2444 HYCRUDE CORPORATION

BENEFICIATION - HYDRORETORTING OF U.S. OIL SHALES PROGRAM YEAR 2 FOR

Mc Quinston
OSh

DRAFT
12.02.87
2:45 PM

BENEFICIATION-HYDRORETORTING OF U.S. OIL SHALES

Program Year 2

For The Period
October 1986 through September 1987

Date Published - December 1987

Prepared By

HYCRUDE Corporation
10 West 35th Street
Chicago, IL 60616

Prepared For The

MINERAL RESOURCES INSTITUTE
School of Mines and Energy Development
The University of Alabama
P.O. Drawer AY
University, Alabama 35486

In Conjunction With

THE UNITED STATES DEPARTMENT OF ENERGY
Grant No. DE-FG21-85LC11066

TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

The following is a summary by task of the work conducted by HYCRUDE and its subcontractors, IGT and Jenike and Johanson, Inc., for the Mineral Resources Institute of the University of Alabama in conjunction with DOE Grant No. DE-FG21-85LC11066 during the period October 1986 through September 1987. The responsibilities of HYCRUDE and its subcontractors for Program Year 2 are contained in Phase II-B of the overall program. IGT has conducted 7 mini-bench-unit (MBU) tests and 1 HAU test during Program Year 2. Jenike and Johanson, Inc. (J&J) has conducted hydroretorting studies, work on the particle integrity of beneficiated oil shale briquettes. HYCRUDE has developed conceptual process designs based on the results of IGT testwork. The second program year report from IGT is contained in the Appendix A and the two reports from J&J covering the attrition testing and briquette strength optimization studies are contained in Appendix B.

PHASE II-B. HYDRORETORTING STUDIES

Task 1. Assessing Hydroretorting Characteristics of Beneficiated Oil Shales

IGT conducted a batch MBU test and an HAU test employing 1/2 inch long x 1/2 inch x 3/8 inch oval shaped briquettes to provide material for the particle integrity testing and assess the particle size effect on hydroretorting oil yields and carbon distribution. The results indicate that the same oil yields and carbon conversions are obtained from hydroretorting of the briquettes as those obtained from hydroretorting a standard +6-40 mesh feedstock.

Six MBU tests were conducted on Alabama, Kentucky and Michigan oil shales to assess the effects of beneficiation organic carbon conversion. The results show a relatively constant organic carbon conversion and percentage of organic carbon to oil for each grade of a particular feedstock. Most significant is the observation of reduced hydrogen requirements for the beneficiated feedstocks. This reduction is due primarily to the removal of pyrite during the beneficiation process. On a percentage basis, the hydrogen requirements for the Alabama, Kentucky and Michigan oil shales were reduced by 44, 47 and 20 percent, respectively.

Task 2. Assessing Integrity of Beneficiated Shale Feedstock

J & J conducted a preliminary series of tests in April on raw and spent beneficiated briquettes which contained no binders. The results indicate that these briquettes were not sufficiently strong to survive processing in the hydroretorting moving-bed reactor as currently proposed. Therefore, a second study was conducted by J&J to produce briquettes from MRI supplied beneficiated oil shale stock using various binders and curing techniques. Twenty-three tests were conducted on briquettes employing binders such as refractory cement, fly ash, dolomite clay and quicklime. Curing time was found to have the most significant effect on briquette strength. However, these binders and curing techniques did not produce briquettes of sufficient strength for processing in the proposed report.

A tests conducted on briquettes employing calcium ligno-sulfonate (lignosite) as suggested by prior MRI work, was found to produce a three and one-half times increase in strength over the "base case" briquettes employing no binder. Combinations of lignosite and hydrated lime will be investigated during Program Year 3.

Task 3. Hydrocarbon Product Evaluation

Analysis of Task 1 MBU results indicate that beneficiation of the oil shale has a minimal effect on product oil quality. For any particular oil shale, the oil heating values are equivalent for all grades of feedstock. Sulfur content varies slightly, however, no specific trend is observed for all shales. Nitrogen content shows a moderate rise with increasing feedstock grade for the Alabama and Michigan oil shales. The Kentucky oil shale exhibits no change in the product oil nitrogen content at various feedstock grades.

Task 4. Scale-up of Hydroretorting Data

HYCRUDE has developed conceptual commercial plant process designs for all MBU runs conducted in Task 1. These designs will provide the basis for the selection of a shale for the conceptual beneficiation-hydroretorting plant design to be generated during Program Year 3.

DRAFT
12.02.87
2:45 PM

PROGRAM OBJECTIVE

The overall objective of the three year program is to evaluate the technical, environmental, and economic feasibility of processing the U.S. oil shales by a combined processing scheme employing MRI beneficiation and the HYTORT process.

The specific objective of the second year program at HYCRUDE are: (1) to evaluate the hydroretorting characteristics of the three selected shales supplied by MRI, (2) to evaluate the particle integrity of a briquetted beneficiated shale supplied by MRI, (3) to evaluate the hydrocarbon products produced from the combined MRI beneficiation-HYTORT process, (4) to scale up the hydroretorting data to a commercial plant scale, and (5) to assess the potential environmental impact for a conceptual commercial HYTORT plant operation which utilizes beneficiated shales as feedstocks.

INTRODUCTION

The concept of moving-bed hydroretorting, the retorting of shale in a hydrogen-rich atmosphere at elevated pressures, has forced a re-evaluation of the potential of the Eastern oil shale resources. Moving-bed hydroretorting, termed the HYTORT Process, has the capability to obtain oil yields of up to 250% of the Fischer Assay oil yields for these shales. HYCRUDE Corporation maintains a continuous effort to develop and commercialize the HYTORT Process, which was initiated at HYCRUDE's parent corporation, IGT. This program is a part of the development effort for the HYTORT Process.

Preliminary test work conducted in conjunction with MRI indicates that it is possible to achieve even higher oil yields from Eastern oil shales by combining HYTORT with the beneficiation techniques being developed by MRI. The MRI technique involves wet ultra-fine grinding (minus 20 microns) of the raw shale followed by froth flotation to recover a concentrate containing 2-2.5 more total organic carbon than in the raw shales. The beneficiation step potentially offers reduced capital and operating costs for production of a given quantity of oil.

By combining the MRI and HYTORT processes, an Indiana New Albany oil shale sample having a Fischer assay oil yield of 13 gal/ton has been upgraded to yield 54 gallon of oil per ton, thereby opening up attractive possibilities for utilizing Eastern oil shales more efficiently. These test results suggest that certain Eastern shales that had previously been considered too low even for HYTORT processing may be recoverable.

In addition to the Eastern Devonian Shales there are other low grade oil shale occurrences in the United States which have attracted only cursory attention. Some of these shales also may respond to beneficiation and hydroretorting to yield shale oil recoveries equivalent to those obtained from the Indiana New Albany shale.

This work is part of an advanced research and development program to evaluate the technical, environmental, and economic feasibility of combining the MRI beneficiation and HYTORT processes for treating selected U.S. oil shales. Oil shales of various grades from different locations nationwide will be tested to determine economically-optimum operating conditions for beneficiation and subsequent HYTORT processing. At the conclusion of the program, the feasibility of this processing approach will be assessed and plans will be formulated for commercial development.

The results from the second-year program year are presented in the following sections.

TECHNICAL PROGRESS REPORT

PHASE II B - HYDRORETORTING STUDIES

Task 1. Assessing Hydroretorting Characteristics of Beneficiated Oil Shales

Objective. The objective of this task is to determine the effects of feed shale particle size, beneficiation grade and the feed shale sulfur content on the hydroretorting characteristics of the three shales (Alabama, Kentucky and Michigan) tested during Program Year 2.

Discussion. The test plan summarized in Table 1 consists of 7 MBU runs and 1 HAU run.

Table 1. Test Plan for Task 1

Run	Shale	Sample	IGT Run No.	Purpose
1	Alabama	MH-1 Briquettes	87MBU-6	Particle size effect and particle integrity testing
2	Alabama	MH-1 Briquette	HAU-MH1-P	Wall and particle size effect
3	Kentucky	MH-2	87MBU-8	Base line
4	Kentucky	MH-2 BCP-1B	87MBU-15	Effect of beneficiation
5	Michigan	MH-12A	87MBU-16	Base line
6	Kentucky	MH-2-BCP-1A	87MBU-14	Effect of beneficiation
7	Alabama	MH-1 Low Sulfur	87MBU-20	Effect of low sulfur
8	Michigan	MH-12 Low Sulfur	87MBU-19	Effect of low sulfur

All of the planned eight runs have been completed and the run results are summarized in IGT's Second Annual Report (Appendix A). Note that runs 1 and 2 are batch reactor tests and all others are flow reactor tests. The operating conditions for each of the regular MBU tests (continuous flow) are summarized in Table 2.

Table 2. Summary of MBU Tests Operating Conditions

Shale Origin	Alabama			Kentucky N.A.			Michigan	
Shale Type	Raw	High S	Low S	Raw	High S	Low S	Raw	Low S
MBU Run No.	86MBU -11*	86MBU -12*	87MBU -20	87MBU -8	87MBU -15	87MBU -14	87MBU -16	87MBU -19
Operating Conditions								
Maximum Bed Temperature, F	1065	1100	960	1000	945	950	945	950
Total Pressure, psi	617	620	615	606	616	609	615	612
Total Shale Residence Time, minutes	64	43	56	60	57	54	60	56

* Test was conducted in Program Year 1.

The operating conditions for the batch tests (87MBU-6 and HAU-MH1-P) are summarized in Table 3.

Table 3. Summary of Operating Conditions for Batch Tests

Shale Origin	Alabama	
Reactor Type	HAU	MBU
Run No.	HAU-MH1-P	87MBU-6
Operating Conditions		
Max. Temp.,	1052	1105
Pressure, psi	613	615
Shale Res. Time, min	30	30

Feed Shale Particle Size Effects

For the envisioned beneficiation/hydroretorting commercial plant operation, the feedstock will be briquetted to a larger size consist (approximately 1/2 inch) than the beneficiated shale consist (-6+40 mesh) used in the MBU runs. To ensure the MBU test results are properly used in the development of conceptual process designs, Run 1 (87MBU-6) was conducted to determine particle size effect on the oil yield and carbon distribution. Run 2 (HAU-MH1-P) was conducted in the HAU unit to determine if the wall effect, the tendency of a packed bed to exhibit higher gas flows at the walls, is sufficiently large to effect the results of MBU tests conducted on large particles.

Comparison of Runs 1 and 2 (87MBU-6 and HAU-MH1-P), both conducted using 3/4 inch long and 1/2 x 3/8 inch oval shaped briquettes, shows that the measured oil production and carbon conversion are similar (See IGT report in Appendix A, Table 3 for a detailed run comparison). Thus the wall effect associated with the processing of large particles do not appear to create any differences between the MBU and the HAU results (2 inch versus 1 inch reactor diameter, respectively). Additionally, comparison of Runs 87MBU-6 (batch 3/4 x 3/8 inch briquette) and Run 86MBU-12 (beneficiated normal particle size), which was conducted in Program Year 1, shows little difference in oil yields and carbon distribution for the Alabama shale. The reconciled oil yields from 87MBU-6 (briquette) and 86MBU-12 (normal size) are 58.7 and 57.1 GPT, respectively. The distribution of organic carbon to gas, oil and residue is 18.1, 48.9, and 32.9 percent for the 87MBU-7 test (briquette) and 18.0, 53.0 and 29.0 percent for 86MBU-12 test (normal size). Based on the results discussed above, it is apparent that the MBU test conducted on a -6+40 mesh beneficiated feedstock will provide the appropriate data for use in development of conceptual process designs.

Beneficiation Grade and Sulfur Content Effects

The percent of Fischer Assay oil yield is used when making comparisons between feedstocks of varying grades to provide a uniform basis for assessment of the effect of beneficiation on the HYTORT oil yield. Listed in Table 4 are oil yields for the raw and beneficiated shales tested.

Note that MRI provided HYCRUDE with two types of beneficiates for both Alabama and Kentucky raw shales. The first type contains more sulfur and is produced by the MRI bulk flotation process. The second type contains less sulfur and is produced by the MRI regrind-flotation process in which the rougher flotation froths are reground before or during the cleaning operations to enhance the removal of pyritic sulfur from the kerogen.

The results shown in Table 4 indicate a relatively constant organic carbon conversion for each grade of a particular oil shale. The organic carbon conversion of the Alabama shale ranging from 71.0 to 72.7 percent, the Kentucky shale from 80.2 to 81.4 percent and the Michigan shale from 80.6 to 84.8 percent. Although the percentage of Fischer Assay oil yield observed in the hydroretorting assay appears to have greater variation (about 30 percent absolute for the Alabama and Kentucky shales), the difference is not significant enough to conclude that any reduction or enhancement in the relative yields has occurred. Additionally, the organic carbon conversion provides a more accurate indication of beneficiation's effect on hydrocarbon yields because the errors associated with a laboratory analyses are less than the $\pm$1 gal/ton and $\pm$ 2 gal/ton errors experienced in the Fischer Assay are hydroretorting assay units, respectively.

Hydrogen Requirements

The hydrogen consumption for the MBU runs on the Alabama, Kentucky and Michigan raw and beneficiated oil shales is shown in Table 5. Employing the hydrogen consumption values in terms of SCF/gal of raw product oil for comparison purposes, it is readily apparent that the beneficiated oil shales require significantly less hydrogen for a given organic carbon conversion.

Table 4. Summary of Oil Yields, Percent Carbon Conversions and Percent Carbon to Oil for the MBU Tests

Shale	ALABAMA		
MBU Run No.	86MBU-11*	86MBU-12*	87MBU-20
Shale Type	Raw	Beneficiated (High Sulfur)	Beneficiated (Low Sulfur)
Sulfur in Feed, %	8.39	12.05	8.97
Fischer Assay, GPT	13.0	30.3	33.9
Hydroretorting Assay, GPT	21.6	57.1	66.6
Percent of Fischer Assay	166	188	196
Organic Carbon Conversion, %	72.6	71.0	72.7
Organic Carbon To Oil, %	49.1	53.0	53.6

Shale	KENTUCKY		
MBU Run No.	87MBU-8	87MBU-15	87MBU-14
Shale Type	Raw	Beneficiated (High Sulfur)	Beneficiated (Low Sulfur)
Sulfur in Feed, %	5.45	6.02	4.55
Fischer Assay	13.3	33.9	50.2
Hydroretorting Assay, GPT	25.4	53.9	88.5
Percent of Fischer Assay	191	159	176
Organic Carbon Conversion, %	81.4	80.2	80.8
Organic Carbon To Oil, %	66.0	63.4	66.7

Table 4. Summary of Oil Yields, Percent Carbon Conversions and Percent Carbon to Oil for the MBU Tests (Cont.)

Shale	MICHIGAN	
MBU Run No.	87MBU-16	87MBU-19
Shale Type	Raw	Beneficiated (Low Sulfur)
Sulfur in Feed, %	4.07	3.4
Fischer Assay	14.8	40.5
Hydroretorting Assay, GPT	26.8	72.4
Percent of Fischer Assay	181	179
Organic Carbon Conversion, %	80.6	84.8
Organic Carbon To Oil, %	68.2	74.1

The maximum observed reductions in hydrogen consumptions on a percentage basis for the Alabama, Kentucky and Michigan oil shales are 44, 47 and 20 percent, respectively. The primary reason for the reduction in hydrogen requirements is believed to be due to the removal of substantial quantities of pyrite in the beneficiation process. The reduction in hydrogen requirements should prove to have a very beneficial effect in the overall plant economics.

Task 2. Assessing Integrity of Beneficiated Shale Feedstock

Objective. The objective of this task is to determine the particle integrity of the briquetted beneficiated Alabama feed shale as well as the integrity of its spent shale.

Discussion. Determination of the particle integrity of he feed processed shale is necessary to assess the amount of particle size degradation which will occur during processing. Due to the limited quantity of spent shale that can be generated from processing the briquetted, beneficiated Alabama shale in the batch MBU test (Task 1), the scope of the integrity test for the spent shale will be narrower than the scope for the raw briquetted, beneficiated Alabama shale. However, J&J measurements of the briquette compressive crushing strength indicate that the spent shale briquettes from Run 87MBU-6 are at least as strong as the raw shale briquettes. The results of tests on the raw shale briquettes can thus be extrapolated for use in a preliminary assessment of spent shale briquette attrition.

Table 5. Comparison of Hydrogen Requirements for Raw and Beneficiated Oil Shale*

Run	Type	SCF/Ton	Gal/Ton	SCF/Gal
Alabama				
86MBU-11	Raw	3857	21.6	178.6
86MBU-12	High Sulfur Beneficiated	6947	57.1	121.7
87MBU-20	Low Sulfur Beneficiated	6709	66.6	100.7
Kentucky				
87MBU-8	Raw	3005	25.4	118.3
86MBU-15	High Sulfur Beneficiated	4420	54.0	81.9
87MBU-14	Low Sulfur Beneficiated	5514	88.6	62.2
Michigan				
87MBU-16	Raw	1856	26.1	71.1
86MBU-19	High Sulfur Beneficiated	4170	72.4	57.6

* Data from page 8, data summary of appropriate MBU Run.

Gravity Flow and Attrition of Beneficiated Oil Shale Briquettes

J & J conducted particle attrition tests on the raw beneficiated oil shale briquettes produced by MRI without any binders to determine particle attrition due to the following four mechanisms:

1. Particle impact on a rigid surface
2. Crushing in cylindrical sections
3. Abrasion on walls
4. Crushing in converging sections

The detailed results of this testing are contained in the J&J HYCRUDE Corporation Report No. 871609-1 of April 27, 1987 (See Appendix B).

A summary of J&J results for particle attrition due to the above four mechanisms (in the same order) is given below:

1. The particles sustained little damage when dropped from 6 feet. Appropriate reactor design should minimize any attrition by this mechanism.

2. The crushing in cylindrical sections refers to the tendency of briquettes to attrite due to the weight of the material itself in an unobstructed cylindrical section. Proposed HYTORT retort designs provided J&J with a basis for calculating an anticipated consolidation stress, which was a maximum of 1100 psf in the cylindrical sections. This value is about 68% of the maximum stress developed in the test program. As a result, a large percentage of broken particles or fines is not expected due to crushing in the cylindrical sections of the proposed retort.

3. The results of small-scale wall abrasion testing indicate that a large amount of fines generation will likely result by the action of this attrition mechanism on the briquettes.

4. Crushing in converging sections addresses the stresses placed on beneficiated shale particles flowing through retort constrictions such as the gas distributor inserts and the mass flow hopper at the vessel bottom. A J&J estimate of fines (-6 mesh) generation at the gas distributors and hoppers is 7%. This compares with a 2-3% fines generation anticipated in the retort due to all mechanisms when processing raw unbeneficiated shale.

This first phase work indicates the need for additional testing to develop stronger beneficiated shale briquettes through the use of binders.

Briquette Strength Tests

For this portion of the test work MRI supplied J&J with a 9 liter sample of oven-dried Alabama oil shale flotation concentrate. From this sample, J&J prepared briquettes using various binders and curing times and temperatures. The detailed results of this effort are contained in J&J's "Report on Briquette Strength Tests" for HYCRUDE Corporation (Final Report 871674-1 in Appendix B).

J & J conducted 23 tests on various briquette types. Using the shear stress of the briquettes without binder as the basis for comparison of relative briquette strengths, it was determined that the most significant operating parameter in briquette preparation was the curing time. These results were for briquettes employing binders such as refractory cement, fly ash, stove liner, dolomite clay and quicklime. However, J&J does not consider these briquettes to be of sufficient strength for processing in a moving-bed retort.

At the suggestion of MRI, J&J conducted tests on briquettes containing 2 percent and 10 percent calcium ligno-sulphonate (lignosite) as the binder. The results are promising in that the strength increases after curing was more than 3-1/2 times the reference strength.

J & J conducted a "hot" test in which briquettes containing 2 percent lignosite and cured for 1 hour at 220 F. After cooling, the briquettes were placed in oven preheated to 650 F for an hour. The "spent" briquettes had changed color from dark brown to light brown and lost almost all of their strength. It must be pointed out this may not be relevant for HYTORT processing, because the retorting medium is hydrogen instead of air used in J&J's "hot" test. In fact, the data from the attrition test program conducted by J&J shows that hydroretorted spent briquettes (prepared without binder from Alabama shale) are at least as strong as the raw briquettes.

In conjunction with the J&J tests, MRI produced briquettes at 10,000 psi in a ram press using 5 percent calcium ligno-sulphonate and 2.5 percent hydrated lime. These particles met the integrity specifications when tested by materials handling procedures conventionally used on coal briquettes. These briquettes withstood 70 pounds of compressive force and doubled in strength after Fischer Assay retorting. Additional work will be conducted during Program Year 3 on this type of briquette.

Task 3. Hydrocarbon Product Evaluation

Objective. The objective of this task is to determine the effect of beneficiation on the properties of the oil products obtained from hydroretorting.

Discussion. The properties of the oil products obtained from processing the raw and beneficiated shales prepared from Alabama, Kentucky and Michigan shales are listed in Tables 6, 7 and 8, respectively. Even though the MBU operating conditions used for each feed shale are not quite identical, the comparisons of the oil properties between the raw and beneficiates still should provide an indication of the effects of beneficiation.

The results indicate that beneficiation has minimal effect on the product oil quality. The heating value for each shale oil is about equivalent for all feedstocks. The oils appear to have a slightly higher API gravity for the beneficiated feedstock, the low sulfur Alabama beneficiate being the only exception.

The sulfur content of the Alabama oil decreased slightly with increasing feedstock grade form 2.27 to 1.82 percent. The Kentucky shale showed no trend, with values ranging from 0.93 to 1.11 percent. The Michigan shale indicated a slight increase in sulfur content with grade going from 0.72 to 0.99 percent.

