was supplied to the retort by use of heated ceramic pellets.

MEASURING PROCESS YIELDS

Fischer Assay Comparisons

The basic measurement of oil shale richness involves pyrolysis by the Fischer assay procedure and measurement of the yield of condensed oil. There are two main Fischer assay procedures, that of the US Bureau of Mines and that of the Tosco Corporation. The former (K. E. Stanfield 1946) utilizes an aluminum retort and incorporates a standard time-temperature profile. The test oil shale is heated from room temperature to 500°C (932°F) in 50 minutes followed by heat soaking at this same final temperature for an additional 20 minutes. The Tosco procedure (L. Goodfellow 1974) follows the same time-temperature profile but uses a gas tight stainless steel retort in place of the aluminum retort. The Tosco procedure generally involves retorting more finely divided oil shale samples to provide increased assurance of sample integrity.

When an oil shale retorting pilot plant, semi-works and, ultimately, a commercial plant are run, a convenient measurement of the process yield is the comparison of oil yield from the large unit to that produced by Fischer assay of a representative oil shale feed sample. This comparison assumes extensive and tedious preparation of a well blended, small sample of oil shale, usually around

100 grams, which is truly representative of that shale fed to the retort over the fixed period of time involved in a material balance. In many cases the larger quantity may be hundreds or thousands of tons. If this procedure is carried out properly the operators can report that their process unit produced a certain percentage of Fischer assay oil. It is conceivable that the plant oil yield may be above 100% of Fischer assay oil yield if the process being studied is more efficient than Fischer assay.

Tosco Material Balance Assay Comparisons

The problem with the above procedure is that it ignores the hydrocarbons produced in the pyrolysis gas. Tosco Corporation has developed an assay procedure which is conducted in the same way as Fischer assay except that the pyrolysis gas is collected in its entirety in a glass container and subsequently measured and assayed by gas chromatography. This procedure is called TMBA (Tosco Material Balance Assay), and it is being adopted in the industry (L. Goodfellow 1974). It provides a means for comparing the entire product slate: gas, oil, water and spent shale - produced by a process unit - to that produced by TMBA. A published comparison was based on TOSCO II operations in the approximately 900 metric ton per day Parachute Creek Semi-Works plant and is given in Table 5.

In Table 5, it was found convenient to compare semi-works plant yields with TMBA yields based on 100 Kgs (or 100 weight units of any type) of assay oil. In the data given the yield of semiworks oil was 99.59% of that produced in TMBA. The yield of total hydrocarbon was 100.65% (116.62/115.82) of that produced by TMBA.

Using these procedures process yields are related to yields produced by

a straightforward laboratory procedure. This is particularly useful when the process involves indirect heating as in the case of Union Type B, Lurgi and TOSCO II. When direct fired retort yields are evaluated the presence of large volumes of nitrogen and combustion derived carbon dioxide in the product gas must be taken into consideration in evaluating the gaseous product.

Organic Carbon Comparisons

Fischer Assay and TMBA yields are reproducible with high precision. Standard deviations of replicate oil yields are 0.6% of the mean oil yield (L. Goodfellow 1974). However, some may regard such comparisons with process yields as troublesome and error prone, particularly if unskilled laboratory personnel or inadequate time-temperature controls are used. A preferred process yield evaluation may be based on the efficiency with which the retort converts carbon in kerogen into oil and gas.

The use of organic carbon distributions to express process yields is, of course, not new. For example, H. L. Feldkirchner (1979) reported data on the conversion of feed raw shale to products in operation of the Hytort process. The following distribution of feed organic carbon in Colorado oil shale to products was reported:

Oil	78	weight percent
Gas	13	weight percent
Residue	<u>9</u>	weight percent
	100	

No experimental details were given in this publication, particularly in regard to the distribution of organic and inorganic carbon dioxide in the gas.