The nitrogen content of the Alabama oil rises from 1.28 to 1.91 percent as the feedstock grade increases. The middle point from run 86MBU-12 has a nitrogen content of 0.40 which is considered an anomaly based on prior data with regard to nitrogen content. The Kentucky oil shows essentially no change in nitrogen content, the values ranging from 1.99 to 2.05 percent. The Michigan oil shows an increase in nitrogen content from 1.35 to 1.64 as the feedstock grade increases.

Task 4. Scale-up of Hydroretorting Data

Objective. The objective of this task is to use the data obtained in Task 1 and 2 to develop a conceptual commercial HYTORT plant design for processing one of the three shales tested during this program year.

Discussion. The present computer program simulating the conceptual commercial process designs provide the product oil cost data for a plant size of 50,000 BPSD. To obtain cost data at other plant capacities, the cost data at 50,000 BPSD must be adjusted. In order to assist MRI with the selection of a shale and the appropriate plant capacity, conceptual process designs have been prepared for all of the MBU tests conducted during this program year. The material balance closure data for each of the MBU tests are contained in Appendix C. The simulations of the retort section for each of the three shales are contained in Appendix D. The cost data at 50,000 BPSD capacity will be examined and adjusted to other plant capacities in Phase III of the program which is to be conducted during the third program year.

Table 6. Oil Properties from MBU Runs Using Alabama Chattanooga Oil Shale

Run No.	87 MBU-11	87 MBU-12	87MBU-20
Shale Feed Descriptions	Head	Beneficiated High Sulfur	Beneficiated Low Sulfur
Oil Properties			
Ultimate Analysis, wt% (dry and solids free basis)			
Carbon	86.17	85.95	86.03
Hydrogen	10.28	10.20	9.98
Sulfur	2.27	2.21	1.82
Nitrogen	1.28	0.40	1.91
Ash	0.00	0.00	0.00
Oxygen (by difference)	0.00	1.24	0.26
C/H Weight Ratio	8.38	8.43	8.62
Viscosity, SSU at 100°F	52.8	39.3	70.2
API Gravity, degrees API	15.7	19.5	14.5
ASTM-D86 Distillation, °F			
IBP	180	150	170
5%	242	212	256
10%	279	255	316
20%	373	334	395
30%	473	412	502
40%	552	481	593
50%	626	551	655
60%	689	622	703
70%	722	688	733
80%	743	734	752
90%	--	--	--
95%	--	--	--
End Point	750	749	753
% Recovery	85.5	87.0	83.5
% Residue	15.5	14.0	16.5
Heating Value, BTU/lb	18053.	17896	17935
Pour Point, °F	-45	-75	-40
Fischer Assay Oil Yield, GPT	13.0	30.3	34.9

Table 7. Oil Properties From MBU Runs Using Kentucky New Albany Oil Shale

Run No.	87 MBU-8	87 MBU-15	87MBU-14
Shale Feed Descriptions	Head	Beneficiated High Sulfur	Beneficiated Low Sulfur
Oil Properties			
Ultimate Analysis, wt% (dry and solids free basis)			
Carbon	85.54	84.33	84.13
Hydrogen	10.07	9.90	10.01
Sulfur	1.03	1.11	0.93
Nitrogen	2.05	2.04	1.99
Ash	0.00	0.00	0.00
Oxygen (by difference)	1.31	2.62	2.94
C/H Weight Ratio	8.49	8.52	8.40
Viscosity, SSU at 100°F	154.1	119.9	101.4
API Gravity, degrees API	13.3	14.1	14.5
ASTM-D86 Distillation, °F			
IBP	189	182	178
5%	302	275	268
10%	354	336	328
20%	456	430	410
30%	565	514	505
40%	635	598	585
50%	688	658	654
60%	722	699	695
70%	746	726	732
80%	--	746	756
90%	--	--	--
95%	--	--	--
End Point	760	756	760
% Recovery	79.0	87.0	83.5
% Residue	22.5	13.0	17.0
Heating Value, BTU/lb	17708	17738	17744
Pour Point, °F	--	-5	-5
Fischer Assay Oil Yield, GPT	13.3	33.9	50.2

DRAFT
12.02.87
2:45 PM

Table 8. Oil Properties From MBU Runs Using Michigan Antrim Oil Shale

Run No.	87 MBU-16	87MBU-19
Shale Feed Desc iptions	Head	Beneficiated Low Sulfur
Oil Properties		
Ultimate Analysis, wt%		
(dry and solids free basis)		
Carbon	85.79	86.01
Hydrogen	10.34	10.41
Sulfur	0.72	0.99
Nitrogen	1.35	1.64
Ash	0.00	0.00
Oxygen (by difference)	1.80	0.95
C/H Weight Ratio	8.30	8.26
Viscosity, SSU at 100°F	103.5	91.0
API Gravity, degrees API	15.6	16.4
ASTM-D86 Distillation, °F		
IBP	208	170
5%	300	280
10%	361	336
20%	459	436
30%	548	523
40%	628	613
50%	688	670
60%	720	701
70%	743	723
80%	760	734
90%	--	--
95%	--	--
End Point	762	736
% Recovery	83.5	82.5
% Residue	17.5	17.5
Heating Value, BTU/lb	18053	18028
Pour Point, °F	-10	-15
Fischer Assay Oil Yield, GPT	14.8	40.5

DRAFT
12.02.87
12:45 AM

APPENDIX A

IGT QUARTERLY REPORT

DRAFT

HYDRORETORTING OF BENEFICIATED SHALES

Annual Status Report
Program Year 2
for the Period October 1986 through September 1987

Work Performed
For
HYCRUDE CORPORATION
10 West 35th Street
Chicago, Illinois 60616

Under Subcontract Between HYCRUDE Corporation
and
Institute of Gas Technology
Under
Subgrant No. 85-087
Between
The Board of Trustees of the University of Alabama
and
HYCRUDE CORPORATION

November 1987

INSTITUTE OF GAS TECHNOLOGY

EXECUTIVE SUMMARY

This report presents the work performed by the Institute of Gas Technology (IGT) from October 1, 1986 through September 30, 1987 under Contract No. HC-IGT-86-2, "Hydroretorting of Beneficiated Shales". The work was performed by IGT under subcontract to the HYCRUDE Corporation for its Subgrant No. 85-087 between the Board of Trustees of the University of Alabama and HYCRUDE Corporation. The program consists of one task during the second program year, Assessing Hydroretorting Characteristics of Beneficiated Shales.

A sample of briquetted beneficiated Alabama Chattanooga (MH-1) shale was hydroretorted under batch conditions in the HAU and the MBU. Results of the two batch tests are presented. Recovered oil yields were 54 and 53 gas/ton for the MBU and HAU, respectively. The reconciled oil yields were 59 and 70 gal/ton for the MBU and HAU, respectively. Wall effects and channeling did not appear to influence oil yield or carbon distribution. A comparison of the results of the MBU test with briquettes of beneficiated Alabama (MH-1) shale, 87MBU-6, and the MBU test with -6+40 mesh size consist of the same shale, 86MBU-12, shows no effect of particle size on oil yield or carbon conversion.

Six continuous MBU tests were made during this program year. Tests were made with raw (MH-2) and beneficiated (MH-2 BCP-1A and MH-2 BCP-1B) Kentucky New Albany, raw (MH-12a) and beneficiated (MH-12 BCP) Michigan Antrim, and beneficiated (MH-1-B) Alabama Chattanooga shales. Detailed results of these tests are presented in the Appendix. Oil yields and conversions were affected by beneficiation. Two beneficiated shales, Michigan Antrim (MH-12 BCP tested in 87MBU-19) and Alabama (MH-1-B tested in 87MBU-20), were found to lose particle integrity during hydroretorting. However, it should be noted that no binders were employed in the production of these beneficiates. Between 97% and 99% of sulfur converted to product gas was recovered as hydrogen sulfide. Trace product gas sulfur compounds were mostly mercaptans.

INTRODUCTION

This report presents the work performed by the Institute of Gas Technology (IGT) from October 1, 1986 through September 30, 1987 under subcontract to HYCRUDE Corporation. This report constitutes IGT's responsibility for program year 2 of a 3 year program conducted for the HYCRUDE Corporation under subgrant from the University of Alabama in conjunction with the latter's DOE grant. The three-year program is divided into three phases. The first phase, corresponding to the first year's work, has been reported previously. The second phase corresponds to work being conducted in the second and third program years and deals with concentrated research efforts on the three shales selected in Phase 1. IGT has no responsibilities in Phase 3 that involves process integration and evaluation. The IGT portion of the Phase 2 work conducted during program year 2 is complete.

Phase IIB Task 1. Assessing Hydroretorting Characteristics of Beneficiated Oil Shale

Hydroretorting Assay Unit (HAU) Tests

During this year, one test was conducted in the hydroretorting Assay Unit (HAU). The test was conducted with pellets of beneficiated Alabama shale (MH-1).

Experimental Equipment and Test Procedure. A schematic flow diagram of the HAU is shown in Figure 1. The HAU test system comprises a reactor, furnace, condenser, liquid collection vessel, feed and product gas metering systems, and a microprocessor. The HAU reactor consists of a 7/8-inch-diameter, 16-inch-long tube mounted concentrically within a pressure-retaining shell, 1-1/2 inches in diameter and 31 inches in length. This unit is enclosed in a three-zone electrically heated furnace. The heaters are computer-controlled to achieve the desired heat-up rate to maintain the reactor at the operating temperature for a predetermined period of time and to maintain isothermal conditions vertically in the shale sample. The metered feed gas enters the bottom of the pressure shell, is preheated as it flows upward in the annular space surrounding the reactor tube and then enters the reactor. Product vapors from the reactor are cooled by an electrically powered chiller. The condensibles are collected in a graduated glass container, and the gaseous product is either continuously depressurized and metered by a dry test meter prior to venting, or collected and analyzed after

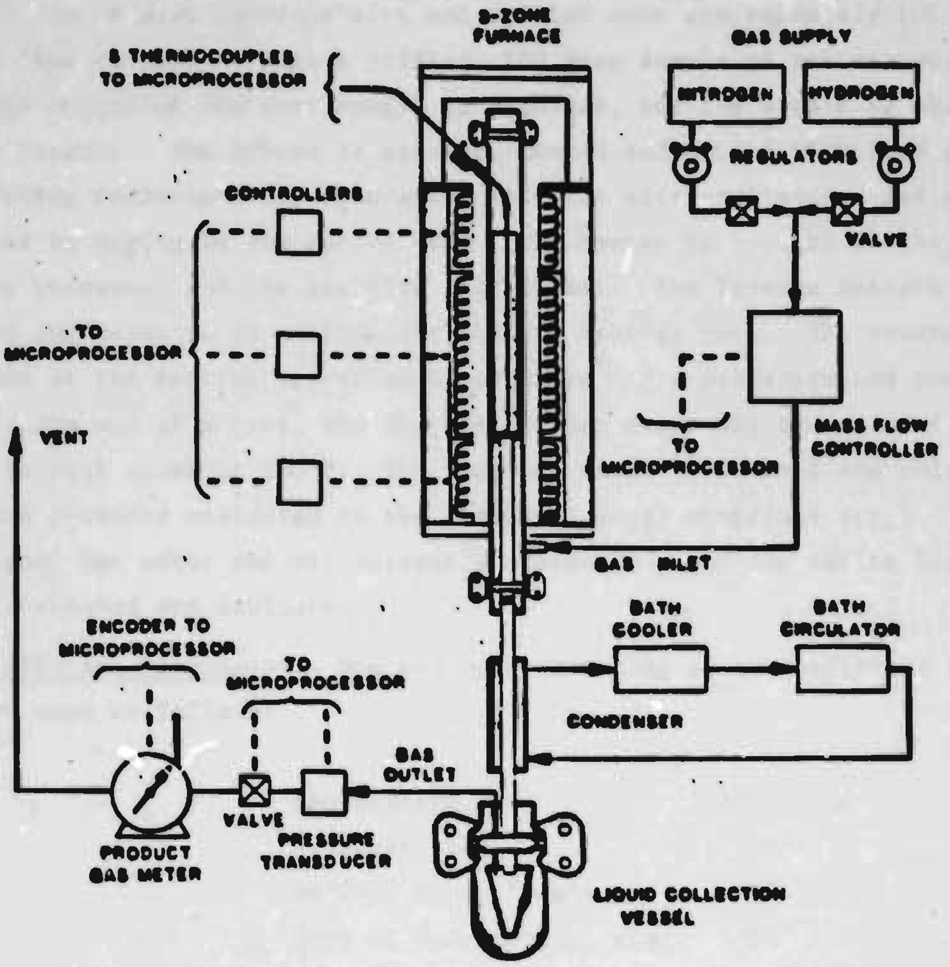


Figure 1. HYDRORETORTING ASSAY UNIT SIMPLIFIED PROCESS FLOW DIAGRAM

the run. No gas analyses were performed as part of this program. Test data, including temperatures, feed and product gas flow rates, and pressures, are continuously recorded.

For usual HAU tests, representative shale samples are crushed, if necessary, to -8 mesh particle size and riffled into approximately 100 gram samples. For the pellet test a riffled, 100 gram sample of pellets was used. The weight of the test sample is recorded, and the sample is charged into the reactor. The system is pressure-tested and purged with feed gas. The operating conditions are programmed into the micro-processor, and a test is started by keying in the run command. The system is brought to the desired operating pressure, and the gas flow rate is set. The furnace heaters are activated and adjusted to achieve the desired heat-up rate. The reactor is maintained at the desired operating temperature for a predetermined period of time. At the end of a test, the furnace is shut down, and the reactor is allowed to cool to about 200°F. The residual shale is removed and weighed, the liquid products collected in the graduated glass container are centrifuged, the water and oil volumes are measured, and the entire liquid sample is weighed and analyzed.

Results and Discussion. Nominal hydroretorting assay conditions for Test HAU-MH1-9 were as follows:

Temperature, °F	1050
Pressure, psig	600
Heat-Up Rate, °F/min	25
Time at Temperature, min	30
Hydrogen Rate, SCF/hr	4

Feed and residue solids analyses are presented in Table 1. Product oil analyses are presented in Table 2. Tables 1 and 2 also contain solids and oil analyses from MBU Test 87MBU-6 conducted with the same beneficiated shale pellets. Test results are summarized in Table 3. Discussion of the two batch tests with beneficiated shale pellets is presented in the Results and Discussion section for the mini-bench unit tests.

Table 1. PELLET TEST SOLIDS ANALYSES

Test	—	87MBU-6	HAU-MH1-P
Sample	Feed	Residue	Residue
Proximate Analysis, wt %	1.09	0	0
Moisture	5.65	1.86	NA
High Temperature Water	44.08	73.53	75.36
Ash			
Ultimate Analysis, wt % dry			
Ash	44.57	73.53	75.36
Organic Carbon	39.14	21.26	18.94
Carbon Dioxide	0	0.04	0
Hydrogen	3.98	0.91	0.91
Sulfur	10.07	8.70	9.32
Nitrogen	0.16	0.64	0.65
Oxygen (by HTW)	5.08	1.65	NA
Total	103.00	106.75	NA
Gross Calorific Value, Btu/lb	7964	NA	NA
Particle Density, g/cm^3	1.23	0.88	NA
True Density, g/cm^3	1.73	2.40	NA

Table 2. PELLET TEST OIL ANALYSES

Test	87MBU-6	HAU-MH1-P
Ultimate Analysis, wt % dry		
Ash	0	0
Carbon	86.28	85.99
Hydrogen	10.85	10.33
Sulfur	1.92	2.34
Nitrogen	0.95	1.34
Oxygen	0	0
Total	100.00	100.00
API Gravity @ 60°F, degrees	24.5	18.9
Specific Gravity, 60/60°F	0.907	0.941
Viscosity, SSU	33.8	—
Pour Point, °F	-50	—
Distillation (G.C.) wt % Received, °F		
IBP	<250	—
5	<250	—
10	285	—
15	345	—
20	385	—
30	460	—
40	535	—
50	610	—
60	680	—
70	780	—
% Recovered by 1018 °F	77	—
% Unrecovered	23	—

65073a-j/RPP

Mini-Bench Unit (MBU) Tests

Seven MBU tests were conducted. One batch test was conducted with pellets of beneficiated Alabama shale (MH-1). Six continuous tests were made. Shales tested in continuous operation were Kentucky New Albany (MH-2), beneficiated Kentucky New Albany (MH-2 BCP-1A and -1B), Michigan Antrim (MH-12a), beneficiated Michigan Antrim (MH-12 BCP), and beneficiated Alabama Chattanooga (MH-1-B) oil shales.

Experimental Equipment and Test Procedure. A flow diagram of the mini-bench unit is shown in Figure 2. The unit consists of a hydroretorting reactor with equipment for feeding and measuring the flow rates of shale and feed gas (hydrogen) and for collecting and/or measuring the flow rates of residue shale, liquid product, and product gas. Simple controls are used to maintain reactor temperatures at the desired values, to maintain constant reactor pressure, and to collect representative samples of the feed and product gas.

Shale is fed by a screw feeder from a pressurized feed hopper that, before testing, is filled with a sufficient amount of shale for the entire run (about 10 pounds). The cold shale enters the top of the reactor, and the residue shale is discharged from the bottom of the reactor into a pressurized residue receiver by a discharge screw feeder.

The feed gas enters the bottom of the reactor after passing through a preheater, and the product gas and vapor leaves the top of the reactor tube. A small purge flow of the feed gas is continuously passed into the feed hopper during the test to make up for the volume of shale lost from the feed hopper as shale is fed into the reactor and to keep exit gas containing liquid product from entering the feed hopper.

The reactor is a 39-1/8-inch-long Schedule 80 pipe with an ID of 1.92 inches. The reactor is heated by a six-zoned electric heater. Each zone is 3 inches long, and the heater extends from about 10 to 28 inches from the bottom of the reactor tube. An additional electric heater is used to heat a portion of the reactor above the main heater. The temperature of each zone is controlled individually by a temperature controller. Six thermocouples are used to measure the inside temperature of the reactor. These temperatures are recorded continuously along with the temperatures of other major pieces of equipment.

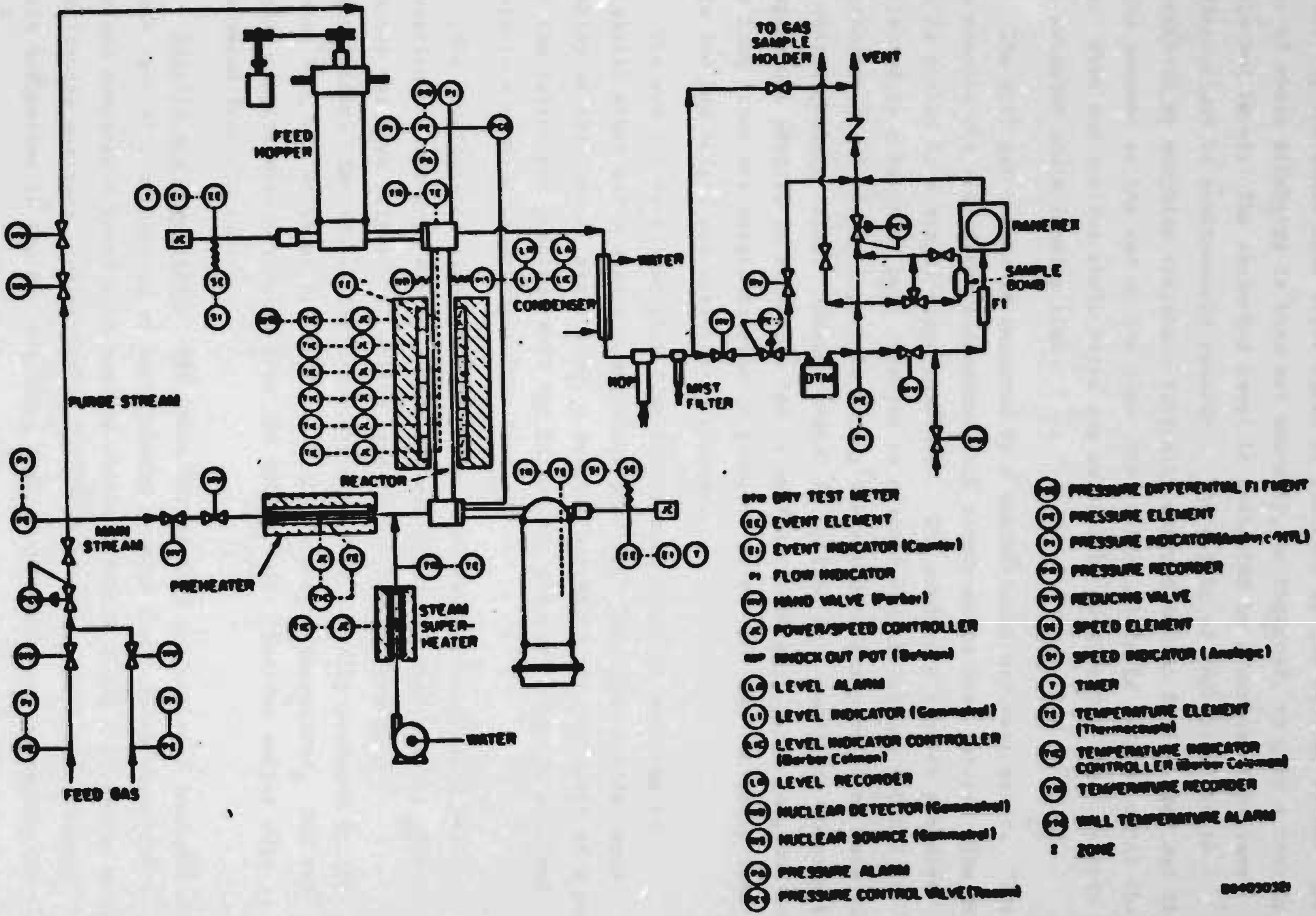


Figure 2. SCHEMATIC OF THE MINI-BENCH UNIT

Both screw feeders are calibrated. The shale is fed at the desired rate by setting the shale feed screw speed of rotation at the desired value. The rate of shale discharge is then set manually, as required, to give a constant shale-bed level. The shale-bed level is indicated by a nuclear-type level indicator and is continuously recorded. The weight of the shale fed is determined by weighing the shale initially charged to the feed hopper and the shale present at the end of the run. The residue shale is weighed after the run. Feed and residue shale rates are calculated by dividing these weights by the measured shale feeding time.