We have adopted the concept of Carbon Efficiency Index (CEI) to express this concept. The CEI mathematically is

$$CEI = \frac{\text{Weight Organic Carbon in Product Oil plus Gas}}{\text{Weight Organic Carbon in Oil Shale}}$$

As an example, the CEI of the TOSCO II product balance given in Table 4 is:

$$\text{CEI} = \frac{96.8 \text{ Kg organic carbon in oil} + 15.7 \text{ Kg organic carbon in gas}}{150.0 \text{ Kg organic carbon in oil shale}}$$

$$\text{CEI} = 0.75$$

The remaining organic carbon is retained in the processed shale along with very small amounts in the process water.

If desired the process CEI can be compared with the CEI of a corresponding TMBA operation, but such a comparison may not be needed on a routine basis.

Two chemical facts are important in using the CEI comparisons. The laboratory does not measure organic carbon directly but determines its value as the difference between total carbon, obtained by standard combustion assay procedures (see below), and mineral carbon as obtained by procedures involving standard mineral acid digestion and measurement of evolved carbon dioxide. Further, carbon dioxide obtained in the process gas by indirect retorting is produced by both kerogen (organic) decomposition and by partial decomposition of contained mineral carbonates such as nahcolite, dawsonite, calcite and dolomite. We are interested primarily only in that product gaseous carbon dioxide which is organic in origin. This value can be obtained by adjusting the total quantity of carbon dioxide in the gas and dissolved in the retort water by subtracting the analytically determined mineral carbon dioxide lost in the conversion of raw shale to processed shale. Thus, careful mineral carbon determinations are required for the raw shale and processed shale. Total carbon dioxide is determined in the gas by gas chromatography.

Energy Efficiency Comparisons

Yields have been expressed for the operation of both the direct and indirect (hot gas heated) versions of the

Paraho process (Heistand 1979). In this procedure the combustion energy of Fischer assay gas was estimated by use of US Bureau of Mines procedure (1951) in which the heating values of gases produced by Fischer assay were determined. This combustion energy of the gas was expressed as equivalent oil (1 liter of oil = 9500 kcal). The sum of product oil plus gas from the process, expressed as equivalent oil, formed the basis of product yield for comparison to Fischer assay oil plus gas. In addition, the combustion energy supplied by the raw shale was added to the retort products to the extent that it was burned in the retort (direct mode). This combustion energy was, again, expressed as equivalent oil. If product oil or gas were burned external to the retort the same amount of energy equivalent was subtracted from the products. This is illustrated in Table 6.

Some of the gas produced in the direct heated Paraho mode is derived from gasification of carbon on the spent shale (Pforzheimer 1979).

This yield analysis does not distinguish between product gas in the dilute form (3,726J/L, 100 Btu/SCF) from the direct heated mode and the 26,080-33,530 J/L (700-900 Btu/SCF) gas of the indirect heated mode.

R. O. Dhont (1979) of Union Oil described product yields from the Union B retort in terms of a thermal efficiency. Thermal efficiency was defined as the "Btu output in the form of products divided by the Btu input in the form of raw oil shale plus other required energy such as steam and power." Values range from 70 to 75%. Oil will be the only product and in calculating this value it was assumed that all of the product high Btu gas was consumed to produce process heat. If the process heat were provided by combustion of spent shale carbon the

gas would become a salable product, and the thermal efficiency would advance to 80-85%.

Dhont reports a value of 3,175 Btu/lb (7385 KJ/Kg) for the calorimetrically determined heating value of raw 34 gal/ton (141 liters/tonne) oil shale.

Calculations from standard heats of formation show that the bomb calorimeter combustion of Piceance Basin raw shale, of 35 gal/ton (146 L/tonne) oil yield, will release about 60 Btu/lb (140 KJ/Kg) from pyrite oxidation (assumed one percent pyrite content) and will absorb about 300 Btu/lb (698 KJ/Kg) from endothermic carbonate decomposition. Other factors in the inorganic chemistry reactions at high temperature may influence the heat of combustion of the raw shale. Oil shales around the world differ greatly in mineral composition and often contain no inorganic carbonates at all. Also, some Colorado oil shales may contain significant concentrations of nahcolite and dawsonite which undergo endothermic decompositions below the temperatures of indirect retorting.