The exit gas volume is measured by a conventional dry test meter. "Spot" gas samples are also taken throughout each steady-state test period. The exit gas is cooled in a single-stage condenser. The condensed liquids are then collected in a knockout pot. The pot is drained and the liquid weighed at approximately 15-minute intervals during the steady-state portion of each run to obtain product rates. "Steady-state" is defined as a condition wherein the temperature profile in the shale bed is uniform; feed gas, purge gas, and exit gas flow rates are constant; reactor pressure is stable; and the shale feed rate and bed height are essentially constant.

The reactor is filled with fine silica sand prior to each run to establish a bed and a stable temperature profile. This also avoids rapid heating of the initial shale feed, a varying bed height at the start of a run, and the subsequent problems with tar formation, and also subjects all feed shale to a similar time-temperature history.

The beneficiated Alabama shale pellet test was conducted in a batch operation. A 400-gram sample of pellets was placed in the reactor. The reactor was then filled with silica sand to provide uniform gas distribution. The shale time-temperature profile, usually produced by the moving bed, was achieved by controlling the furnace temperatures. Gas and liquid samples were collected over the entire test. Residue solids were recovered from the reactor.

Results and Discussion. MBU tests during this program year included one batch test with briquettes of beneficiated Alabama Chattanooga shale (MH-1) and six continuous tests with various shales. Tables 1 and 2 presented solids and liquids analyses, respectively, for the batch tests with beneficiated shale briquettes in the MBU and HAU. Table 3 presents test summaries and

Table 3. MINI-BENCH UNIT AND HAU TEST SUMMARIES

Run Identification	87MBU-6	HAU-MH1-P	87MBU-8	87MBU-14
Shale Source	Alabama (MH-1) Pellets	Alabama (MH-1) Pellets	Kentucky New Albany (MH-2 Head Sample)	Kentucky New Albany (MH-2 BCP 1-B Beneficiated
Maximum Bed Temperature, °F	1105	1052	1000	950
Average Retorting Temperature, °F	1065	1052	965	947
Total Pressure, psia	615	613	606	609
Hydrogen Partial Pressure, psia	435-600	591	577	581
Total Heat-Up Time, min	40	40	29	26
Shale Residence Time at Temperature, min	30	30	31	28
Oil Yield, GPT, Recovered	54.2	53	22.1	83.5
Reconciled	58.7	70	25.4	88.6
Hydrogen Consumption, SCF/ton*	6390	7480	2860	6030
Organic Carbon Conversion, % (Adjusted by Ash Balance)	67.1	71.4	81.4	80.8
Selectivity to Oil, % - Adjusted	73.0	85.6	81.1	82.5
Hydrocarbon Gas Yield, MM-Btu/ton Methane Equivalent - Adjusted	4.45	NA	1.34	4.12
Organic Carbon to Gas, %	18.1	10.3	15.4	14.1
Oil, %	48.9	61.1	66.0	66.7
Residue, %	32.9	28.6	18.6	19.2
Sulfur Conversion to Gas, %†	43.4	39.5	50.0	20.5
Oil, %	4.2	6.5	2.0	7.3
Residue, %	52.4	54.0	48.1	72.2
Water Production, gal/ton dry feed shale	12.4	18.6	7.4	15.4
Water Production, gal/ton dry feed shale (less shale moisture)	9.7	15.9	5.1	10.9

* By combined hydrogen method

† Includes dissolved gases in water

Table 3, Cont'd. MINI-BENCH UNIT AND HAU TEST SUMMARIES

Run Identification	87MBU-15	87MBU-16	87MBU-19	87MBU-20
Shale Source	Kentucky New Albany (MH-2 BCP-1A beneficiated)	Michigan Antrim (MH-12a Head Sample)	Michigan Antrim (MH-12 BCP Beneficiated)	Alabama (MH-1-B Beneficiated)
Maximum Bed Temperature, °F	945	945	950	960
Average Retorting Temperature, °F	942	943	942	953
Total Pressure, psia	616	615	612	615
Hydrogen Partial Pressure, psia	582	588	595	582
Total Heat-Up Time, min	28	27	25	22
Shale Residence Time at Temperature, min	29	33	31	34
Oil Yield, GPT, Recovered	55.3	24.8	72.9	70.2
Reconciled	54.0	26.8	72.4	66.6
Hydrogen Consumption, SCF/ton*	4450	1876	4920	6430
Organic Carbon Conversion, % (Adjusted by Ash Balance)	80.2	80.6	84.8	72.7
Selectivity to Oil, % - Adjusted	79.0	84.6	87.4	73.8
Hydrocarbon Gas Yield, MM-Btu/ton Methane Equivalent - Adjusted	3.17	1.06	2.30	5.26
Organic Carbon to Gas, %	16.8	12.4	10.7	19.1
Oil, %	63.4	68.2	74.1	53.6
Residue, %	19.8	19.4	15.2	27.3
Sulfur Conversion to Gas, %†	40.6	46.1	19.7	30.0
Oil, %	4.0	1.9	7.8	5.3
Residue, %	55.4	52.1	72.5	64.7
Water Production, gal/ton dry feed shale	12.1	8.5	17.7	10.7
Water Production, gal/ton dry feed shale (less shale moisture)	8.6	3.6	14.0	7.0

* By combined hydrogen method

† Includes dissolved gases in water

reconciled results of the two batch pellet tests and the other six MBU tests. Detailed test calculations for the continuous MBU tests are presented in the Appendix.

The batch tests with 3/4 x 3/8 inch briquettes of beneficiated Alabama MH-1 shale were conducted under the same hydrogen partial pressure and with similar time-temperature histories. To insure even feed gas distribution in the MBU, sand was added along with the shale briquettes to the reactor. No sand was added to the shale charged to the HAU. The MBU reactor is a 2-inch pipe, whereas, the HAU reactor is a 1-inch pipe.

Although the measured oil yields for the shales retorted in the MBU and HAU were 53 and 54 GPT, respectively, the reconciled oil yields were 58.7 and 70 GPT, respectively. The carbon balance for the MBU test was 95.9% while the carbon balance for the HAU test was only 84.0%. For both tests the missing carbon is expected to be primarily unrecovered oil. On an unreconciled basis the MBU test showed 8.7% more carbon to gas and 4.3% more carbon in the residue than the corresponding HAU test. The specific gravity of the MBU produced oil is lighter than that produced in the HAU, 0.907 and 0.941, respectively. The low gravity product oil and the high feed carbon distribution to gas from the MBU indicates that some cracking of the oil may have occurred in the reactor.

Based on a comparison of the measured oil yields and the carbon conversions to products by hydroretorting in the two test units, there does not appear to be a negative wall effect from 2-inch to 1-inch diameter reactor on oil yield. That is, there was probably no channeling occuring in the two test units which would cause maldistribution of gas. There is also no apparent particle size effect on yields and carbon conversions in the MBU. The pellet test, 87MBU-6, with 3/4 X 3/8-inch briquettes and Test 86MBU-12 with -6+40 mesh shale both used beneficiated Alabama MH-1 shale. The reconciled oil yields from the pellet test and 86MBU-12 were 58.7 and 57.1 gal/ton, respectively. The distribution of organic carbon to gas, oil, and residue was 18.1, 48.9, and 32.9% for the pellet test and 18.0, 53.0 and 29.0 for Test 86MBU-12.

Test 87MBU-8 was conducted with Kentucky New Albany (MH-2) Head sample shale. Shale was retorted for 30 minutes in 600 psig hydrogen at an average 965°F. Yields and conversions were typical for a raw New Albany shale hydroretorted under these conditions. The reconciled oil yield was 25.4 gallons per ton of dry shale with an organic carbon selectivity to oil of 81%. Sulfur conversions to gas and oil were 50% and 2%, respectively. Hydrogen consumption was 2860 SCF per ton of dry shale.

Beneficiated New Albany shales were used for Tests 87MBU-14 and -15. Test conditions and shale residence times were the same as 87MBU-8. Test 87MBU-14 with MH-2 BCP 1B shale resulted in a reconciled oil yield of 88.6 gallons per ton of dry shale. The organic carbon selectivity to oil, 82%, was similar to the Head sample test. The 20% sulfur conversion to gas was lower than for the Head sample. Hydrogen consumption was 6030 SCF per ton of dry shale. Test 87MBU-15 with MH-2 BCP 1A shale also showed a reconciled oil yield, 54.0 gallons per ton of dry shale, well above the Head sample test. Organic carbon selectivity to oil, 79%, was similar to the Head sample test. Sulfur conversion to gas was 41%, and hydrogen consumption was 4450 SCF per ton of dry shale. Shale beneficiation lowered the overall hydrogen consumption. New Albany Head sample shale with a 13.6% organic carbon content had an oil yield of 25.4 gallon/ton and a hydrogen consumption of 113 SCF/gallon of oil. Beneficiated New Albany shale BCP-1A with a 29.5% organic carbon content had an oil yield of 54.0 gallon/ton and a hydrogen consumption of 82 SCF/gallon of oil. Beneficiated New Albany shale BCP-1B with a 45.7% organic carbon content had an oil yield of 88.6 gallon/ton and a hydrogen consumption of 68 SCF/gallon of oil.

Tests 87MBU-16 and -19 were made with raw (MH-12a) and beneficiated (MH-12 BCP) Michigan Antrim shale. Both tests were made with a shale residence time of 30 minutes, a reactor pressure of 600 psig, and an average retorting temperature of 950°F. The Head sample had a reconciled oil yield of 26.8 gallon per ton of dry shale and an organic carbon selectivity to oil of 85%. Sulfur conversion to gas was 46%. The hydrogen consumption of 1880 SCF per ton of dry shale corresponded to 70 SCF per gallon of oil. The beneficiated Michigan shale had a reconciled oil yield of 72.4 gallons per ton of dry shale and an 87% organic carbon selectivity to oil. Sulfur conversion to gas, 20%, was lower than for the Head sample. The hydrogen consumption of 4920 SCF per ton of dry shale corresponded to 68 SCF per gallon of oil.

Shale particle integrity of the Michigan Antrim Head sample was not greatly affected by hydroretorting. Particle integrity of the beneficiated

Michigan shale was severely affected by hydroretorting. Sieve analyses of the raw and spent beneficiated shales are presented in Table 4. Particle deterioration occurred during hydroretorting. The screw calibration test with the raw shale of the beneficiated shale (without binders) did not affect particle size. All shale recovered from the reactor, and, therefore, before entering the discharge screw, showed a loss in particle integrity (Table 4). Shale removal from the reactor by the discharge screw in Test 87MBU-19 with beneficiated Michigan shale was poor, but the test was completed successfully with a shortened steady state period.

Results from Test 87MBU-19 showed an unreconciled oxygen balance of 164%. This surprisingly high balance is believed to be due to the feed shale high temperature water analysis. The usual reconciliation procedure closed the oxygen balance by assigning a negative oxygen content to the spent shale. Since this value does not affect the oil yield, carbon distribution, sulfur distribution, or hydrogen consumption, the value was not altered.

Test 87MBU-20 was made with a beneficiated Alabama shale (MH-1-B). This shale was tested at the same conditions as the other continuous MBU tests during this program year. The reconciled oil yield was 66.6 gallons per ton of raw shale, and the organic carbon selectivity to oil was 74%. Sulfur conversion to gas was 30%. The hydrogen consumption of 6430 SCF per ton of dry shale corresponded to 97 SCF per gallon of oil. This beneficiated shale (produced without binders) also lost particle integrity during hydroretorting (Table 4). Again, the particle integrity was disturbed by the retorting process and not by the shale feed screw.

The main sulfur containing gas produced during hydroretorting is hydrogen sulfide. Table 5 shows the product gas trace sulfur analyses for the continuous PDU tests conducted in the first and second program years. Results show that between 0.8% and 3.1% of the product gas sulfur is in gases other than hydrogen sulfide. After hydrogen sulfide, the largest sulfur-containing gases are methyl, ethyl, and 1-propyl mercaptan. Small amounts of thiophene, dimethyl sulfide, and carbon disulfide were observed. The production of carbonyl sulfide is unclear because the large hydrogen sulfide peak obscured the carbonyl sulfide peak in all product gas samples.

Table 4. MBU TEST SHALE SIEVE ANALYSES

Test Sample		87MBU-19 Feed	87MBU-19 Residue	87MBU-20 Feed	87MBU-20 Residue
Minimum Particle Size, microns		Cumulative Weight %			
3327	(6 mesh)	0.3	0	2.0	0
2362	(8 mesh)	20.8	0	26.7	0
1680	(12 mesh)	40.4	0	44.2	0
1190	(16 mesh)	57.8	0	60.9	0
833	(20 mesh)	71.4	0	74.9	0
595	(30 mesh)	—	0	82.5	0
420	(40 mesh)	90.7	0	92.0	0
297	(50 mesh)	95.2	0	96.6	0
250	(60 mesh)	96.5	0	97.3	0
177	(80 mesh)	98.7*	0	98.2*	0
50.8		—	0	—	0.2
40.3		—	0	—	1.0
32.0		—	0	—	7.5
25.4		—	0.1	—	19.8
20.2		—	0.3	—	34.1
16.0		—	1.1	—	45.9
12.7		—	3.5	—	55.1
10.1		—	9.9	—	62.9
8.0		—	21.1	—	69.4
6.4		—	34.9	—	74.7
5.0		—	50.0	—	79.6
4.0		—	65.1	—	84.5
3.17		—	78.4	—	89.3
2.52		—	87.6	—	92.4
2.00		—	93.6	—	95.1
1.59		—	97.0	—	97.0
1.26		—	98.8	—	98.2
1.00		—	99.6	—	98.9
0.79		—	99.9	—	99.4
0.63		—	100.0	—	99.7
0.50		—	—	—	99.8
0.40		—	—	—	99.9
0.31		—	—	—	99.98
0.25		—	—	—	100.0

* Remaining shale is below 80 mesh

Table 5. MBU TEST PRODUCT GAS SULFUR COMPOUNDS

Test	86MBU-11	86MBU-12	87MBU-8	87MBU-14	87MBU-15	87MBU-16	87MBU-19	87MBU-20
Compound, ppm by volume								
Hydrogen Sulfide	31300	30300	7220	1250	5070	6000	560	8100
Carbonyl Sulfide	OB	OB	OB	OB	OB	OB	NA	OB
Carbon Disulfide	16	14	0.1	0.1	0.2	0.3	NA	0.1
Sulfur Dioxide	BDL	BDL	BDL	BDL	BDL	BDL	NA	BDL
Methyl Mercaptan	127	120	45	25	36	21	NA	59
Ethyl Mercaptan	90	86	20	10	18	16	NA	36
1-propyl Mercaptan	18	16	2.2	1.4	2.2	2.0	NA	8.2
n-propyl Mercaptan	7.0	7.2	3.8	1.4	3.2	3.5	NA	6.3
t-butyl Mercaptan	BDL	BDL	0.8	0.1	0.3	0.5	NA	0.7
Dimethyl Sulfide	1.1	1.1	0.2	0.2	0.2	0.1	NA	1.0
Methyl Ethyl Sulfide	BDL	BDL	0.2	BDL	0.1	BDL	NA	BDL
Dimethyl Disulfide	BDL	BDL	BDL	BDL	BDL	BDL	NA	BDL
Thiophane	BDL	BDL	BDL	BDL	BDL	BDL	NA	BDL
Thiophene	1.9	1.7	0.6	0.4	0.5	0.4	NA	1.8
C_1-Thiophenes	2.3	1.9	1.5	0.5	0.7	1.0	NA	0.8
C_2-Thiophenes	1.1	0.4	1.5	0.1	0.3	0.5	NA	BDL
Other C4 S cmpds	BDL	BDL	BDL	BDL	BDL	BDL	NA	BDL
C5 S cmpds	BDL	BDL	BDL	BDL	BDL	BDL	NA	BDL
C6+ S cmpds	BDL	BDL	BDL	BDL	BDL	BDL	NA	BDL
Unidentified S cmpds	3	1	2	1	1	2	NA	3

OB - Obscured by hydrogen sulfide readings
BDL - Below detectable limit
NA - Not available

APPENDIX

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Oil Shale Type	New Albany
Source	Kentucky
Oil Shale Particle Size (U.S. Sieve)	-6+40
Run No.	87MBU-8
Run Date	4/1/87
Test Duration, hrs	3.20
Total Shale Feed Time, hrs	3.16
Steady State Operating Period, hrs	1.00
Operating Conditions	
Bed Height, ft	1.46
Shale Preheat Height, ft	0.71
Reactor Pressure, psig	591.5
Average Bed Temperature, F	
Zone 1	780.
Zone 2	920.
Zone 3	1000.
Zone 4	970.
Zone 5	900.
Zone 6	790.
Zone 7 Bed Height -	590.
Oil Shale Feed Rate, lb/hr	2.042
Oil Shale Space Velocity, lb/ft(3)-hr	69.66
Oil Shale Residence Time, min	60.1
Hydrogen Feed Gas Rate, SCF/hr	61.62
Feed Gas Superficial Velocity, ft/s	.0597
Feed Gas Residence Time, s	9.6
Hydrogen/Oil Shale Ratio, SCF/lb shale fed	30.5
Shale Feed Hopper Purge Rate, SCF/hr	1.70
Total Hydrogen Feed Gas Rate, SCF/hr	63.29
Helium Tracer Gas Rate, SCF/hr	1.23

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No. 87MBU-8

Test Results	Residue Weight By Weight Measurement		Residue Weight By Ash balance
Product Gas Rate (as measured), SCF/hr		66.29	
Product Gas Rate, SCF/hr		62.87	
Product Gas Yield, SCF/lb shale fed		31.1	
Residue Shale Rate, lb/hr	1.645		1.661
Residue Shale Yield, lb/lb shale fed	0.806		0.813
Product Oil Rate, lb/hr		0.1829	
Product Oil Yield, lb/lb shale fed		0.0904	
Product Oil Yield, gal/ton		22.2	
Product Water Rate (as measured), lb/hr		0.0658	
Water Product Rate, lb/hr		0.0624	
Water Product Yield, lb/lb shale fed		0.0308	
Water Product Yield, gal/ton		7.4	
Organic Carbon Distribution in Products,%			
Gaseous Hydrocarbons		15.1	
Liquid Products		56.9<57.1>	
Solid Residue	18.4		18.6
Total	90.4< 90.6>		90.6< 90.8>
Overall Material Balance, %	98.4(98.3)		99.0(99.0)
Total Carbon Balance, %	91.4		91.6
Hydrogen Balance, %	103.1(103.0)		103.1(103.0)
Oxygen Balance, %	88.6		88.9
Sulfur Balance, %	89.1		89.6
Nitrogen Balance, %	80.9		81.1
Selectivity to Oil, %		79.1<79.1>	

Numbers in < > include organic carbon in water phase liquids
Numbers in ( ) indicate balances have been corrected for accumulated gases in new shale pores formed by hydroretorting

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS - COUNTERCURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-8			
	Feed Gas	Product Gas		
		Metered	H(2)S Adj	N(2) & He Free
Gas Composition, mol %				
Hydrogen Sulfide	0.00	0.76	0.76	0.79
Nitrogen	0.00	0.73	0.73	0.00
Carbon Monoxide	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.11	0.11	0.11
Hydrogen	98.09	95.44	95.44	98.04
Helium	1.91	1.91	1.91	0.00
Methane	0.00	0.57	0.57	0.59
Ethane	0.00	0.20	0.20	0.21
Propane	0.00	0.09	0.09	0.09
n-Butane	0.00	0.05	0.04	0.05
Iso-Butane	0.00	0.00	0.00	0.00
Pentanes	0.00	0.03	0.03	0.03
Hexanes	0.00	0.03	0.03	0.03
Heptanes	0.00	0.00	0.00	0.00
Ethylene	0.00	0.02	0.01	0.02
Propylene	0.00	0.04	0.04	0.04
Butene	0.00	0.02	0.02	0.02
Pentene	0.00	0.00	0.00	0.00
Hexene	0.00	0.00	0.00	0.00
Heptene	0.00	0.00	0.00	0.00
Butadiene	0.00	0.00	0.00	0.00
Pentadiene	0.00	0.00	0.00	0.00
Cyclopentadiene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
M. Acet./Propadiene	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00
Xylene	0.00	0.00	0.00	0.00
Ethyl Benzene	0.00	0.00	0.00	0.00
Styrene	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00
Specific Gravity (Air = 1.00)	0.071	0.097	0.097	0.090

ANALYSES OF EASTERN SHALE FEED AND RESIDUE - MINI-BENCH TEST

Run No.		87MBU-8		
Sample	Feed		Residue	
Lab No.	870400601		870400602	
Moisture	0.93		0.00	
Modified Ultimate Analysis (wt %, dry basis)				
Ash	77.19		94.01	
HTW in Ash	0.08		0.05	
MOX Oxygen in Ash	2.42		2.78	
Residual Mineral Oxides		74.23		91.18
Organic Carbon		13.59		3.08
Organic Hydrogen		1.29		0.16
Sulfur		5.45		3.19
Nitrogen		0.47		0.15
Carbon Dioxide		0.59		0.65
High Temperature Water		3.17		1.59
MOX Oxygen		1.23		0.00
Oxygen (by difference)		0.00		0.00
Total		100.02		100.00
Screen Analysis, U.S. Sieve, wt %				
6	0.0		0.0	
8	7.3		3.7	
12	18.4		14.5	
16	23.4		22.3	
20	16.6		16.3	
30	20.4		17.2	
40	10.7		10.0	
Pan	3.2		16.0	
Total	100.0		100.0	
Gross Heating Value, BTU/lb	2806.0		557.0	
Bulk Density, g/cc	1.12		0.97	
Mercury Density, g/cc	--		--	
Helium Density, g/cc	--		--	