In order to isolate the energy efficiency calculation from mineral carbonate decomposition effects it is desirable to leach the feed raw shale with mineral acid and determine the heating value of the leached raw shale. This allows calculation of an energy efficiency based on organic components only, except for the combustion energy of any contained pyrite. If pyrite content is high then corrections can be made.

We can then express the Energy Efficiency Index (EEI) as follows:

$$\text{E.E.I.} = \frac{\text{Combustion Energy of Oil Plus Gas}}{\text{Combustion Energy of Mineral Acid Leached Raw-Shale}}$$

EXPERIMENTAL PROCEDURES

Tosco Material Balance Assays (TMBA) were run as described previously (L. Goodfellow 1974).

Calorimetry work was done in a Parr Adiabatic Calorimeter. Oil samples were run in accordance with American Society for Testing and Materials (ASTM) procedure D240-76 "Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter." Raw and spent shales were run in like fashion except for several modifications. The samples were mixed with equal amounts of benzoic acid to achieve complete combustion, and the results were calculated to a benzoic acid free basis. A special platinum cup, which allows only minimum sample contact, is used as a sample holder rather than the usual cups to allow for better oxygen contact and thus further assure complete combustion.

Total carbon analyses were run on a Perkin Elmer 240C Elemental Analyzer. This instrument combusts the sample in oxygen converting all carbon to carbon dioxide. The amount of this carbon dioxide is determined by thermal conductivity.

Mineral carbons were determined by a Coulometrics Inc. CO₂ Coulometer. In this instrument CO₂ is released from the sample by acid. The CO₂ is carried to a coulometer cell where the amount of CO₂ is determined. This instrument was also used for the Total Organic Carbon content of the one water sample tested. The sample was first treated with HCl to release any inorganic carbon (as CO₂). The sample was then syringe injected into a 950°C furnace with oxygen where any carbon was converted to CO₂ and measured as above.

To obtain acid leached shale a raw shale sample was carefully reacted with 1:1 HCl at room temperature. The sample was mixed with a stirring rod until no CO₂ evolution was observed. The sample was then recovered by filtering through acid hardened filter paper which had been tared. The sample was washed several times to remove all acid and allowed to air dry and finally dried at 105°C until a constant weight was obtained.

EXPERIMENTAL RESULTS

To illustrate some of the above carbon efficiencies and energy efficiencies Tosco Material Balance Assays (TMBA's) were run in duplicate on (1) raw shale, (2) on the same shale with NaOH in the collection tube to retain carbonates in the process water for analysis, and (3) on a hydrochloric acid leached sample of the shale. The hydrochloric acid frees the carbonates to eliminate the endothermic contribution of the carbonates.

The acid leached material amounted to 54% by weight of the original shale. The recovery of major elements was as follows:

Organic Carbon - $21.03\% \times 0.54 = 11.36\%$ or 99.4% recovery (11.43% organic C initially)

Hydrogen - $2.93\% \times 0.54 = 1.58\%$ or 95.3% recovery (1.66% initially)

Sulfur - $1.04\% \times 0.54 = 0.56\%$ or 98.5% recovery (0.57% initially)

Table 7 shows product yields, analyses and calorimetric heating values obtained in a normal TMBA product collection mode. This mode is called the "Usual Procedure" and ignores the small amounts of organic and inorganic carbon in the retort water. These data are representative of data obtained by indirect heating processes. In Table 9 we have displayed the corresponding balances and indexes.

Table 8 shows product yields, analyses and calorimetric heating values which were obtained in a manner slightly modified in that the retort water, collected with added caustic, was analyzed for total carbon and mineral carbon. Organic carbon content was calculated in the usual manner. For this discussion it was assumed that mineral carbon in the retort water was derived only from mineral carbonate decomposition in the retort. This more complex procedure may be adopted

when desired.

Tables 9 and 10 display the corresponding balances and indexes.

Table 11 illustrates the distributions of total, mineral and organic carbon in TMBA gases.

Table 12 reports the properties of the acid leached raw shale.

DISCUSSION

In measuring process yields from indirect retorting of oil shale it is clear that direct comparison of process oil yields with those from Fischer assay is not particularly useful. However, total hydrocarbon yields from a process may be compared with total hydrocarbon yields from Tosco Material Balance Assay (TMBA) to obtain a useful correlation which will readily register both yield losses and changes in gas/oil ratios.

The use of organic carbon correlations, carbon efficiency index (CEI), eliminates the need for Fischer assay or TMBA but presents the need for classifying gaseous carbon dioxide as to organic and inorganic origin. This can be done by subtracting total mineral carbon in spent shale from that in raw shale and calculating as mineral derived carbon dioxide. In many cases this may be a small value. In Table 11 mineral derived CO_2 was, however, about 77 percent of total CO_2 . In cases where precise accounting of organic carbon is required for balance purposes it may be necessary to analyze retort water carbon forms. This, however, is not required in calculating CEI. The CEI value is a useful correlation, but it is not a good measure of energy efficiency - a more important concept. CEI does not distinguish between carbon in high heating value volatile hydrocarbons and that remaining as coke in the spent shale.

The preferred measure of indirect heated oil shale process yields is the

Energy Efficiency Index (EEI). This index is the ratio of the sum of the combustion energy of product oil and gas to the combustion energy of the corresponding feed raw shale after leaching with mineral acid. The mineral acid leaching removes inorganic carbonates which may vary greatly in concentration and are decomposed endothermally in the calorimeter. Mineral acid treatment, however, does not remove pyrite, which burns in the calorimeter. At pyrite concentrations above one to two percent it may be desirable to use a correction factor.

When the CEI and EEI values in Tables 9 and 10 are compared, it is seen that the latter value is significantly higher. This reflects the preferential conversion of kerogen hydrogen to high heating value volatile products. Hydrogen compound distribution is an important variable in combustion energy balances and is not registered when only organic carbon is considered.

CONCLUSION

The Energy Efficiency Index (EEI) is the preferred representation of indirectly heated oil shale retort product yield.

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Table 1

TYPICAL CHEMICAL ANALYSIS OF KEROGEN

<u>Element</u>	<u>Weight Percent</u>
Carbon	80.52
Hydrogen	10.30
Nitrogen	2.39
Sulfur	1.04
Oxygen	5.75
	<u>100.00</u>

Table 2

TYPICAL ANALYSIS OF OIL SHALE MINERALS

<u>Component</u>	<u>Weight Percent</u>
Dolomite	32
Calcite	16
Quartz	15
Illite	19
Albite	10
Microcline	6
Pyrite	1
Analcite	1
	<u>100</u>

Table 3

GAS COMBUSTION RETORT PRODUCT SLATE

	<u>Weight of Component (Kg)</u>
<u>Feed</u>	
Raw Shale	907 (25.5 G.P.T. assay, 106.4 liters/tonne)
<u>Products</u>	
Processed Shale	NG
Oil	77.8*
Gas	171 cu.m.**
Water	34.5

* 92.2 L/tonne or 86.6 vol. percent of Fischer assay.

** ca 3743 J/L dry gas heating value. NG = Not Given. The processed shale contained 2.1% organic carbon.

Table 4

TOSCO II RETORTING -

PRODUCT AND ORGANIC CARBON BALANCES (A. F. Lenhart 1968)

	<u>Weight of Component (Kg)</u>	<u>Distribution of Components (Wt. %)</u>	<u>Weight Organic Carbon (Kg)</u>	<u>Distribution of Organic Carbon (Wt. %)</u>
<u>Feed</u>				
Raw Shale (33 G.P.T. assay) (137 liters/tonne)	907		150	
<u>Products</u>				
Processed Shale	747.5	82.4	36.9	24.6
Oil	114.3*	12.6	96.8	64.6
Gas	32.2**	3.5	15.7	10.5
Water	10.4	1.2	nil	nil
	<u>904.4</u>	<u>99.7</u>	<u>149.4</u>	<u>99.7</u>

* 33 gallons
** ca 850 Btu/SCF dry gas heating value.