ELEMENTAL DISTRIBUTION FOR 87MBU-8

	Inlet		Outlet (by ash)		Outlet Adjusted	
	lb/hr	%	lb/hr	%	lb/hr	%
Total Carbon						
Raw Shale	0.278	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.054	19.4	0.054	19.4
Hydrocarbon Gas	0.000	0.0	0.041	14.9	0.043	15.3
Carbon Oxides	0.000	0.0	0.002	0.8	0.002	0.8
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.2	0.001	0.2
Product Oil	0.000	0.0	0.156	56.2	0.179	64.2
Total	0.278	100.0	0.255	91.6	0.278	100.0
Hydrogen						
Raw Shale (dry basis)	0.033	8.9	0.000	0.0	0.000	0.0
Moisture	0.002	0.6	0.000	0.0	0.000	0.0
Feed Gas	0.337	90.5	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.006	1.5	0.006	1.5
Product Gas	0.000	0.0	0.352	94.6	0.338	90.8
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.1	0.000	0.1
Product Water	0.000	0.0	0.007	1.9	0.007	1.9
Product Oil	0.000	0.0	0.018	4.9	0.021	5.6
Total	0.372	100.0	0.384	103.0	0.372	100.0
Oxygen						
Raw Shale (dry basis)	0.091	84.3	0.000	0.0	0.000	0.0
Moisture	0.017	15.7	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.031	29.2	0.043	39.9
Product Gas as Carbon Oxides	0.000	0.0	0.006	5.7	0.006	5.7
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.2	0.000	0.2
Product Water	0.000	0.0	0.055	51.6	0.055	51.6
Product Oil	0.000	0.0	0.002	2.2	0.003	2.5
Total	0.107	100.0	0.095	88.9	0.107	100.0
Sulfur						
Raw Shale	0.110	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.053	48.1	0.053	48.1
Product Gas	0.000	0.0	0.043	39.2	0.054	49.4
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.6	0.001	0.6
Product Oil	0.000	0.0	0.002	1.7	0.002	2.0
Total	0.110	100.0	0.099	89.6	0.110	100.0
Nitrogen						
Raw Shale	0.010	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.002	26.2	0.004	39.5
Dissolved Gas in Sour Water	0.000	0.0	0.001	15.5	0.001	15.5
Product Oil	0.000	0.0	0.004	39.4	0.004	45.0
Total	0.010	100.0	0.008	81.1	0.010	100.0

LIQUID PRODUCT PROPERTIES - MINI-BENCH TEST WITH EASTERN SHALE

Run No.	87MBU-8
Lab No.	870400405, 870400406
Stream Identification	Oil Phase
Ultimate Analysis, wt % (dry and solids free basis)	
Carbon	85.54
Hydrogen	10.07
Sulfur	1.03
Nitrogen	2.05
Ash	0.00
Oxygen (by difference)	1.31
C/H Weight Ratio	8.49
Viscosity, SSU at 100 F	154.1
Specific Gravity (60/60 F)	0.977
API Gravity, degrees API	13.3
Distillation, F	ASTM D86
IBP	189.
5%	302.
10%	354.
20%	456.
30%	565.
40%	635.
50%	688.
60%	722.
70%	746.
80%	--
90%	--
95%	--
End Point	760.
% Recovery	79.0
% Residue	22.5
Heating Value, BTU/lb	17708.
Pour Point, F	--
Stream Identification	Water Phase
Mineral Carbon, wt %	0.10
Organic Carbon, wt %	0.86
Nitrogen, wt %	2.24
Sulfur, wt %	1.02

COMBINED HYDROGEN DISTRIBUTION FOR 87MBU-8

Appearance of Combined Hydrogen	Outlet (by ash) lb/hr	Outlet (by ash) %	Outlet (Adjusted) lb/hr	Outlet (Adjusted) %
Product Gas (HC + H(2)S)	0.016	39.6	0.017	38.7
Product Oil	0.018	46.9	0.021	48.9
Dissolved Gas in Sour Water	0.000	1.2	0.000	1.1
Net Product Water (total product water - feed moisture)	0.005	12.4	0.005	11.3
Total	0.039	100.0	0.043	100.0

HYDROGEN CONSUMPTION SCF/TON

1.	Direct Measurement	92.
2.	Helium Tracer	1846.
3.	Appearance of Combined Hydrogen	2869.
4.	Forced Oxygen Balance	3140.

MINI-BENCH UNIT TEST 87MBU-8
STATISTICAL ANALYSIS DATA - PHASE TWO

Dependent Variables

1.	Hydrogen Consumption (SCF/ton)		3005.
2.	Oil Yield (gal/ton)	Recovered	22.2
		Reconciled	25.4
3.	Oil Properties	Pour Point (F)	--
		API (@ 60 F)	13.3
		C/H Ratio	8.49
		S (wt %)	1.03
		N (wt %)	2.05
		Viscosity (SSU)	154.1
		Distillate Fractions	
		Temp. (F) 10 %	354.
		50 %	688.
		E.P.	760.
4.	Organic Carbon Conversion (%) (Adjusted by Ash Balance)		81.4
5.	Selectivity to Oil (%) (Adjusted)		81.0
6.	Hydrocarbon Gas Yield (MM BTU/ton) Methane Equivalent - Adjusted		1.34
7.	Organic Carbon to	Gas (%)	15.5
		Oil (%)	65.9
		Residue (%)	18.6
8.	Sulfur Conv. to	Gas (%)	50.0
		Oil (%)	2.0
		Residue (%)	48.1
9.	Water Production (lb/hr)		0.0624
	Water Production (lb/hr) (less shale moisture)		0.0434

Independent Variables

1.	Maximum Bed Temperature (F)	1000.
2.	Total Pressure (psia)	606.
	Hydrogen Partial Pressure (psia)	577.
3.	Shale Residence Time (min)	60.

Hydrogen Consumption is Average of Combined Hydrogen and Forced Oxygen methods
Sulfur in gas is 49.4 % to product gas and 0.6 % to dissolved gas

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Oil Shale Type	MH-2 BCP 1B
Source	Kentucky
Oil Shale Particle Size (U.S. Sieve)	-6+40
Run No.	87MBU-14
Run Date	6/29/87
Test Duration, hrs	4.00
Total Shale Feed Time, hrs	3.96
Steady State Operating Period, hrs	2.00
Operating Conditions	
Bed Height, ft	1.46
Shale Preheat Height, ft	0.71
Reactor Pressure, psig	594.5
Average Bed Temperature, F	
Zone 1	700.
Zone 2	940.
Zone 3	950.
Zone 4	950.
Zone 5	920.
Zone 6	740.
Zone 7 Bed Height -	600.
Oil Shale Feed Rate, lb/hr	1.173
Oil Shale Space Velocity, lb/ft(3)-hr	40.00
Oil Shale Residence Time, min	54.1
Hydrogen Feed Gas Rate, SCF/hr	66.02
Feed Gas Superficial Velocity, ft/s	.0612
Feed Gas Residence Time, s	9.5
Hydrogen/Oil Shale Ratio, SCF/lb shale fed	57.4
Shale Feed Hopper Purge Rate, SCF/hr	3.13
Total Hydrogen Feed Gas Rate, SCF/hr	69.08
Helium Tracer Gas Rate, SCF/hr	1.35

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-14	
Test Results	Residue Weight By Weight Measurement	Residue Weight By Ash balance
Product Gas Rate (as measured), SCF/hr	68.03	
Product Gas Rate, SCF/hr	63.59	
Product Gas Yield, SCF/lb shale fed	55.2	
Residue Shale Rate, lb/hr	0.545	0.590
Residue Shale Yield, lb/lb shale fed	0.464	0.503
Product Oil Rate, lb/hr	0.3882	
Product Oil Yield, lb/lb shale fed	0.3372	
Product Oil Yield, gal/ton	83.5	
Product Water Rate (as measured), lb/hr	0.0787	
Water Product Rate, lb/hr	0.0741	
Water Product Yield, lb/lb shale fed	0.0644	
Water Product Yield, gal/ton	15.4	
Organic Carbon Distribution in Products,%		
Gaseous Hydrocarbons	13.7	
Liquid Products	62.0<62.3>	
Solid Residue	17.7	19.2
Total	93.4< 93.7>	94.9< 95.2>
Overall Material Balance, %	95.2(95.3)	98.1(98.2)
Total Carbon Balance, %	94.3	95.8
Hydrogen Balance, %	98.7(99.0)	98.8(99.1)
Oxygen Balance, %	129.3	131.1
Sulfur Balance, %	87.6	93.2
Nitrogen Balance, %	92.0	94.3
Selectivity to Oil, %	81.9<82.0>	

Numbers in < > include organic carbon in water phase liquids
Numbers in ( ) indicate balances have been corrected for accumulated gases in new shale pores formed by hydroretorting

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS -
COUNTERCURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No. 87MBU-14

	Feed Gas	Product Gas		
		Metered	H(2)S Adj	N(2) & He Free
Gas Composition, mol %				
Hydrogen Sulfide	0.00	0.12	0.12	0.13
Nitrogen	0.00	0.10	0.10	0.00
Carbon Monoxide	0.00	0.07	0.07	0.07
Carbon Dioxide	0.00	0.07	0.07	0.07
Hydrogen	97.72	95.93	95.93	97.91
Helium	2.28	1.92	1.92	0.00
Methane	0.00	0.98	0.98	1.00
Ethane	0.00	0.35	0.35	0.36
Propane	0.00	0.15	0.15	0.16
n-Butane	0.00	0.07	0.07	0.07
Iso-Butane	0.00	0.00	0.00	0.00
Pentanes	0.00	0.02	0.02	0.02
Hexanes	0.00	0.06	0.06	0.06
Heptanes	0.00	0.00	0.00	0.00
Ethylene	0.00	0.04	0.04	0.04
Propylene	0.00	0.06	0.06	0.07
Butene	0.00	0.04	0.04	0.05
Pentene	0.00	0.00	0.00	0.00
Hexene	0.00	0.00	0.00	0.00
Heptene	0.00	0.00	0.00	0.00
Butadiene	0.00	0.00	0.00	0.00
Pentadiene	0.00	0.00	0.00	0.00
Cyclopentadiene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
M. Acet./Propadiene	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00
Xylene	0.00	0.00	0.00	0.00
Ethyl Benzene	0.00	0.00	0.00	0.00
Styrene	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00
Specific Gravity (Air = 1.00)	0.071	0.091	0.091	0.089

ANALYSES OF EASTERN SHALE FEED AND RESIDUE - MINI-BENCH TEST

Run No.		87MBU-14		
Sample	Feed		Residue	
Lab No.	870701401		870701402	
Moisture	1.85		0.00	
Modified Ultimate Analysis (wt %, dry basis)				
Ash	40.29		78.58	
HTW in Ash	0.44		0.66	
MOX Oxygen in Ash	0.21		5.23	
Residual Mineral Oxides		38.63		71.68
Organic Carbon		45.72		17.08
Organic Hydrogen		4.08		0.73
Sulfur		4.55		6.41
Nitrogen		1.28		0.75
Carbon Dioxide		0.05		0.08
High Temperature Water		5.70		1.51
MOX Oxygen		0.00		1.76
Oxygen (by difference)		0.00		0.00
Total		100.01		100.00
Screen Analysis, U.S. Sieve, wt %				
6	0.4		0.0	
8	15.0		0.9	
12	14.7		5.6	
16	16.2		11.7	
20	13.8		11.2	
30	11.5		9.0	
40	10.9		8.9	
50	4.5		7.8	
60	10.8		44.9	
80	0.9		0.0	
Pan	1.3		0.0	
Total	100.0		100.0	
Gross Heating Value, BTU/lb	9104.0		3380.0	
Bulk Density, g/cc	0.58		0.49	
Mercury Density, g/cc	1.01		0.82	
Helium Density, g/cc	--		--	

LIQUID PRODUCT PROPERTIES - MINI-BENCH TEST WITH EASTERN SHALE

Run No.	87MBU-14
Lab No.	870702002, 870702003
Stream Identification	Oil Phase
Ultimate Analysis, wt %	
(dry and solids free basis)	
Carbon	84.13
Hydrogen	10.01
Sulfur	0.93
Nitrogen	1.99
Ash	0.00
Oxygen (by difference)	2.94
C/H Weight Ratio	8.40
Viscosity, SSU at 100 F	101.4
Specific Gravity (60/60 F)	0.969
API Gravity, degrees API	14.5
Distillation, F	ASTM D86
IBP	178.
5%	268.
10%	328.
20%	410.
30%	505.
40%	585.
50%	654.
60%	695.
70%	732.
80%	756.
90%	--
95%	--
End Point	760.
% Recovery	83.5
% Residue	17.0
Heating Value, BTU/lb	17744.
Pour Point, F	-5.
Stream Identification	Water Phase
Mineral Carbon, wt %	0.20
Organic Carbon, wt %	1.80
Nitrogen, wt %	2.22
Sulfur, wt %	0.21

ELEMENTAL DISTRIBUTION FOR 87MBU-14

	Inlet		Outlet (by ash)		Outlet Adjusted	
	lb/hr	%	lb/hr	%	lb/hr	%
Total Carbon						
Raw Shale	0.526	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.101	19.2	0.101	19.2
Hydrocarbon Gas	0.000	0.0	0.072	13.7	0.074	14.1
Carbon Oxides	0.000	0.0	0.003	0.6	0.003	0.6
Dissolved Gas in Sour Water	0.000	0.0	0.002	0.3	0.002	0.3
Product Oil	0.000	0.0	0.327	62.0	0.347	65.8
Total	0.526	100.0	0.504	95.8	0.526	100.0
Hydrogen						
Raw Shale (dry basis)	0.054	12.8	0.000	0.0	0.000	0.0
Moisture	0.002	0.6	0.000	0.0	0.000	0.0
Feed Gas	0.368	86.6	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.005	1.3	0.005	1.3
Product Gas	0.000	0.0	0.368	86.6	0.369	86.9
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.1	0.001	0.1
Product Water	0.000	0.0	0.008	2.0	0.008	2.0
Product Oil	0.000	0.0	0.039	9.1	0.041	9.7
Total	0.425	100.0	0.421	99.1	0.425	100.0
Oxygen						
Raw Shale (dry basis)	0.059	75.3	0.000	0.0	0.000	0.0
Moisture	0.019	24.7	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.019	23.9	-0.006	-8.1
Product Gas as Carbon Oxides	0.000	0.0	0.006	7.6	0.006	7.6
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.5	0.000	0.5
Product Water	0.000	0.0	0.066	84.5	0.066	84.5
Product Oil	0.000	0.0	0.011	14.6	0.012	15.5
Total	0.078	100.0	0.102	131.1	0.078	100.0
Sulfur						
Raw Shale	0.052	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.038	72.2	0.038	72.2
Product Gas	0.000	0.0	0.007	13.8	0.011	20.1
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.3	0.000	0.3
Product Oil	0.000	0.0	0.004	6.9	0.004	7.3
Total	0.052	100.0	0.049	93.2	0.052	100.0
Nitrogen						
Raw Shale	0.015	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.004	30.0	0.005	32.5
Dissolved Gas in Sour Water	0.000	0.0	0.002	11.9	0.002	11.9
Product Oil	0.000	0.0	0.008	52.4	0.008	55.6
Total	0.015	100.0	0.014	94.3	0.015	100.0

COMBINED HYDROGEN DISTRIBUTION FOR 87MBU-14

	Outlet (by ash)		Outlet (Adjusted)	
Appearance of Combined Hydrogen	lb/hr	%	lb/hr	%
Product Gas (HC + H(2)S)	0.019	29.4	0.020	29.3
Product Oil	0.039	60.5	0.041	61.1
Dissolved Gas in Sour Water	0.001	1.0	0.001	0.9
Net Product Water (total product water - feed moisture)	0.006	9.1	0.006	8.7
Total	0.064	100.0	0.067	100.0

HYDROGEN CONSUMPTION SCF/TON

1.	Direct Measurement	6155.
2.	Helium Tracer	*****
3.	Appearance of Combined Hydrogen	6027.
4.	Forced Oxygen Balance	5001.

MINI-BENCH UNIT TEST 87MBU-14
STATISTICAL ANALYSIS DATA - PHASE TWO

Dependent Variables

1.	Hydrogen Consumption (SCF/ton)		5514.
2.	Oil Yield (gal/ton)	Recovered	83.5
		Reconciled	88.6
3.	Oil Properties	Pour Point (F)	-5.
		API (@ 60 F)	14.5
		C/H Ratio	8.40
		S (wt %)	0.93
		N (wt %)	1.99
		Viscosity (SSU)	101.4
		Distillate Fractions	
		Temp. (F) 10 %	328.
		50 %	654.
		E.P.	760.
4.	Organic Carbon Conversion (%) (Adjusted by Ash Balance)		80.8
5.	Selectivity to Oil (%) (Adjusted)		82.5
6.	Hydrocarbon Gas Yield (MM BTU/ton) Methane Equivalent - Adjusted		4.12
7.	Organic Carbon to	Gas (%)	14.1
		Oil (%)	66.7
		Residue (%)	19.2
8.	Sulfur Conv. to	Gas (%)	20.5
		Oil (%)	7.3
		Residue (%)	72.2
9.	Water Production (lb/hr)		0.0741
	Water Production (lb/hr) (less shale moisture)		0.0524

Independent Variables

1.	Maximum Bed Temperature (F)	950.
2.	Total Pressure (psia)	609.
	Hydrogen Partial Pressure (psia)	581.
3.	Shale Residence Time (min)	54.

Hydrogen Consumption is Average of Combined Hydrogen
and Forced Oxygen methods
Sulfur in gas is 20.1 % to product gas and 0.3 % to dissolved gas

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-15	
Test Results	Residue Weight By Weight Measurement	Residue Weight By Ash balance
Product Gas Rate (as measured), SCF/hr	68.42	
Product Gas Rate, SCF/hr	63.47	
Product Gas Yield, SCF/lb shale fed	46.4	
Residue Shale Rate, lb/hr	0.896	0.910
Residue Shale Yield, lb/lb shale fed	0.646	0.656
Product Oil Rate, lb/hr	0.3066	
Product Oil Yield, lb/lb shale fed	0.2242	
Product Oil Yield, gal/ton	55.3	
Product Water Rate (as measured), lb/hr	0.0730	
Water Product Rate, lb/hr	0.0689	
Water Product Yield, lb/lb shale fed	0.0504	
Water Product Yield, gal/ton	12.1	
Organic Carbon Distribution in Products,%		
Gaseous Hydrocarbons	16.4	
Liquid Products	64.1<64.3>	
Solid Residue	19.5	19.8
Total	100.0<100.3>	100.3<100.6>
Overall Material Balance, %	99.6(99.6)	100.4(100.4)
Total Carbon Balance, %	100.8	101.1
Hydrogen Balance, %	100.1(100.1)	100.1(100.1)
Oxygen Balance, %	101.3	101.7
Sulfur Balance, %	94.8	95.6
Nitrogen Balance, %	105.6	106.0
Selectivity to Oil, %	79.6<79.6>	

Numbers in < > include organic carbon in water phase liquids
Numbers in ( ) indicate balances have been corrected for accumulated gases in new shale pores formed by hydroretorting

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS - COUNTERCURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-15			
	Feed Gas	Product Gas		
		Metered	H(2)S Adj	N(2) & He Free
Gas Composition, mol %				
Hydrogen Sulfide	0.00	0.51	0.51	0.52
Nitrogen	0.00	0.15	0.15	0.00
Carbon Monoxide	0.00	0.05	0.05	0.05
Carbon Dioxide	0.00	0.06	0.05	0.06
Hydrogen	97.30	95.08	95.08	97.79
Helium	2.70	2.63	2.63	0.00
Methane	0.00	0.77	0.77	0.79
Ethane	0.00	0.26	0.26	0.27
Propane	0.00	0.12	0.12	0.12
n-Butane	0.00	0.05	0.05	0.05
Iso-Butane	0.00	0.00	0.00	0.00
Pentanes	0.00	0.01	0.01	0.01
Hexanes	0.00	0.03	0.03	0.03
Heptanes	0.00	0.00	0.00	0.00
Ethylene	0.00	0.05	0.05	0.05
Propylene	0.00	0.05	0.05	0.05
Butene	0.00	0.18	0.18	0.19
Pentene	0.00	0.00	0.00	0.00
Hexene	0.00	0.00	0.00	0.00
Heptene	0.00	0.00	0.00	0.00
Butadiene	0.00	0.00	0.00	0.00
Pentadiene	0.00	0.00	0.00	0.00
Cyclopentadiene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
M. Acet./Propadiene	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00
Xylene	0.00	0.00	0.00	0.00
Ethyl Benzene	0.00	0.00	0.00	0.00
Styrene	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00
Specific Gravity (Air - 1.00)	0.071	0.094	0.094	0.092