Table 5

THE TOSCO II SYSTEM SEMI-WORKS
PLANT YIELDS

	Kgs Yield/100 Kg Fischer Assay Oil	
	Semi-Works Plant	TOSCO Material Balance Assay
H ₂	0.41	0.84
CO	0.91	1.16
C ₁	2.22	3.17
C ₂	2.84	2.45
C ₂₋	1.37	1.06
C ₃	1.62	1.63
C ₃₋	1.41	1.41
Sub-Total	10.78	11.72
i-C ₄	0.13	0.07
n-C ₄	0.68	0.67
C ₄₋	1.38	1.10
C ₅	1.67	1.14
C ₆	1.17	0.69
C ₇	0.76	0.34
C ₈	0.36	0.13
C ₈₊	0.10	--
Fischer Assay Oil	99.59	100.00
Sub-Total	105.84	104.14
Total	116.62	115.86
CO ₂	8.58	9.14
H ₂ S	1.34	1.14
GRAND TOTAL	126.54	126.14

Table 6

PARAHO PROCESS YIELDS (Liters/Tonne)

	Direct Mode	Indirect Mode
Raw Shale Feed Assay Oil + Gas	123	115
Paraho Retort Product Oil + Gas	126	115
Combustion Energy	+14	-14
TOTAL	140	101
Yields (Vol % of Assay)		
Product Oil + Gas	102.4	100
Retort Overall	113.8	87.8

Table 7

OIL SHALE INDIRECT RETORTING ANALYSES - USUAL PROCEDURE

	Weight of Component* (Kg)	Weight Percent Total Carbon	Weight Percent Mineral Carbon	Weight Percent Organic Carbon	Higher Heating Values (KJ/Kg)**
TMBA #2239					
<u>Feed</u>					
Raw Shale	907.2	16.88	5.45	11.43	5,208
<u>Products</u>					
Spent Shale	789.3	8.61	5.89	2.72	556
Oil	87.0	84.79	ND	84.79	42,960
Gas	24.2	44.30	12.20	32.10	20,950
Water	6.6	ND	ND	ND	ND
Total	907.1				
Recovery					
TMBA #2278					
<u>Feed</u>					
Raw Shale	907.2	16.88	5.45	11.43	5,208
<u>Products</u>					
Spent Shale	789.3	8.82	5.87	2.95	544
Oil	87.0	84.97	ND	84.97	43,020
Gas	23.3	44.42	13.25	31.17	21,310
Water	7.6	ND	ND	ND	ND
Total	907.2				

* Normalized data

** Raw shale, acid leached, gave 54 wt. percent yield of product which had HHV of 9930 KJ/Kg.

ND - Not Determined

Table 8

OIL SHALE INDIRECT RETORTING ANALYSES - RETORT WATER ANALYZED

	<u>Weight of Component* (Kg)</u>	<u>Weight Percent Total Carbon</u>	<u>Weight Percent Mineral Carbon</u>	<u>Weight Percent Organic Carbon</u>	<u>Higher Heating Values (KJ/Kg)**</u>
<u>TMBA #2240</u>					
<u>Feed</u>					
Raw Shale	907.2	16.88	5.45	11.43	5,208
<u>Products</u>					
Spent Shale	789.0	8.65	5.92	2.73	633
Oil	87.5	83.78	ND	83.78	42,310
Gas	24.0	44.92	10.39	34.53	21,546
Water	6.7	9.46	3.38	6.08	ND
Total	907.0				