ANALYSES OF EASTERN SHALE FEED AND RESIDUE - MINI-BENCH TEST

Run No.		87MBU-15		
Sample	Feed		Residue	
Lab No.	870701901		870701902	
Moisture	1.44		0.00	
Modified Ultimate Analysis (wt %, dry basis)				
Ash	57.93		87.02	
HTW in Ash	0.52		0.40	
MOX Oxygen in Ash	3.05		4.52	
Residual Mineral Oxides		54.36		82.10
Organic Carbon		29.52		8.77
Organic Hydrogen		2.71		0.40
Sulfur		6.02		5.01
Nitrogen		0.80		0.39
Carbon Dioxide		0.08		0.04
High Temperature Water		4.46		1.84
MOX Oxygen		0.82		1.25
Oxygen (by difference)		1.23		0.20
Total		100.00		100.00
Screen Analysis, U.S. Sieve, wt %				
6	0.4		0.0	
8	27.1		1.4	
12	19.2		11.2	
16	16.7		19.2	
20	14.0		15.8	
30	8.8		11.2	
40	7.2		10.8	
50	3.2		9.8	
60	1.3		9.0	
80	0.6		5.5	
Pan	1.5		6.1	
Total	100.0		100.0	
Gross Heating Value, BTU/lb	5887.0		1764.0	
Bulk Density, g/cc	0.72		0.52	
Mercury Density, g/cc	1.17		0.76	
Helium Density, g/cc	--		--	

LIQUID PRODUCT PROPERTIES - MINI-BENCH TEST WITH EASTERN SHALE

Run No.	87MBU-15
Lab No.	870702102, 870702103
Stream Identification	Oil Phase
Ultimate Analysis, wt % (dry and solids free basis)	
Carbon	84.33
Hydrogen	9.90
Sulfur	1.11
Nitrogen	2.04
Ash	0.00
Oxygen (by difference)	2.62
C/H Weight Ratio	8.52
Viscosity, SSU at 100 F	119.9
Specific Gravity (60/60 F)	0.972
API Gravity, degrees API	14.1
Distillation, F	ASTM D86
IBP	182.
5%	275.
10%	336.
20%	430.
30%	514.
40%	598.
50%	658.
60%	699.
70%	726.
80%	746.
90%	--
95%	--
End Point	756.
% Recovery	87.0
% Residue	13.0
Heating Value, BTU/lb	17738.
Pour Point, F	-5.
Stream Identification	Water Phase
Mineral Carbon, wt %	0.10
Organic Carbon, wt %	1.60
Nitrogen, wt %	2.46
Sulfur, wt %	0.33

ELEMENTAL DISTRIBUTION FOR 87MBU-15

	Inlet		Outlet (by ash)		Outlet Adjusted	
	lb/hr	%	lb/hr	%	lb/hr	%
Total Carbon						
Raw Shale	0.404	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.080	19.8	0.080	19.8
Hydrocarbon Gas	0.000	0.0	0.066	16.4	0.068	16.8
Carbon Oxides	0.000	0.0	0.002	0.6	0.002	0.6
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.3	0.001	0.3
Product Oil	0.000	0.0	0.259	64.0	0.252	62.5
Total	0.404	100.0	0.408	101.1	0.404	100.0
Hydrogen						
Raw Shale (dry basis)	0.044	10.7	0.000	0.0	0.000	0.0
Moisture	0.002	0.5	0.000	0.0	0.000	0.0
Feed Gas	0.362	88.7	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.006	1.4	0.006	1.4
Product Gas	0.000	0.0	0.364	89.3	0.365	89.4
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.1	0.001	0.1
Product Water	0.000	0.0	0.008	1.9	0.008	1.9
Product Oil	0.000	0.0	0.030	7.4	0.030	7.3
Total	0.408	100.0	0.409	100.1	0.408	100.0
Oxygen						
Raw Shale (dry basis)	0.083	82.4	0.000	0.0	0.000	0.0
Moisture	0.018	17.6	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.028	28.1	0.027	26.6
Product Gas as Carbon Oxides	0.000	0.0	0.005	4.7	0.005	4.7
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.2	0.000	0.2
Product Water	0.000	0.0	0.061	60.8	0.061	60.8
Product Oil	0.000	0.0	0.008	8.0	0.008	7.8
Total	0.101	100.0	0.102	101.7	0.101	100.0
Sulfur						
Raw Shale	0.082	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.046	55.4	0.046	55.4
Product Gas	0.000	0.0	0.029	35.8	0.033	40.3
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.3	0.000	0.3
Product Oil	0.000	0.0	0.003	4.1	0.003	4.0
Total	0.082	100.0	0.079	95.6	0.082	100.0
Nitrogen						
Raw Shale	0.011	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.004	32.5	0.003	27.8
Dissolved Gas in Sour Water	0.000	0.0	0.002	16.4	0.002	16.4
Product Oil	0.000	0.0	0.006	57.2	0.006	55.8
Total	0.011	100.0	0.012	106.0	0.011	100.0

COMBINED HYDROGEN DISTRIBUTION FOR 87MBU-15

	Outlet (by ash)		Outlet (Adjusted)	
Appearance of Combined Hydrogen	lb/hr	%	lb/hr	%
Product Gas (HC + H(2)S)	0.018	33.1	0.019	34.5
Product Oil	0.030	55.7	0.030	54.3
Dissolved Gas in Sour Water	0.001	1.1	0.001	1.1
Net Product Water (total product water - feed moisture)	0.005	10.0	0.005	10.0
Total	0.054	100.0	0.055	100.0

HYDROGEN CONSUMPTION SCF/TON

1.	Direct Measurement	4345.
2.	Helium Tracer	-315.
3.	Appearance of Combined Hydrogen	4446.
4.	Forced Oxygen Balance	4393.

MINI-BENCH UNIT TEST 87MBU-15
STATISTICAL ANALYSIS DATA - PHASE TWO

Dependent Variables

1.	Hydrogen Consumption (SCF/ton)		4420.
2.	Oil Yield (gal/ton)	Recovered	55.3
		Reconciled	54.0
3.	Oil Properties	Pour Point (F)	-5.
		API (@ 60 F)	14.1
		C/H Ratio	8.52
		S (wt %)	1.11
		N (wt %)	2.04
		Viscosity (SSU)	119.9
		Distillate Fractions	
		Temp. (F) 10 %	336.
		50 %	658.
		E.P.	756.
4.	Organic Carbon Conversion (%) (Adjusted by Ash Balance)		80.2
5.	Selectivity to Oil (%) (Adjusted)		79.0
6.	Hydrocarbon Gas Yield (MM BTU/ton) Methane Equivalent - Adjusted		3.17
7.	Organic Carbon to	Gas (%)	16.8
		Oil (%)	63.4
		Residue (%)	19.8
8.	Sulfur Conv. to	Gas (%)	40.6
		Oil (%)	4.0
		Residue (%)	55.4
9.	Water Production (lb/hr)		0.0689
	Water Production (lb/hr) (less shale moisture)		0.0489

Independent Variables

1.	Maximum Bed Temperature (F)	945.
2.	Total Pressure (psia)	616.
	Hydrogen Partial Pressure (psia)	582.
3.	Shale Residence Time (min)	57.

Hydrogen Consumption is Average of Combined Hydrogen and Forced Oxygen methods
Sulfur in gas is 40.3 % to product gas and 0.3 % to dissolved gas

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Oil Shale Type	MH-2 BCP 1A
Source	Kentucky
Oil Shale Particle Size (U.S. Sieve)	-6+40
Run No.	87MBU-15
Run Date	7/2/87
Test Duration, hrs	3.75
Total Shale Feed Time, hrs	3.71
Steady State Operating Period, hrs	2.00
Operating Conditions	
Bed Height, ft	1.46
Shale Preheat Height, ft	0.71
Reactor Pressure, psig	601.5
Average Bed Temperature, F	
Zone 1	820.
Zone 2	940.
Zone 3	940.
Zone 4	945.
Zone 5	910.
Zone 6	750.
Zone 7 Bed Height -	560.
Oil Shale Feed Rate, lb/hr	1.387
Oil Shale Space Velocity, lb/ft(3)-hr	47.31
Oil Shale Residence Time, min	56.8
Hydrogen Feed Gas Rate, SCF/hr	64.97
Feed Gas Superficial Velocity, ft/s	.0601
Feed Gas Residence Time, s	7.7
Hydrogen/Oil Shale Ratio, SCF/lb shale fed	47.5
Shale Feed Hopper Purge Rate, SCF/hr	3.13
Total Hydrogen Feed Gas Rate, SCF/hr	68.01
Helium Tracer Gas Rate, SCF/hr	1.89

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Oil Shale Type	MH-12A Antrim Head
Source	Michigan
Oil Shale Particle Size (U.S. Sieve)	-6+40
Run No.	87MBU-16
Run Date	7/9/87
Test Duration, hrs	4.00
Total Shale Feed Time, hrs	3.96
Steady State Operating Period, hrs	2.00
Operating Conditions	
Bed Height, ft	1.38
Shale Preheat Height, ft	0.62
Reactor Pressure, psig	600.5
Average Bed Temperature, F	
Zone 1	825.
Zone 2	940.
Zone 3	945.
Zone 4	945.
Zone 5	900.
Zone 6	660.
Zone 7 Bed Height -	550.
Oil Shale Feed Rate, lb/hr	1.953
Oil Shale Space Velocity, lb/ft(3)-hr	70.62
Oil Shale Residence Time, min	60.8
Hydrogen Feed Gas Rate, SCF/hr	64.63
Feed Gas Superficial Velocity, ft/s	.0596
Feed Gas Residence Time, s	6.9
Hydrogen/Oil Shale Ratio, SCF/lb shale fed	33.7
Shale Feed Hopper Purge Rate, SCF/hr	3.13
Total Hydrogen Feed Gas Rate, SCF/hr	67.70
Helium Tracer Gas Rate, SCF/hr	1.52

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-16	
Test Results	Residue Weight By Weight Measurement	Residue Weight By Ash balance
Product Gas Rate (as measured), SCF/hr	70.04	
Product Gas Rate, SCF/hr	65.40	
Product Gas Yield, SCF/lb shale fed	34.1	
Residue Shale Rate, lb/hr	1.613	1.613
Residue Shale Yield, lb/lb shale fed	0.826	0.826
Product Oil Rate, lb/hr	0.1904	
Product Oil Yield, lb/lb shale fed	0.0993	
Product Oil Yield, gal/ton	24.8	
Product Water Rate (as measured), lb/hr	0.0741	
Water Product Rate, lb/hr	0.0676	
Water Product Yield, lb/lb shale fed	0.0353	
Water Product Yield, gal/ton	8.5	
Organic Carbon Distribution in Products,%		
Gaseous Hydrocarbons	12.0	
Liquid Products	63.7<65.0>	
Solid Residue	19.4	19.4
Total	95.1< 96.4>	95.1< 96.4>
Overall Material Balance, %	100.1(100.1)	100.1(100.1)
Total Carbon Balance, %	96.3	96.3
Hydrogen Balance, %	101.8(101.6)	101.8(101.6)
Oxygen Balance, %	101.0	101.0
Sulfur Balance, %	99.5	99.5
Nitrogen Balance, %	90.1	90.1
Selectivity to Oil, %	84.2<84.5>	

Numbers in < > include organic carbon in water phase liquids
Numbers in ( ) indicate balances have been corrected for accumulated gases in new shale pores formed by hydroretorting

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS - COUNTERCURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-16			
	Feed Gas	Product Gas		
		Metered	H(2)S Adj	N(2) & He Free
Gas Composition, mol %				
Hydrogen Sulfide	0.00	0.60	0.60	0.61
Nitrogen	0.00	0.01	0.01	0.00
Carbon Monoxide	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.03	0.03	0.03
Hydrogen	97.80	96.34	96.34	98.56
Helium	2.20	2.25	2.25	0.00
Methane	0.00	0.45	0.45	0.46
Ethane	0.00	0.11	0.11	0.11
Propane	0.00	0.10	0.10	0.11
n-Butane	0.00	0.03	0.03	0.03
Iso-Butane	0.00	0.00	0.00	0.00
Pentanes	0.00	0.01	0.01	0.01
Hexanes	0.00	0.01	0.01	0.01
Heptanes	0.00	0.00	0.00	0.00
Ethylene	0.00	0.03	0.03	0.03
Propylene	0.00	0.01	0.01	0.01
Butene	0.00	0.02	0.02	0.02
Pentene	0.00	0.00	0.00	0.00
Hexene	0.00	0.00	0.00	0.00
Heptene	0.00	0.00	0.00	0.00
Butadiene	0.00	0.00	0.00	0.00
Pentadiene	0.00	0.00	0.00	0.00
Cyclopentadiene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
M. Acet./Propadiene	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00
Xylene	0.00	0.00	0.00	0.00
Ethyl Benzene	0.00	0.00	0.00	0.00
Styrene	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00
Specific Gravity (Air = 1.00)	0.071	0.085	0.085	0.084

ANALYSES OF EASTERN SHALE FEED AND RESIDUE - MINI-BENCH TEST

Run No.		87MBU-16		
Sample	Feed		Residue	
Lab No.	870704201		870704202	
Moisture	1.82		0.00	
Modified Ultimate Analysis (wt %, dry basis)				
Ash	77.81		92.50	
HTW in Ash	0.44		0.56	
MOX Oxygen in Ash	2.90		3.12	
Residual Mineral Oxides		74.47		88.82
Organic Carbon		13.37		3.09
Organic Hydrogen		1.37		0.19
Sulfur		4.07		2.52
Nitrogen		0.36		0.16
Carbon Dioxide		1.03		0.85
High Temperature Water		3.51		2.61
MOX Oxygen		0.36		0.61
Oxygen (by difference)		1.46		1.15
Total		100.00		100.00
Screen Analysis, U.S. Sieve, wt %				
6	0.2		0.0	
8	34.6		4.9	
12	26.3		17.8	
16	16.7		21.4	
20	10.0		10.4	
30	6.1		9.9	
40	4.6		7.8	
50	1.1		11.9	
60	0.1		12.4	
80	0.1		2.3	
Pan	0.2		1.2	
Total	100.0		100.0	
Gross Heating Value, BTU/lb	2700.0		626.0	
Bulk Density, g/cc	1.15		1.02	
Mercury Density, g/cc	2.00		1.45	
Helium Density, g/cc	2.47		2.70	

LIQUID PRODUCT PROPERTIES - MINI-BENCH TEST WITH EASTERN SHALE

Run No.	87MBU-16
Lab No.	870704402, 870704403
Stream Identification	Oil Phase
Ultimate Analysis, wt %	
(dry and solids free basis)	
Carbon	85.79
Hydrogen	10.34
Sulfur	0.72
Nitrogen	1.35
Ash	0.00
Oxygen (by difference)	1.80
C/H Weight Ratio	8.30
Viscosity, SSU at 100 F	103.5
Specific Gravity (60/60 F)	0.962
API Gravity, degrees API	15.6
Distillation, F	ASTM D86
IBP	208.
5%	300.
10%	361.
20%	459.
30%	548.
40%	628.
50%	688.
60%	720.
70%	743.
80%	760.
90%	--
95%	--
End Point	762.
% Recovery	83.5
% Residue	17.5
Heating Value, BTU/lb	18053.
Pour Point, F	-10.
Stream Identification	Water Phase
Mineral Carbon, wt %	0.40
Organic Carbon, wt %	4.50
Nitrogen, wt %	1.44
Sulfur, wt %	0.32

ELEMENTAL DISTRIBUTION FOR 87MBU-16

	Inlet		Outlet (by ash)		Outlet Adjusted	
	lb/hr	%	lb/hr	%	lb/hr	%
Total Carbon						
Raw Shale	0.262	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.054	20.5	0.054	20.5
Hydrocarbon Gas	0.000	0.0	0.031	11.7	0.032	12.1
Carbon Oxides	0.000	0.0	0.001	0.3	0.001	0.3
Dissolved Gas in Sour Water	0.000	0.0	0.004	1.4	0.004	1.4
Product Oil	0.000	0.0	0.163	62.4	0.172	65.7
Total	0.262	100.0	0.252	96.3	0.262	100.0
Hydrogen						
Raw Shale (dry basis)	0.034	8.5	0.000	0.0	0.000	0.0
Moisture	0.004	1.0	0.000	0.0	0.000	0.0
Feed Gas	0.361	90.5	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.008	1.9	0.008	1.9
Product Gas	0.000	0.0	0.369	92.6	0.361	90.7
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.2	0.001	0.2
Product Water	0.000	0.0	0.008	1.9	0.008	1.9
Product Oil	0.000	0.0	0.020	4.9	0.021	5.2
Total	0.398	100.0	0.405	101.6	0.398	100.0
Oxygen						
Raw Shale (dry basis)	0.109	77.5	0.000	0.0	0.000	0.0
Moisture	0.032	22.5	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.076	53.9	0.074	52.7
Product Gas as Carbon Oxides	0.000	0.0	0.002	1.5	0.002	1.5
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.6	0.001	0.6
Product Water	0.000	0.0	0.060	42.7	0.060	42.7
Product Oil	0.000	0.0	0.003	2.4	0.004	2.6
Total	0.141	100.0	0.142	101.0	0.141	100.0
Sulfur						
Raw Shale	0.078	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.041	52.1	0.041	52.1
Product Gas	0.000	0.0	0.035	45.4	0.036	45.8
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.3	0.000	0.3
Product Oil	0.000	0.0	0.001	1.8	0.001	1.9
Total	0.078	100.0	0.078	99.5	0.078	100.0
Nitrogen						
Raw Shale	0.007	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.003	37.4	0.003	45.3
Dissolved Gas in Sour Water	0.000	0.0	0.001	15.5	0.001	15.5
Product Oil	0.000	0.0	0.003	37.2	0.003	39.2
Total	0.007	100.0	0.006	90.1	0.007	100.0

COMBINED HYDROGEN DISTRIBUTION FOR 87MBU-16

	Outlet (by ash)		Outlet (Adjusted)	
Appearance of Combined Hydrogen	lb/hr	%	lb/hr	%
Product Gas (HC + H(2)S)	0.010	29.5	0.010	29.4
Product Oil	0.020	57.6	0.021	58.3
Dissolved Gas in Sour Water	0.001	2.4	0.001	2.3
Net Product Water (total product water - feed moisture)	0.004	10.5	0.004	10.1
Total	0.034	100.0	0.036	100.0

HYDROGEN CONSUMPTION SCF/TON

1.	Direct Measurement	323.
2.	Helium Tracer	2502.
3.	Appearance of Combined Hydrogen	1876.
4.	Forced Oxygen Balance	1835.

2444 HYCRUDE CORPORATION

BENEFICIATION- HYDRORETORTING OF U.S. OIL SHALES PROGRAM YEAR 2

MINI-BENCH UNIT TEST 87MBU-16
STATISTICAL ANALYSIS DATA - PHASE TWO

Dependent Variables

1.	Hydrogen Consumption (SCF/ton)		1856.
2.	Oil Yield (gal/ton)	Recovered	24.8
		Reconciled	26.1
3.	Oil Properties	Pour Point (F)	-10.
		API (@ 60 F)	15.6
		C/H Ratio	8.30
		S (wt %)	0.72
		N (wt %)	1.35
		Viscosity (SSU)	103.5
		Distillate Fractions	
		Temp. (F) 10 %	361.
		50 %	688.
		E.P.	762.
4.	Organic Carbon Conversion (%) (Adjusted by Ash Balance)		80.6
5.	Selectivity to Oil (%) (Adjusted)		84.6
6.	Hydrocarbon Gas Yield (MM BTU/ton) Methane Equivalent - Adjusted		1.06
7.	Organic Carbon to	Gas (%)	12.4
		Oil (%)	68.2
		Residue (%)	19.4
8.	Sulfur Conv. to	Gas (%)	46.1
		Oil (%)	1.9
		Residue (%)	52.1
9.	Water Production (lb/hr)		0.0676
	Water Production (lb/hr) (less shale moisture)		0.0321

Independent Variables

1.	Maximum Bed Temperature (F)	945.
2.	Total Pressure (psia)	615.
	Hydrogen Partial Pressure (psia)	588.
3.	Shale Residence Time (min)	61.