* Normalized

** Raw shale, acid leached, gave 54 wt. percent yield of product which had HHV of 9930 KJ/Kg

ND - Not Determined

Table 9

OIL SHALE INDIRECT RETORTING BALANCES AND INDEXES - USUAL PROCEDURE

	<u>Weight of Component* (Kg)</u>	<u>Weight Total Carbon (Kg)</u>	<u>Weight Mineral Carbon (Kg)</u>	<u>Weight Organic Carbon (Kg)</u>	<u>(Combustion Energy (KJ x 10⁶))</u>		<u>CEI</u>	<u>EI</u>
					<u>Actual</u>	<u>Leached</u>		
<u>TMBA #2239</u>								
<u>Feed</u>								
Raw Shale	907.2	153.1	49.4	103.7	4.72	4.86**	78.7	87.4
<u>Products</u>								
Spent Shale	789.3	67.9	46.5	21.5	0.44			
Oil	87.0	73.8	--	73.8	3.74			
Gas	24.2	10.7	2.9	7.8	0.51			
			(by Diff)					
Water	6.6	--	--	ND	--			
Total	907.1	152.4	49.4	103.1	4.69			
Recovery		(99.6%)		(99.4%)	(99.5%)			
<u>TMBA #2278</u>								
<u>Feed</u>								
Raw Shale	907	153.1	49.4	103.7	4.72	4.86	78.3	89.7
<u>Products</u>								
Spent Shale	789.3	69.6	46.4	23.3	0.43			
Oil	87.0	73.9	--	73.9	3.74			
Gas	23.3	10.3	3.0	7.3	0.50			
Water	7.6	--	--	--	--			
Total	907.2	153.8	109	104.5	4.67			
Recovery		(100.5%)		(100.7%)	(98.9%)			

* Normalized data

** 907 x 54% yield x 9930 KJ/Kg = 4.86 x 10⁶ KJ. This value used in calculation of EEI.

ND - Not Determined

Table 10

OIL SHALE INDIRECT RETORTING BALANCES AND INDEXES -
RETORT WATER ANALYZED

	Weight of Component* (Kg)	Weight Total Carbon (Kg)	Weight Mineral Carbon (Kg)	Weight Organic Carbon (Kg)	(Combustion Energy (KJ x 10 ⁶))		CEI	EEI
					Actual	Leached		
TMBA #2240								
<u>Feed</u>								
Raw Shale	907.2	153.1	49.4	103.7	4.73	4.86**	78.7	86.8
<u>Products</u>								
Spent Shale	789.0	68.3	46.7	21.5	0.50			
Oil	87.5	73.3	--	73.3	3.70			
Gas	24.0	10.8	2.5	8.3	0.52			
		(by diff.)						
Water	6.7	0.6	0.2	0.4	-			
Total	907.2	153	49.4	103.5	4.72			
Recovery		(99.9%)		(99.8%)	(99.7%)			

* Normalized

** 907 x 54% yield x 9930 KJ/Kg = 4.86 x 10⁶ KJ. This value used in calculation of EEI.

ND - Not Determined

Table 11

ORGANIC DERIVED CARBON DIOXIDE FROM DUPLICATE TMBA DETERMINATIONS

TMBA Procedure	TMBA No.	Total C (as CO ₂) in Gas (Kg/tonne*)	Mineral C (as CO ₂) in Gas Plus Water (Kg/tonne*)	Organic C (as CO ₂) in Gas Plus Water (Kg/tonne*)
Retort Water Analyzed	2240 2282	4.0 4.0	2.8 3.1	1.2 0.9
Acid Leached Raw Shale	2242 2275	1.1 1.1	0 0	1.1 1.1

* Kg of carbon per tonne of raw shale feed. Values were obtained from TMBA gas analysis.

** As indicated previously, these values are equal to the differences between mineral carbon in raw shale and mineral carbon in spent shale.

Table 12

PROPERTIES OF ACID LEACHED RAW SHALE
(54 weight percent of raw shale)

<u>Elemental Analysis Component</u>	<u>Weight Percent</u>
Total Carbon	21.0
Mineral Carbon	0.0
Organic Carbon	21.0
Sulfur	1.04
<u>Higher Heating Value</u>	9,930 KJ/Kg