Hydrogen Consumption is Average of Combined Hydrogen
and Forced Oxygen methods
Sulfur in gas is 45.8 % to product gas and 0.3 % to dissolved gas

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Oil Shale Type	MH-12 BCP Antrim Beneficiated
Source	Michigan
Oil Shale Particle Size (U.S. Sieve)	-6+40
Run No.	87MBU-19
Run Date	9/21/87
Test Duration, hrs	2.50
Total Shale Feed Time, hrs	2.46
Steady State Operating Period, hrs	1.50
Operating Conditions	
Bed Height, ft	1.35
Shale Preheat Height, ft	0.60
Reactor Pressure, psig	597.5
Average Bed Temperature, F	
Zone 1	800.
Zone 2	940.
Zone 3	950.
Zone 4	935.
Zone 5	910.
Zone 6	850.
Zone 7 Bed Height -	580.
Oil Shale Feed Rate, lb/hr	1.272
Oil Shale Space Velocity, lb/ft(3)-hr	46.87
Oil Shale Residence Time, min	55.6
Hydrogen Feed Gas Rate, SCF/hr	60.02
Feed Gas Superficial Velocity, ft/s	.0547
Feed Gas Residence Time, s	10.6
Hydrogen/Oil Shale Ratio, SCF/lb shale fed	47.9
Shale Feed Hopper Purge Rate, SCF/hr	3.13
Total Hydrogen Feed Gas Rate, SCF/hr	63.15

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.		87MBU-19	
Test Results	Residue Weight By Weight Measurement		Residue Weight By Ash balance
Product Gas Rate (as measured), SCF/hr		61.61	
Product Gas Rate, SCF/hr		58.28	
Product Gas Yield, SCF/lb shale fed		46.5	
Residue Shale Rate, lb/hr	0.798		0.797
Residue Shale Yield, lb/lb shale fed	0.627		0.627
Product Oil Rate, lb/hr		0.3646	
Product Oil Yield, lb/lb shale fed		0.2909	
Product Oil Yield, gal/ton		72.9	
Product Water Rate (as measured), lb/hr		0.0974	
Water Product Rate, lb/hr		0.0926	
Water Product Yield, lb/lb shale fed		0.0739	
Water Product Yield, gal/ton		17.7	
Organic Carbon Distribution in Products, %			
Gaseous Hydrocarbons		10.3	
Liquid Products		74.1<74.4>	
Solid Residue	15.2		15.2
Total	99.6< 99.9>		99.6< 99.9>
Overall Material Balance, %	102.3(102.4)		102.3(102.3)
Total Carbon Balance, %	100.1		100.1
Hydrogen Balance, %	100.7(100.7)		100.7(100.7)
Oxygen Balance, %	164.0		164.0
Sulfur Balance, %	88.9		88.8
Nitrogen Balance, %	102.8		102.8
Selectivity to Oil, %		87.8<87.8>	

Numbers in < > include organic carbon in water phase liquids
Numbers in ( ) indicate balances have been corrected for accumulated gases in new shale pores formed by hydroretorting

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS - COUNTERCURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-19			
	Feed Gas	Product Gas		
		Metered	H(2)S Adj	N(2) Free
Gas Composition, mol %				
Hydrogen Sulfide	0.00	0.06	0.06	0.06
Nitrogen	0.00	0.33	0.33	0.00
Carbon Monoxide	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.05	0.05	0.05
Hydrogen	100.00	98.50	98.50	98.82
Helium	0.00	0.00	0.00	0.00
Methane	0.00	0.54	0.54	0.55
Ethane	0.00	0.18	0.18	0.18
Propane	0.00	0.08	0.08	0.08
n-Butane	0.00	0.04	0.04	0.04
Iso-Butane	0.00	0.00	0.00	0.00
Pentanes	0.00	0.04	0.04	0.04
Hexanes	0.00	0.06	0.06	0.06
Heptanes	0.00	0.00	0.00	0.00
Ethylene	0.00	0.04	0.04	0.04
Propylene	0.00	0.05	0.05	0.05
Butene	0.00	0.03	0.03	0.03
Pentene	0.00	0.00	0.00	0.00
Hexene	0.00	0.00	0.00	0.00
Heptene	0.00	0.00	0.00	0.00
Butadiene	0.00	0.00	0.00	0.00
Pentadiene	0.00	0.00	0.00	0.00
Cyclopentadiene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
M. Acet./Propadiene	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00
Xylene	0.00	0.00	0.00	0.00
Ethyl Benzene	0.00	0.00	0.00	0.00
Styrene	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00
Specific Gravity (Air = 1.00)	0.070	0.085	0.085	0.082

ANALYSES OF EASTERN SHALE FEED AND RESIDUE - MINI-BENCH TEST

Run No.	87MBU-19			
Sample	Feed		Residue	
Lab No.	870907501		870907502	
Moisture	1.51		0.00	
Modified Ultimate Analysis (wt %, dry basis)				
Ash	56.43		88.68	
HTW in Ash	0.45		0.47	
MOX Oxygen in Ash	1.60		2.38	
Residual Mineral Oxides		54.38		85.24
Organic Carbon		33.76		8.06
Organic Hydrogen		3.32		0.37
Sulfur		3.67		4.18
Nitrogen		0.83		0.38
Carbon Dioxide		0.11		0.09
High Temperature Water		3.93		1.68
MOX Oxygen		0.00		0.00
Oxygen (by difference)		0.00		0.00
Total		100.00		100.00
Screen Analysis, U.S. Sieve, wt %				
6	0.3		--	
8	20.5		--	
12	19.6		--	
16	17.4		--	
20	13.6		--	
40	19.3		--	
50	4.5		--	
60	1.3		--	
80	1.2		--	
400	--		0.0	
Pan	2.3		100.0	
Total	100.0		100.0	
Gross Heating Value, BTU/lb	6771.0		1612.0	
Bulk Density, g/cc	0.70		0.36	
Mercury Density, g/cc	1.01		0.64	
Helium Density, g/cc	--		--	

LIQUID PRODUCT PROPERTIES - MINI-BENCH TEST WITH EASTERN SHALE

Run No.	87MBU-19
Lab No.	870907602, 870907603
Stream Identification	Oil Phase
Ultimate Analysis, wt %	
(dry and solids free basis)	
Carbon	86.01
Hydrogen	10.41
Sulfur	0.99
Nitrogen	1.64
Ash	0.00
Oxygen (by difference)	0.95
C/H Weight Ratio	8.26
Viscosity, SSU at 100 F	91.0
Specific Gravity (60/60 F)	0.957
API Gravity, degrees API	16.4
Distillation, F	ASTM D86
IBP	170.
5%	280.
10%	336.
20%	436.
30%	523.
40%	613.
50%	670.
60%	701.
70%	723.
80%	734.
90%	--
95%	--
End Point	736.
% Recovery	82.5
% Residue	17.5
Heating Value, BTU/lb	18028.
Pour Point, F	-15.

Stream Identification	Water Phase
Mineral Carbon, wt %	0.20
Organic Carbon, wt %	1.10
Nitrogen, wt %	1.73
Sulfur, wt %	0.72

ELEMENTAL DISTRIBUTION FOR 87MBU-19

	Inlet		Outlet (by ash)		Outlet Adjusted	
	lb/hr	%	lb/hr	%	lb/hr	%
Total Carbon						
Raw Shale	0.423	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.064	15.2	0.064	15.2
Hydrocarbon Gas	0.000	0.0	0.044	10.3	0.045	10.7
Carbon Oxides	0.000	0.0	0.001	0.2	0.001	0.2
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.3	0.001	0.3
Product Oil	0.000	0.0	0.314	74.1	0.312	73.6
Total	0.423	100.0	0.424	100.1	0.423	100.0
Hydrogen						
Raw Shale (dry basis)	0.047	12.2	0.000	0.0	0.000	0.0
Moisture	0.002	0.6	0.000	0.0	0.000	0.0
Feed Gas	0.336	87.2	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.004	1.2	0.004	1.2
Product Gas	0.000	0.0	0.335	86.9	0.333	86.2
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.2	0.001	0.2
Product Water	0.000	0.0	0.010	2.7	0.010	2.7
Product Oil	0.000	0.0	0.038	9.8	0.038	9.8
Total	0.386	100.0	0.388	100.7	0.386	100.0
Oxygen						
Raw Shale (dry basis)	0.045	72.4	0.000	0.0	0.000	0.0
Moisture	0.017	27.6	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.012	20.1	-0.027	-43.8
Product Gas as Carbon Oxides	0.000	0.0	0.003	4.4	0.003	4.4
Dissolved Gas in Sour Water	0.000	0.0	0.001	0.8	0.001	0.8
Product Water	0.000	0.0	0.082	133.1	0.082	133.1
Product Oil	0.000	0.0	0.003	5.6	0.003	5.6
Total	0.062	100.0	0.101	164.0	0.062	100.0
Sulfur						
Raw Shale	0.046	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.033	72.5	0.033	72.5
Product Gas	0.000	0.0	0.003	7.0	0.008	18.2
Dissolved Gas in Sour Water	0.000	0.0	0.001	1.5	0.001	1.5
Product Oil	0.000	0.0	0.004	7.8	0.004	7.8
Total	0.046	100.0	0.041	88.8	0.046	100.0
Nitrogen						
Raw Shale	0.010	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.003	29.1	0.003	26.7
Dissolved Gas in Sour Water	0.000	0.0	0.002	16.2	0.002	16.2
Product Oil	0.000	0.0	0.006	57.5	0.006	57.1
Total	0.010	100.0	0.011	102.8	0.010	100.0

COMBINED HYDROGEN DISTRIBUTION FOR 87MBU-19

	Outlet (by ash)		Outlet (Adjusted)	
Appearance of Combined Hydrogen	lb/hr	%	lb/hr	%
Product Gas (HC + H(2)S)	0.012	20.0	0.013	21.3
Product Oil	0.038	65.0	0.038	63.8
Dissolved Gas in Sour Water	0.001	1.0	0.001	1.0
Net Product Water (total product water - feed moisture)	0.008	14.1	0.008	13.9
Total	0.058	100.0	0.059	100.0

HYDROGEN CONSUMPTION SCF/TON

1. Direct Measurement	3915.
2. Appearance of Combined Hydrogen	4916.
3. Forced Oxygen Balance	3424.

MINI-BENCH UNIT TEST 87MBU-19
STATISTICAL ANALYSIS DATA - PHASE TWO

Dependent Variables

1.	Hydrogen Consumption (SCF/ton)		4170.
2.	Oil Yield (gal/ton)	Recovered	72.9
		Reconciled	72.4
3.	Oil Properties	Pour Point (F)	-15.
		API (@ 60 F)	16.4
		C/H Ratio	8.26
		S (wt %)	0.99
		N (wt %)	1.64
		Viscosity (SSU)	91.0
		Distillate Fractions	
		Temp. (F) 10 %	336.
		50 %	670.
		E.P.	736.
4.	Organic Carbon Conversion (%) (Adjusted by Ash Balance)		84.8
5.	Selectivity to Oil (%) (Adjusted)		87.4
6.	Hydrocarbon Gas Yield (MM BTU/ton) Methane Equivalent - Adjusted		2.30
7.	Organic Carbon to	Gas (%)	10.7
		Oil (%)	74.1
		Residue (%)	15.2
8.	Sulfur Conv. to	Gas (%)	19.7
		Oil (%)	7.8
		Residue (%)	72.5
9.	Water Production (lb/hr)		0.0926
	Water Production (lb/hr) (less shale moisture)		0.0734

Independent Variables

1.	Maximum Bed Temperature (F)	950.
2.	Total Pressure (psia)	612.
	Hydrogen Partial Pressure (psia)	595.
3.	Shale Residence Time (min)	56.

Hydrogen Consumption is Average of Combined Hydrogen and Forced Oxygen methods
Sulfur in gas is 18.2 % to product gas and 1.5 % to dissolved gas

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Oil Shale Type	MH-1-B Beneficiated
Source	Alabama
Oil Shale Particle Size (U.S. Sieve)	-6+40
Run No.	87MBU-20
Run Date	9/28/87
Test Duration, hrs	4.25
Total Shale Feed Time, hrs	4.21
Steady State Operating Period, hrs	2.00
Operating Conditions	
Bed Height, ft	1.29
Shale Preheat Height, ft	0.54
Reactor Pressure, psig	600.0
Average Bed Temperature, F	
Zone 1	700.
Zone 2	950.
Zone 3	960.
Zone 4	950.
Zone 5	905.
Zone 6	810.
Zone 7 Bed Height -	560.
Oil Shale Feed Rate, lb/hr	1.195
Oil Shale Space Velocity, lb/ft(3)-hr	46.01
Oil Shale Residence Time, min	52.7
Hydrogen Feed Gas Rate, SCF/hr	59.12
Feed Gas Superficial Velocity, ft/s	.0548
Feed Gas Residence Time, s	8.7
Hydrogen/Oil Shale Ratio, SCF/lb shale fed	50.2
Shale Feed Hopper Purge Rate, SCF/hr	3.13
Total Hydrogen Feed Gas Rate, SCF/hr	62.19
Helium Tracer Gas Rate, SCF/hr	1.15

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS
COUNTER-CURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-20		
Test Results	Residue Weight By Weight Measurement		Residue Weight By Ash balance
Product Gas Rate (as measured), SCF/hr		61.23	
Product Gas Rate, SCF/hr		57.00	
Product Gas Yield, SCF/lb shale fed		48.4	
Residue Shale Rate, lb/hr	0.652		0.657
Residue Shale Yield, lb/lb shale fed	0.545		0.550
Product Oil Rate, lb/hr		0.3339	
Product Oil Yield, lb/lb shale fed		0.2837	
Product Oil Yield, gal/ton		70.2	
Product Water Rate (as measured), lb/hr		0.0552	
Water Product Rate, lb/hr		0.0524	
Water Product Yield, lb/lb shale fed		0.0445	
Water Product Yield, gal/ton		10.7	
Organic Carbon Distribution in Products, %			
Gaseous Hydrocarbons		18.7	
Liquid Products		56.4<56.4>	
Solid Residue	27.1		27.3
Total	102.1<102.2>		102.3<102.4>
Overall Material Balance, %	98.7(98.8)		99.1(99.2)
Total Carbon Balance, %	102.2		102.5
Hydrogen Balance, %	99.7(99.9)		99.7(100.0)
Oxygen Balance, %	82.3		82.5
Sulfur Balance, %	102.8		103.4
Nitrogen Balance, %	118.3		118.7
Selectivity to Oil, %		75.1<75.2>	

Numbers in < > include organic carbon in water phase liquids
Numbers in ( ) indicate balances have been corrected for accumulated gases in new shale pores formed by hydroretorting

MINI-BENCH OPERATING CONDITIONS AND TEST RESULTS - COUNTERCURRENT MOVING-BED OPERATION WITH EASTERN SHALE

Run No.	87MBU-20			
	Feed Gas	Product Gas		
		Metered	H(2)S Adj	N(2) & He Free
Gas Composition, mol %				
Hydrogen Sulfide	0.00	0.67	0.67	0.69
Nitrogen	0.00	0.11	0.11	0.00
Carbon Monoxide	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.02	0.02	0.02
Hydrogen	98.18	94.64	94.64	96.48
Helium	1.82	1.80	1.80	0.00
Methane	0.00	1.60	1.60	1.63
Ethane	0.00	0.57	0.57	0.58
Propane	0.00	0.22	0.22	0.22
n-Butane	0.00	0.11	0.11	0.11
Iso-Butane	0.00	0.00	0.00	0.00
Pentanes	0.00	0.05	0.05	0.05
Hexanes	0.00	0.03	0.03	0.03
Heptanes	0.00	0.00	0.00	0.00
Ethylene	0.00	0.08	0.08	0.08
Propylene	0.00	0.09	0.09	0.09
Butene	0.00	0.06	0.06	0.06
Pentene	0.00	0.00	0.00	0.00
Hexene	0.00	0.00	0.00	0.00
Heptene	0.00	0.00	0.00	0.00
Butadiene	0.00	0.00	0.00	0.00
Pentadiene	0.00	0.00	0.00	0.00
Cyclopentadiene	0.00	0.00	0.00	0.00
Acetylene	0.00	0.00	0.00	0.00
M. Acet./Propadiene	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00
Xylene	0.00	0.00	0.00	0.00
Ethyl Benzene	0.00	0.00	0.00	0.00
Styrene	0.00	0.00	0.00	0.00
Total	100.00	100.03	100.03	100.03
Specific Gravity (Air = 1.00)	0.071	0.103	0.103	0.101

ANALYSES OF EASTERN SHALE FEED AND RESIDUE - MINI-BENCH TEST

Run No.		87MBU-20		
Sample	Feed		Residue	
Lab No.	870910501		870910502	
Moisture	1.53		0.00	
Modified Ultimate Analysis (wt %, dry basis)				
Ash	41.23		73.85	
HTW in Ash	0.20		0.34	
MOX Oxygen in Ash	4.03		9.75	
Residual Mineral Oxides		37.00		63.76
Organic Carbon		43.29		21.17
Organic Hydrogen		3.64		0.87
Sulfur		9.27		10.75
Nitrogen		0.84		0.66
Carbon Dioxide		0.00		0.00
High Temperature Water		5.42		1.95
MOX Oxygen		0.00		0.84
Oxygen (by difference)		0.54		0.00
Total		100.00		100.00
Screen Analysis, U.S. Sieve, wt %				
6	2.0		--	
8	24.7		--	
12	17.5		--	
16	16.7		--	
20	14.0		--	
30	7.6		--	
40	9.5		--	
50	4.6		--	
60	0.7		--	
80	0.9		--	
270	--		0.2	
325	--		0.8	
400	--		6.5	
Pan	1.8		92.5	
Total	100.0		100.0	
Gross Heating Value, BTU/lb	8849.0		4206.0	
Bulk Density, g/cc	0.65		0.54	
Mercury Density, g/cc	1.10		0.85	
Helium Density, g/cc	--		--	

LIQUID PRODUCT PROPERTIES - MINI-BENCH TEST WITH EASTERN SHALE

Run No.	87MBU-20
Lab No.	870910602, 870910603
Stream Identification	Oil Phase
Ultimate Analysis, wt % (dry and solids free basis)	
Carbon	86.03
Hydrogen	9.98
Sulfur	1.82
Nitrogen	1.91
Ash	0.00
Oxygen (by difference)	0.26
C/H Weight Ratio	8.62
Viscosity, SSU at 100 F	70.2
Specific Gravity (60/60 F)	0.969
API Gravity, degrees API	14.5
Distillation, F	ASTM D86
IBP	170.
5%	256.
10%	316.
20%	395.
30%	502.
40%	593.
50%	655.
60%	703.
70%	733.
80%	752.
90%	--
95%	--
End Point	753.
% Recovery	83.5
% Residue	16.5
Heating Value, BTU/lb	17935.
Pour Point, F	-40.
Stream Identification	Water Phase
Mineral Carbon, wt %	0.02
Organic Carbon, wt %	0.53
Nitrogen, wt %	1.85
Sulfur, wt %	2.00

ELEMENTAL DISTRIBUTION FOR 87MBU-20

	Inlet		Outlet (by ash)		Outlet Adjusted	
	lb/hr	%	lb/hr	%	lb/hr	%
Total Carbon						
Raw Shale	0.510	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.139	27.3	0.139	27.3
Hydrocarbon Gas	0.000	0.0	0.095	18.7	0.097	19.1
Carbon Oxides	0.000	0.0	0.000	0.1	0.000	0.1
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.1	0.000	0.1
Product Oil	0.000	0.0	0.287	56.4	0.273	53.5
Total	0.510	100.0	0.522	102.5	0.510	100.0
Hydrogen						
Raw Shale (dry basis)	0.050	13.1	0.000	0.0	0.000	0.0
Moisture	0.002	0.5	0.000	0.0	0.000	0.0
Feed Gas	0.331	86.4	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.007	1.9	0.007	1.9
Product Gas	0.000	0.0	0.336	87.8	0.338	88.3
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.1	0.000	0.1
Product Water	0.000	0.0	0.006	1.5	0.006	1.5
Product Oil	0.000	0.0	0.033	8.7	0.032	8.2
Total	0.383	100.0	0.383	100.0	0.383	100.0
Oxygen						
Raw Shale (dry basis)	0.063	79.5	0.000	0.0	0.000	0.0
Moisture	0.016	20.5	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.017	21.3	0.031	38.9
Product Gas as Carbon Oxides	0.000	0.0	0.001	1.3	0.001	1.3
Dissolved Gas in Sour Water	0.000	0.0	0.000	0.0	0.000	0.0
Product Water	0.000	0.0	0.047	58.7	0.047	58.7
Product Oil	0.000	0.0	0.001	1.1	0.001	1.0
Total	0.079	100.0	0.065	82.5	0.079	100.0
Sulfur						
Raw Shale	0.109	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.071	64.7	0.071	64.7
Product Gas	0.000	0.0	0.035	32.0	0.032	29.0
Dissolved Gas in Sour Water	0.000	0.0	0.001	1.0	0.001	1.0
Product Oil	0.000	0.0	0.006	5.6	0.006	5.3
Total	0.109	100.0	0.113	103.4	0.109	100.0
Nitrogen						
Raw Shale	0.010	100.0	0.000	0.0	0.000	0.0
Spent Shale	0.000	0.0	0.004	43.9	0.003	28.5
Dissolved Gas in Sour Water	0.000	0.0	0.001	10.3	0.001	10.3
Product Oil	0.000	0.0	0.006	64.5	0.006	61.2
Total	0.010	100.0	0.012	118.7	0.010	100.0

COMBINED HYDROGEN DISTRIBUTION FOR 87MBU-20

Appearance of Combined Hydrogen	Outlet (by ash) lb/hr	Outlet (by ash) %	Outlet (Adjusted) lb/hr	Outlet (Adjusted) %
Product Gas (HC + H(2)S)	0.027	41.7	0.027	43.2
Product Oil	0.033	51.9	0.032	50.2
Dissolved Gas in Sour Water	0.000	0.5	0.000	0.5
Net Product Water (total product water - feed moisture)	0.004	5.9	0.004	6.1
Total	0.064	100.0	0.063	100.0

HYDROGEN CONSUMPTION SCF/TON

1. Direct Measurement 6868.
2. Helium Tracer 2484.
3. Appearance of Combined Hydrogen 6429.
4. Forced Oxygen Balance 6989.

MINI-BENCH UNIT TEST 87MBU-20
STATISTICAL ANALYSIS DATA - PHASE TWO

Dependent Variables

1.	Hydrogen Consumption (SCF/ton)		6709.
2.	Oil Yield (gal/ton)	Recovered	70.2
		Reconciled	66.6
3.	Oil Properties	Pour Point (F)	-40.
		API (@ 60 F)	14.5
		C/H Ratio	8.62
		S (wt %)	1.82
		N (wt %)	1.91
		Viscosity (SSU)	70.2
		Distillate Fractions	
		Temp. (F) 10 %	316.
		50 %	655.
		E.P.	753.
4.	Organic Carbon Conversion (%) (Adjusted by Ash Balance)		72.7
5.	Selectivity to Oil (%) (Adjusted)		73.8
6.	Hydrocarbon Gas Yield (MM BTU/ton) Methane Equivalent - Adjusted		5.26
7.	Organic Carbon to	Gas (%)	19.1
		Oil (%)	53.6
		Residue (%)	27.3
8.	Sulfur Conv. to	Gas (%)	30.0
		Oil (%)	5.3
		Residue (%)	64.7
9.	Water Production (lb/hr)		0.0524
	Water Production (lb/hr) (less shale moisture)		0.0341

Independent Variables

1.	Maximum Bed Temperature (F)	960.
2.	Total Pressure (psia)	615.
	Hydrogen Partial Pressure (psia)	582.
3.	Shale Residence Time (min)	53.

Hydrogen Consumption is Average of Combined Hydrogen and Forced Oxygen methods
Sulfur in gas is 29.0 % to product gas and 1.0 % to dissolved gas

DRAFT
12.02.87
12:45 AM

APPENDIX B

JENIKE & JOHANSON, INC. REPORT
April 22, 1987

GRAVITY FLOW AND ATTRITION OF BENEFICIATED OIL SHALE PELLETS

Hycrude Corp.

871609-1

2

Jenike & Johanson, inc.

2 Executive Park Drive · North Billerica, MA 01862 · (617) 667-5136

April 22, 1987

GRAVITY FLOW AND ATTRITION OF BENEFICIATED OIL SHALE PELLETS

Hycrude Corp.
871609-1

1 BACKGROUND

Hycrude, in conjunction with the School of Mines and Energy Development at the University of Alabama, is evaluating the use of beneficiated oil shale pellets in the Hytort process. The pellet's gravity flow and particle attrition properties are a necessary part of this evaluation. Jenike & Johanson, Inc. was asked to measure these properties on small samples of the pellets, and to provide a preliminary evaluation of full-scale behavior. This work is based on similar tests and analysis with spent oil shale performed for IGT and provided in Jenike & Johanson report #820796.

2 GRAVITY FLOW PROPERTIES

The critical flow properties for gravity flow in the retort are:

- compressive yield strength - predicts potential for forming flow obstructions;
- kinematic wall friction angles - determine slope angles for inserts and hoppers;
- gas permeability - used to describe two-phase flow behavior;
- bulk density - necessary for vessel design and above analyses.

The results of our tests are given in the attached Flow Properties Test Report. The following is a summary of these test results.

Two samples of beneficiated oil shale pellets were received for flow properties/attrition testing. The raw (unretorted) sample consisted of about 10 lbs. of gray-brown lozenge-shaped pellets (about 0.35 by 0.45 by 0.9 in.) with some broken pellets and dust. The spent (retorted) sample consisted of about 0.5 lbs. of black whole pellets, broken pellets and dust. Because of the limited sample sizes, no tests of compressive yield strength could be made and the remaining properties had to be measured at room temperature and 'as received' moisture content instead of under actual process conditions. Consequently, the following properties, design criteria and evaluation must be considered to be very preliminary. Moisture (volatiles) content was determined by drying a sample at 107 C for two hours and calculated on a wet basis.

Wall friction tests were performed on both pellet samples. The wall surfaces for the raw pellets consisted of cast-in-place refractory with a <u>rough</u> (sprayed) finish and a <u>smooth</u> finish formed by casting against a smooth steel plate. The smooth refractory and an oxidized sample of 2B finish stainless steel sheet were used with the spent pellets since a smooth finish is necessary in the hopper and a steel hopper surface may be practical. In summary, the rough refractory has a high wall friction angle of about 45° and thus is not suitable for a hopper or insert walls. The smooth refractory requires steep hopper walls for mass flow (flow along the walls) while the oxidized 2B stainless steel finish is slightly less frictional than the smooth refractory but still requires relatively steep hopper walls for mass flow.

Gas permeability was not measured because the estimated superficial gas counterflow velocity of 1.5 fps is not severe for the 'as received' pellets, and we could not generate representative samples of degraded pellets at this preliminary stage (see section 3).

The bulk density of the raw pellets was estimated to be 40 lbs/cu.ft. After attrition, the bulk density is likely to increase due to denser particle packing. One limited test indicated a bulk density of approximately 45 lbs/cu.ft. Retorting appears to reduce particle density. For example, one limited measurement of bulk density with some broken pellets and fines resulted in a bulk density of 35 lbs/cu.ft.

3 PARTICLE ATTRITION PROPERTIES

For a baseline, the approximate compressive crushing strength of individual pellets was determined as shown in Fig. 1. We found that the strength of 12 whole raw pellets varied from 7.1 to 19.4 lbs. with an average strength of 13.2 lbs. while that of 16 whole spent pellets varied from 4.5 to 30 lbs. with an average strength of 18.3 lbs. Although there is a lot of scatter in the data, the spent pellets do not appear to be any weaker than the raw pellets; hence, the following attrition tests with raw pellets (used because of the extremely limited sample size of spent pellets) should provide conservative results. As noted above, all tests were run at room conditions due to the limited sample size; consequently, our conclusions are preliminary at best.

There are four main mechanisms of particle attrition within the retort: particle impact on filling, particle crushing during flow through cylindrical sections, particle abrasion by the wall surfaces, and particle crushing during flow through converging sections. Each is addressed below.

3.1 Particle Impact

There is usually a difference in the amount of particle attrition between particle impact on a rigid surface and on a bed of material. For this preliminary evaluation, we simulated the more severe attrition associated with impact on a rigid surface.

Solid whole raw pellets were dropped from heights ranging from 6 ft. to 14 ft. Impact tended to split or chip the pellets but not generate many fines (-6 mesh). Particles dropped 6 ft. or less sustained little damage, particles dropped 10 ft. mostly split and chipped, and essentially all particles dropped 14 ft. split and/or chipped. Malformed pellets did not fare as well.

We could not practically simulate larger free-fall heights associated with initially filling the retort without a more complex setup. However, the raw pellet particles are relatively fragile and we suspect that a significant quantity of broken pellets and fines will be generated after impacting inserts, hopper walls or the material bed during filling. This indicates that the retort may need to be operated before adding gas in order to clear the fines in the lower portions of the retort and/or that stronger pellets are desireable. Keeping the top level within 6 ft. of the filling point should minimize attrition due to impact during steady-state operation.

3.2 Crushing - Cylindrical Sections

Measurements of bulk density versus consolidation stress were made in both an 8 in. and 3.75 in. diameter cell to give an indication of attrition in a cylinder. The 8 in. cell is more appropriate for this size of pellets; however, larger consolidation stresses can be developed in the smaller cell.

The test results in Fig. 2 (8 in. cell) and Fig. 3 (3.75 in. cell) show a nonlinear relationship which is indicative of particle attrition. There are no distinct inflection points; however, the 8 in. cell test results indicate that pellets likely start to rearrange themselves with minor chipping at a consolidation stress of about 400 psf. The 3.75 in. cell test results indicate the onset of particle crushing at a consolidation stress of about 1200 psf, which was confirmed by crushing sounds eminating from the apparatus. The percentage of broken particles and fines (minus 6 mesh)as a function of consolidation stress is shown in Fig. 4.

The proposed retort is likely to develop consolidation stresses of up to 1100 psf in the cylindrical sections. This value is about 68% of the maximum stress developed with raw, nonbeneficiated shale due to the lower bulk density. As a result, we do not expect a large percentage of broken particles or fines due to crushing in the cylindrical sections.

3.3 Abrasion on Walls

As particles slide along the retort walls, fines are likely to be produced as a function of contact stress, wall roughness and travel distance. The relationship of the latter two to contact stress is not likely to be linear. Since an in-depth analysis of this phenomenon is beyond the scope of this evaluation, limited tests were run to provide some preliminary indication of attrition by this mechanism.

The quantity of broken particles was determined after running standard wall friction tests on the smooth and rough refractories. The contact stress varied from 5 to 410 psf with an approximate average stress of 150 psf. The results and observations are:

- we did not see a significant sensitivity to wall roughness;

- approximately 13% (by weight) broken pellets and fines were generated in a 0.6 in. deep by 3.75 in. diameter cell after approximately 4 in. of travel;

- <u>assuming</u> that 4% of the broken pellets and fines were due to the maximum consolidation stress of 410 psf (see Fig. 4), about 9% broken pellets and fines were developed due to abrasion on the walls - or 27% per foot travel;

- <u>assuming</u> that approximately half the pellets in the cell were not in contact with the wall and therefore not being abraded by it, each pellet at the wall is only likely to survive about 2 ft. of travel at an <u>average</u> stress of 150 psf;

- since the <u>average</u> contact stress in the retort is likely to approach 500 psf, attrition due to wall abrasion is likely to be much greater than estimated above;

- the locations of maximum wall surface area and contact stress coincide at the inserts; consequently, severe abrasive attrition is likely to occur relatively high in the retort.

Our conclusion from this extremely crude evaluation is that a large amount of fines will likely be generated along the walls and inserts which may disturb the gas distribution. This result was not anticipated; consequently, further work is essential to increase particle hardness and/or to more precisely quantify attrition by this mechanism.

3.4 <u>Crushing - Converging Sections</u>

As pellets flow through converging sections at the inserts and in the hopper, they are exposed to large consolidation stresses and to significant shear strains. Tests were run by simulating the stress and strain history of the pellets as they flow through the retort. These tests were performed as described in report 820796 with results shown in Fig. 5.

The tests indicate that:

- pellet attrition does not appear to be a linear function of consolidation stress;

- pellet attrition does not appear to be proportional to strain except for the relatively small strains associated with the inserts (note results for hopper alone);

- attrition of these raw beneficiated pellets appears to be approximately five times greater than that of the spent shale described in report 820796.

Adding the percentage of the broken particles and fines (-6 mesh) generated due to crushing at insert levels A, B and C, and the hopper from Fig. 5, results in approximately 53% and 7% by weight, respectively, at the retort outlet. One test was run simulating the entire retort and resulted in the generation of 38% by weight of broken particles and 8.6% by weight of fines.

This indicates that preliminary estimates of particle attrition, due to crushing in converging sections, can be made for different retort configurations from Fig. 5.

4 WORK TO BE DONE

The cumulative amount of broken pellets and fines generated by the four attrition mechanisms appears to be severe with these raw beneficiated pellets. Attrition is most pronounced due to particle impact on initial filling, abrasion at the walls and crushing in converging sections. We therefore recommend that the following be determined:

- the optimum pellet strength with and/or without binders;
- the appropriate pelletization process and design parameters necessary to develop optimum pellet strength;
- a better method of quantifying attrition due to wall abrasion and reevaluting the probable level of attrition in the proposed retort;
- flow and attrition properties of optimum pellets during process conditions;
- retort geometry details necessary to minimize attrition.

We at Jenike & Johanson have considerable experience in this type of work and look forward to working with Hycrude and/or the University of Alabama in each of the above areas. Our fees for this work will be based on the per diem rates and standard fees noted in the attached Fee Schedule.

Pellet strength optimization tests will be charged at $1,400 per test condition plus two to four days of an engineer's time to set up test procedures, evaluate results, and prepare a report. For example, tests with 'as received' beneficiated oil shale powder and also with one binder added in two concentrations to the 'as received' powder constitutes three test conditions. Determining the appropriate process and developing design parameters may require $1,050 per pellet mix for additional tests and from five to ten days of an engineer's time. Developing a better method of quantifying and estimating attrition due to wall abrasion is likely to require two to four days of both an engineer and a technician. We believe that it is premature to estimate the time required to complete the remaining tasks since this work will depend on the outcome of the previous tasks.

For pellet optimization tests, we will require a minimum of two liters of beneficiated oil shale powder for each test condition, e.g., tests with two binders and the 'as received' powder constitutes three test conditions. This sample should be sent to the attention of Dr. John W. Carson at this address. No additional raw beneficiated pellet samples are required for the wall abrasion attrition work.

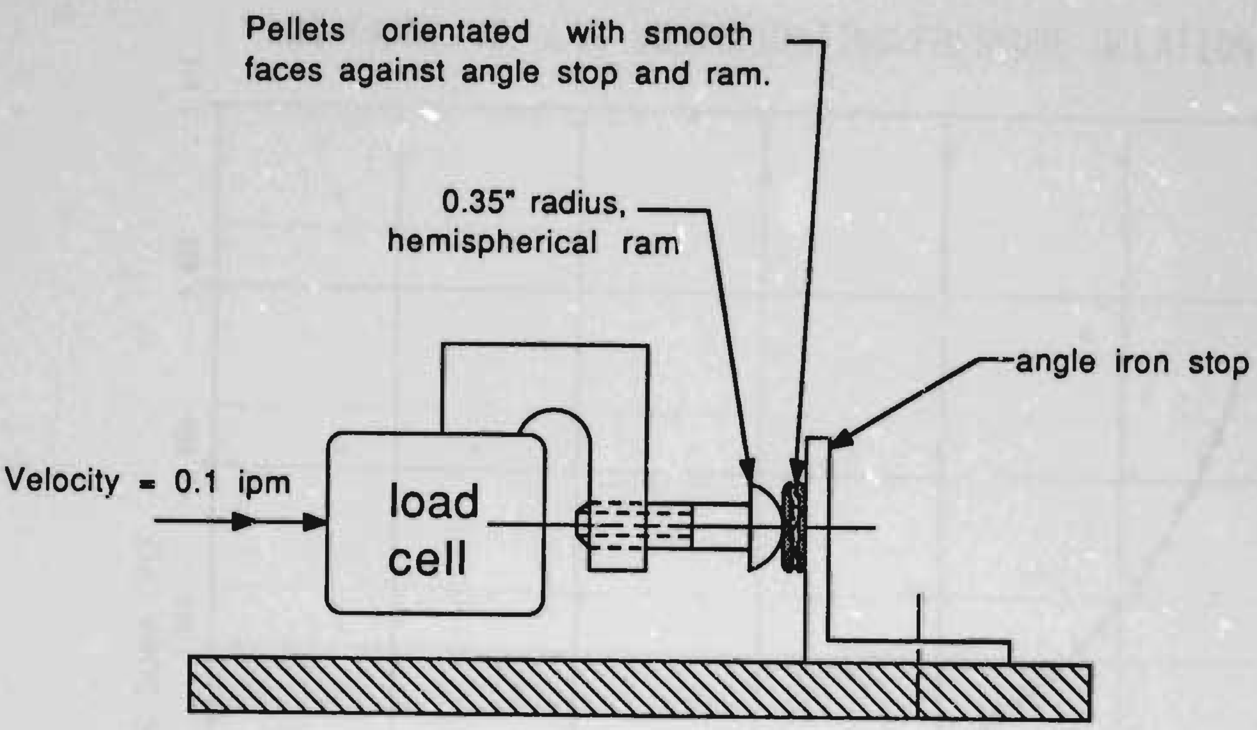


Figure 1. Apparatus Used to Measure Approximate Particle Compressive Strength

871609

BULK MATERIAL: OIL SHALE PELLETS
PARTICLE SIZE: AS REC'D
MOISTURE % WT: 1.22
TEMPERATURE: 72 DEG F

CREATE: 03/03/87
RUN: 03/03/87

JOB#: 871609
ID#: 14288

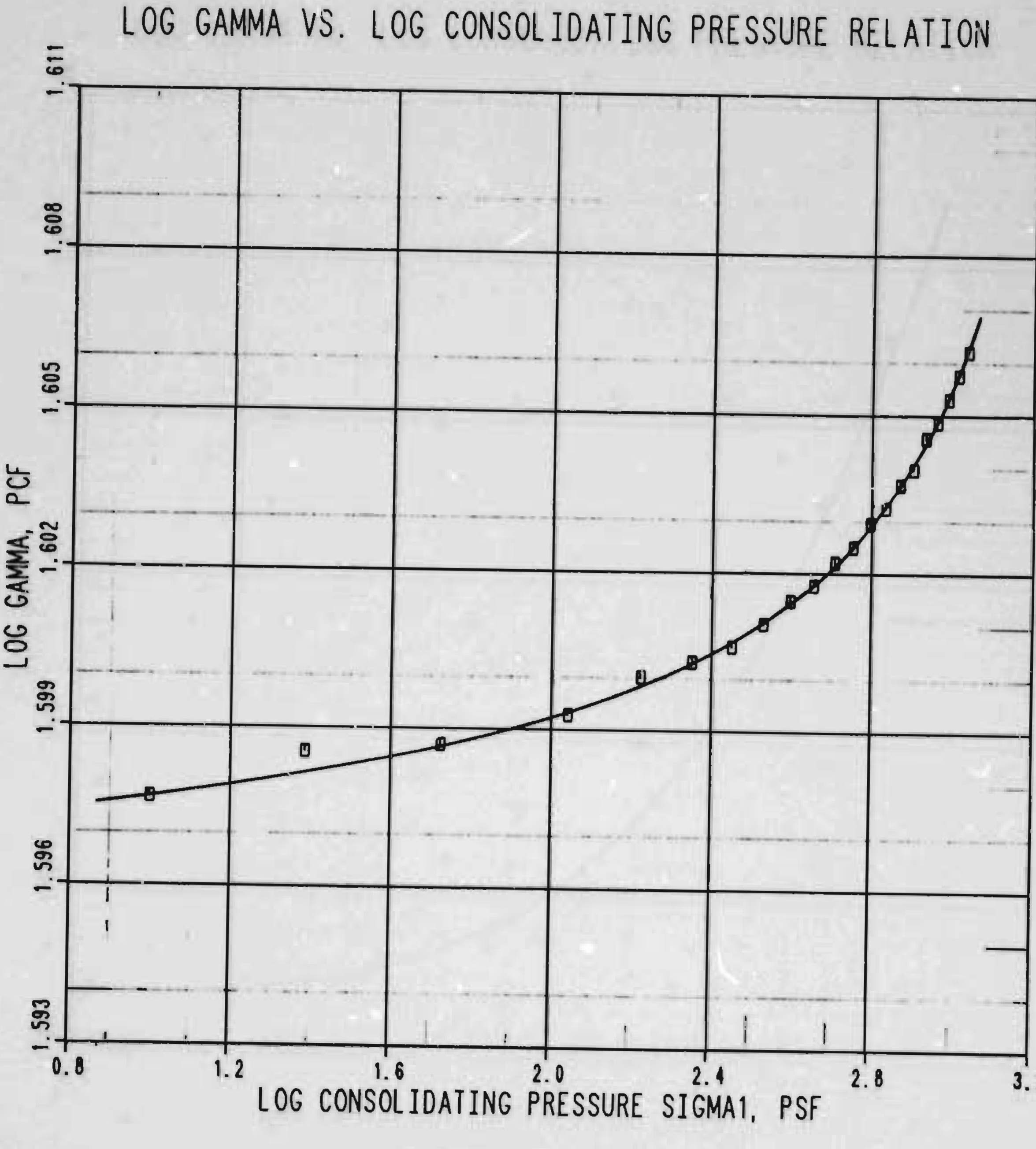


Figure 2. Bulk Density - Consolidation Stress Relationship for Whole Raw Pellets in an 8" Diameter Cell

BULK MATERIAL: OIL SHALE PELLETS
PARTICLE SIZE: AS REC'D
MOISTURE % WT: 1.22%
TEMPERATURE: 72 DEG F

CREATE: 03/05/87
RUN: 03/05/87

JOB#: 871609
ID#: 14294

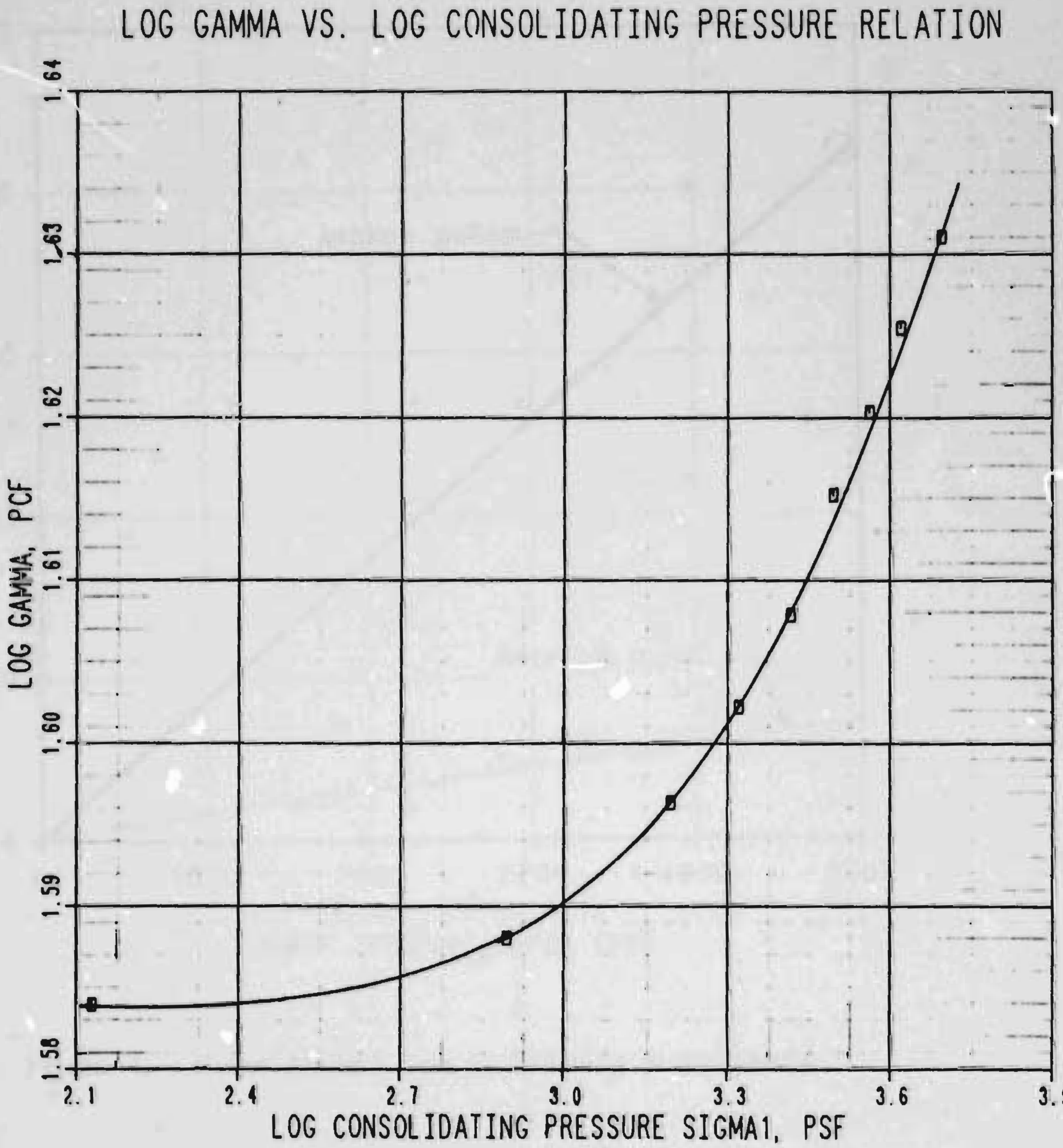


Figure 3. Bulk Density - Consolidation Stress Relationship for Whole Raw Pellets in a 3.75" Diameter Cell

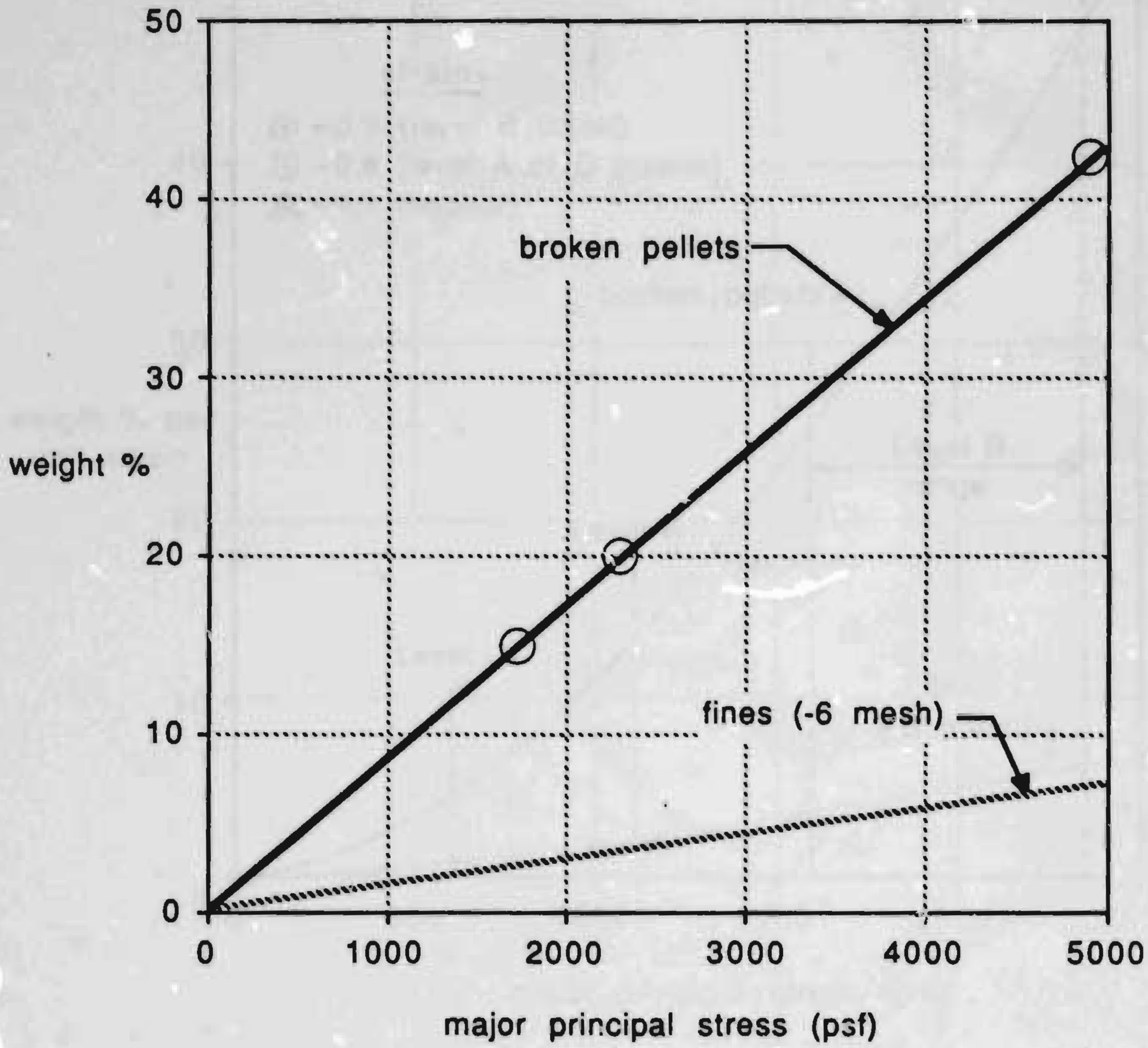


Figure 4. Pellet Attrition Due to Crushing in a Cylinder

871609

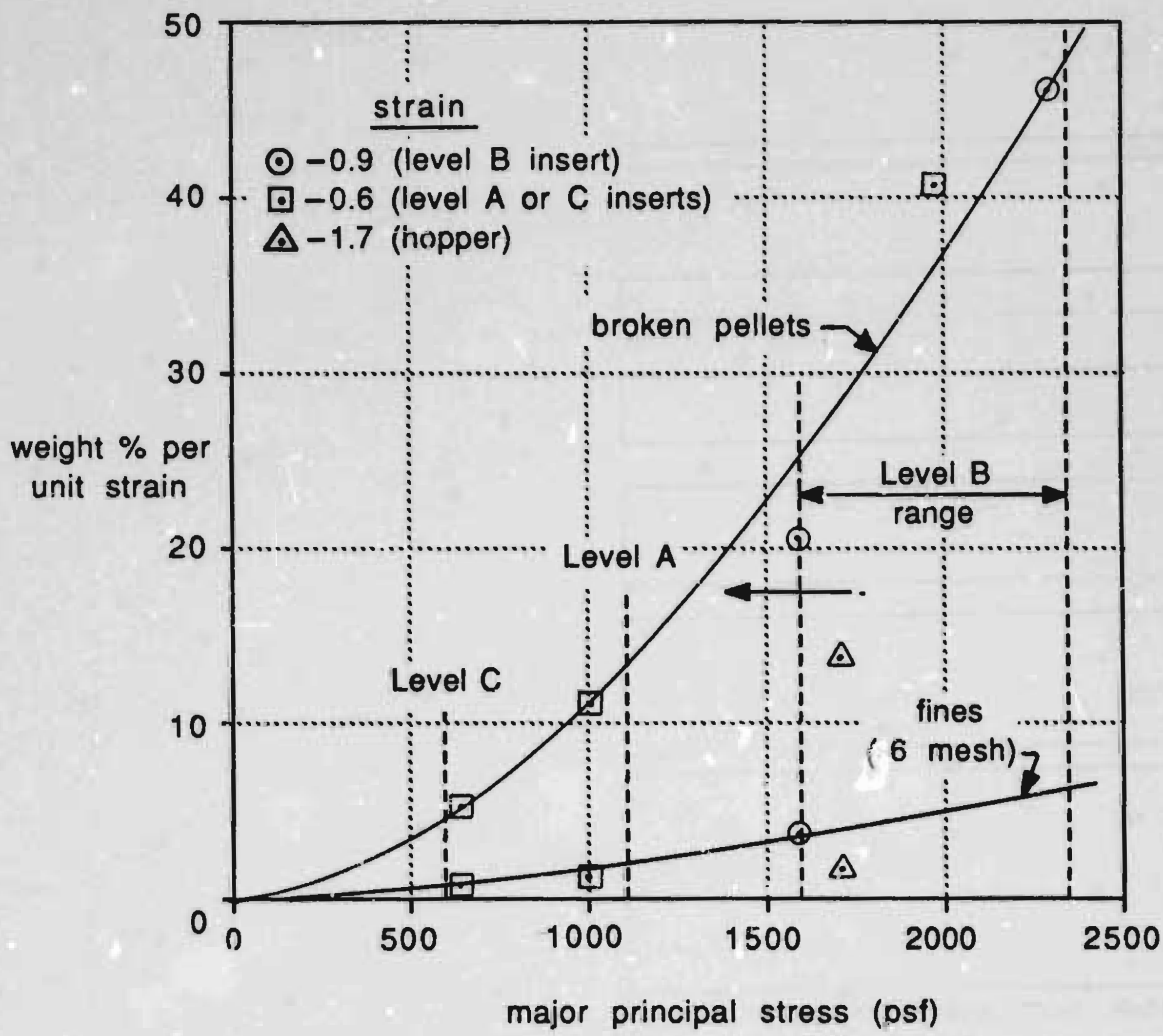


Figure 5. Pellet Attrition Due to Crushing in Converging Sections

FLOW PROPERTIES TEST REPORT

Hycrude Corp.

871609

Jenike & Johanson, inc.

2 Executive Park Drive · North Billerica, MA 01862 · (617) 667-5136

CONTENTS

INTRODUCTION

This test report describes the flow properties of your material. These properties are expressed in terms of bin dimensions required to ensure dependable flow, maximum hopper angles for mass flow and, if tested, minimum chute angles and critical discharge rates through bin outlets. All dimensions represent limiting conditions for flow; therefore, larger outlets, steeper hoppers and chutes, and flow rates below critical are acceptable. If your material is one which will compact excessively in a large bin, the largest diameter or width and height of the cylinder to limit this compaction is also given.

In case you are unfamiliar with the use of this type of data, an Appendix follows the main body of the report. Most of the symbols used in the report are shown in the figures on pages A16 to A18. A Glossary of Terms and Symbols is provided on pages A12 to A15.

SUMMARY OF TESTS PERFORMED

This report presents various flow property test results as indicated for the following material(s) :

BULK MATERIAL	DESCRIPTION	PARTICLE SIZE	MOISTURE CONTENT
1	BENEFICIATED SHALE	PELLETS	1.2%(A/R)
2	SPENT OIL SHALE	PELLETS	AS REC'D

BULK MATERIAL	TIME hr	TEMPERATURE °F	RELATIVE HUMIDITY	BIN DIM	BULK DENSITY	HOPPER ANGLES	CHUTE ANGLES	FLOW RATE	OTHER
1	0.0	72	NA		X	X			
2	0.0	72	NA			X			

BULK MATERIAL 1: BENEFICIATED SHALE

PARTICLE SIZE PELLETS
MOISTURE CONTENT 1.2%(A/R)

SECTION II. BULK DENSITY

TEMPERATURE 72 deg F

EH, ft	0.5	1.0	2.5	5.0	10.0	20.0	40.0	80.0
SIGMA1, psf	20.	40.	100.	200.	400.	803.	1611.	3231.
GAMMA, pcf	39.6	39.7	39.8	39.9	40.0	40.2	40.3	40.4

COMPRESSIBILITY PARAMETERS

Bulk density GAMMA, is a function of the principal consolidating pressure SIGMA1, as follows:

GAMMA is the greater of $GAMMA0\ (SIGMA1/SIGMA0)^{BETA}$ and GAMMAM.

For GAMMA between 39.6 and 40.4 pcf

GAMMA0 = 39.5 pcf

SIGMA0 = 13.0 psf

BETA = 0.00408

Minimum density GAMMAM = 39.4 pcf

BULK MATERIAL 1: BENEFICIATED SHALE

PARTICLE SIZE PELLETS
MOISTURE CONTENT 1.2%(A/R)

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS-FLOW

WALL MATERIAL: CAST REFRACTORY (ROUGH)

STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

WIDTH OF OVAL, ft	0.30	0.50	1.0	2.0	4.0	10.0	12.2
DIA OF CONE, ft	0.60	1.00	2.0	4.0	8.0	20.0	24.5
Wall Friction Angle							
PHI-PRIME, deg	45.	45.	45.	45.	45.	45.	45.
Hopper Angles							
THETA-P, deg	16.	16.	16.	16.	16.	16.	16.
THETA-C, deg	4.	4.	4.	4.	4.	4.	4.

Note: Flow along hopper walls is questionable.

WALL MATERIAL: CAST REFRACTORY (SMOOTH)

STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

WIDTH OF OVAL, ft	0.30	0.50	1.0	2.0	4.0	10.0	12.2
DIA OF CONE, ft	0.60	1.00	2.0	4.0	8.0	20.0	24.5
Wall Friction Angle							
PHI-PRIME, deg	32.	32.	32.	32.	32.	32.	32.
Hopper Angles							
THETA-P, deg	18.	18.	18.	18.	18.	18.	18.
THETA-C, deg	5.	5.	5.	5.	5.	5.	5.

BULK MATERIAL 2: SPENT OIL SHALE

PARTICLE SIZE PELLETS
MOISTURE CONTENT AS REC'D

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS-FLOW

WALL MATERIAL: 2B STAINLESS SHEET (OXIDIZED)

STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

WIDTH OF OVAL, ft	0.11	0.25	0.5	1.0	2.0	4.0	12.2
DIA OF CONE, ft	0.22	0.50	1.0	2.0	4.0	8.0	24.4
Wall Friction Angle							
PHI-PRIME, deg	29.	29.	29.	29.	29.	29.	29.
Hopper Angles							
THETA-P, deg	22.	22.	22.	22.	22.	22.	22.
THETA-C, deg	10.	10.	10.	10.	10.	10.	10.

WALL MATERIAL: CAST REFRACTORY (SMOOTH)

STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

WIDTH OF OVAL, ft	0.11	0.25	0.5	1.0	2.0	4.0	12.2
DIA OF CONE, ft	0.22	0.50	1.0	2.0	4.0	8.0	24.4
Wall Friction Angle							
PHI-PRIME, deg	31.	31.	31.	31.	31.	31.	31.
Hopper Angles							
THETA-P, deg	18.	18.	18.	18.	18.	18.	18.
THETA-C, deg	6.	6.	6.	6.	6.	6.	6.

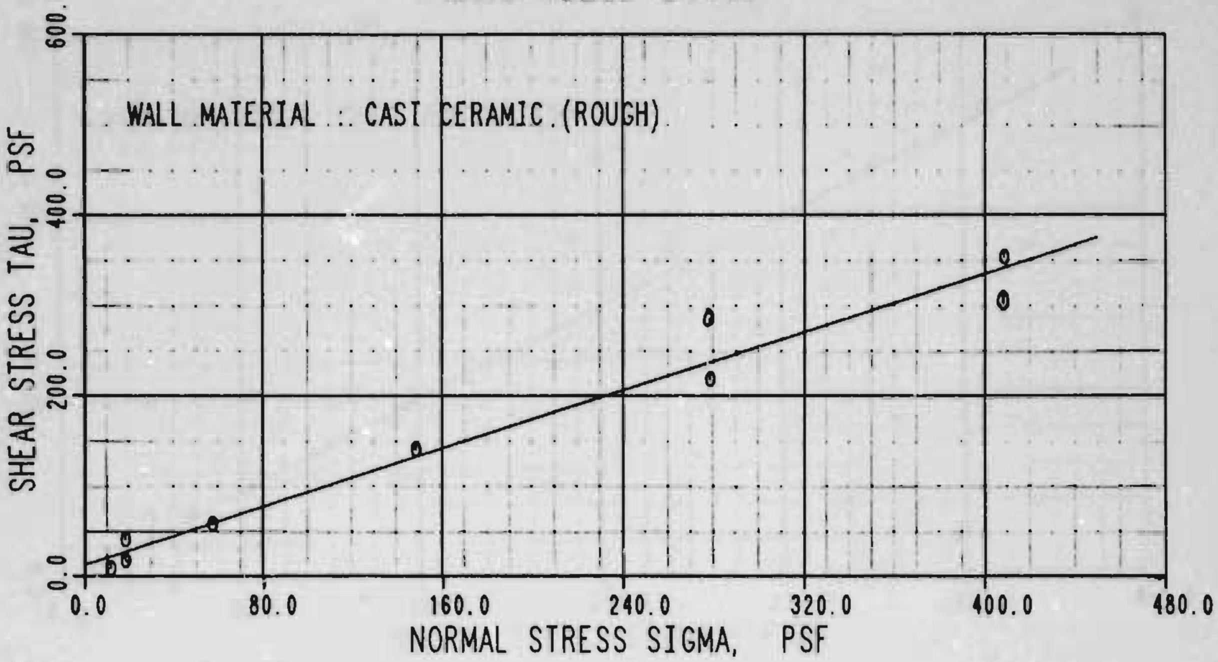
PLOT17474 AL

BULK MATERIAL: OIL SHALE PELLETS (1ST.)
PARTICLE SIZE: AS REC'D
MOISTURE % WT: 1.22%
TEMPERATURE 72 deg F
STORAGE TIME AT REST 0.0 hrs

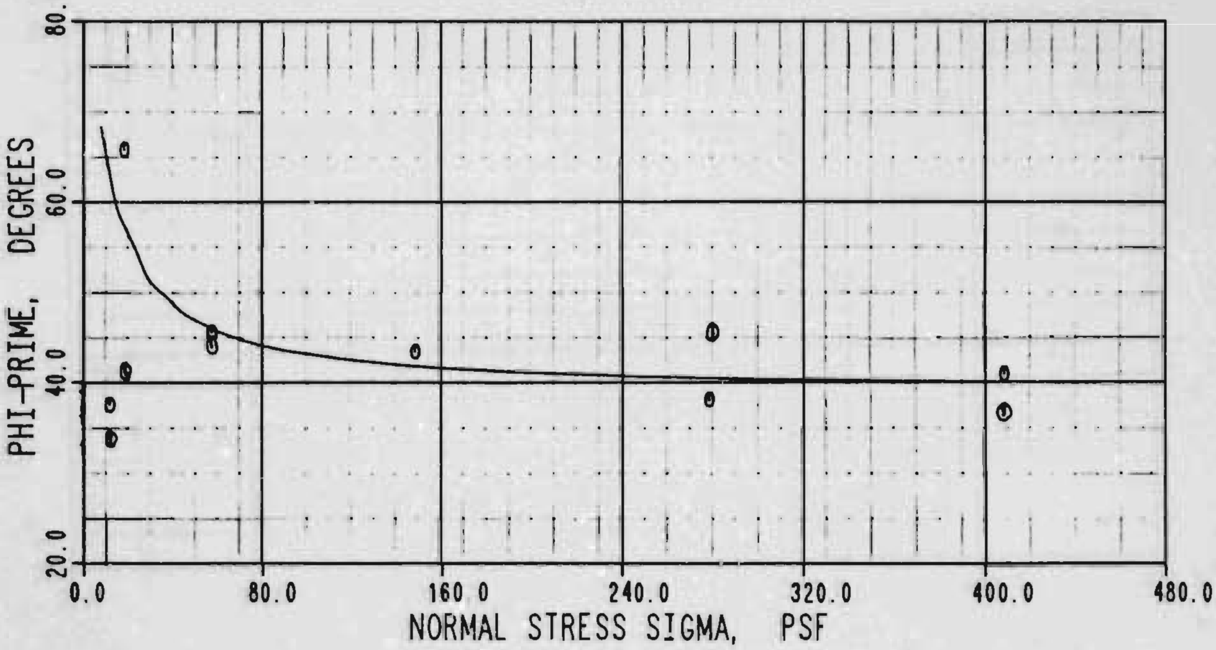
CREATE: 03/03/87
RUN: 03/03/87

JOB#: 871609
ID#: 14288

WALL YIELD LOCUS



WALL FRICTION ANGLE



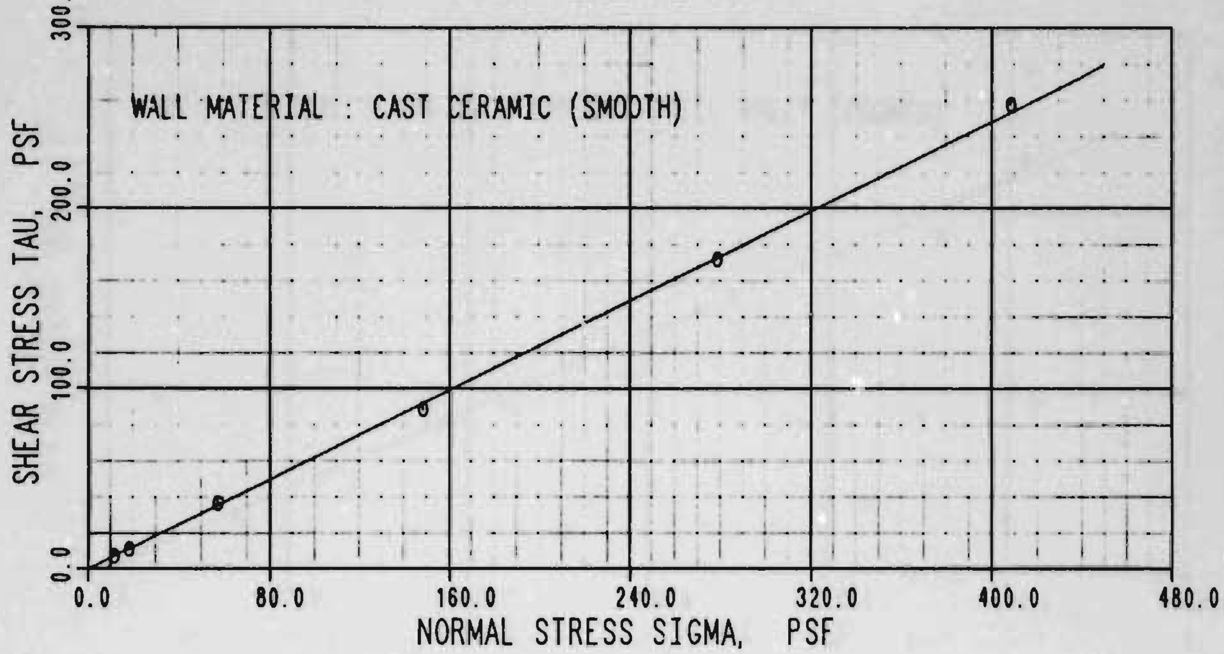
PLOT17472 AL

BULK MATERIAL: OIL SHALE PELLETS (1ST.)
PARTICLE SIZE: AS REC'D
MOISTURE % WT: 1.22%
TEMPERATURE 72 deg F
STORAGE TIME AT REST 0.0 hrs

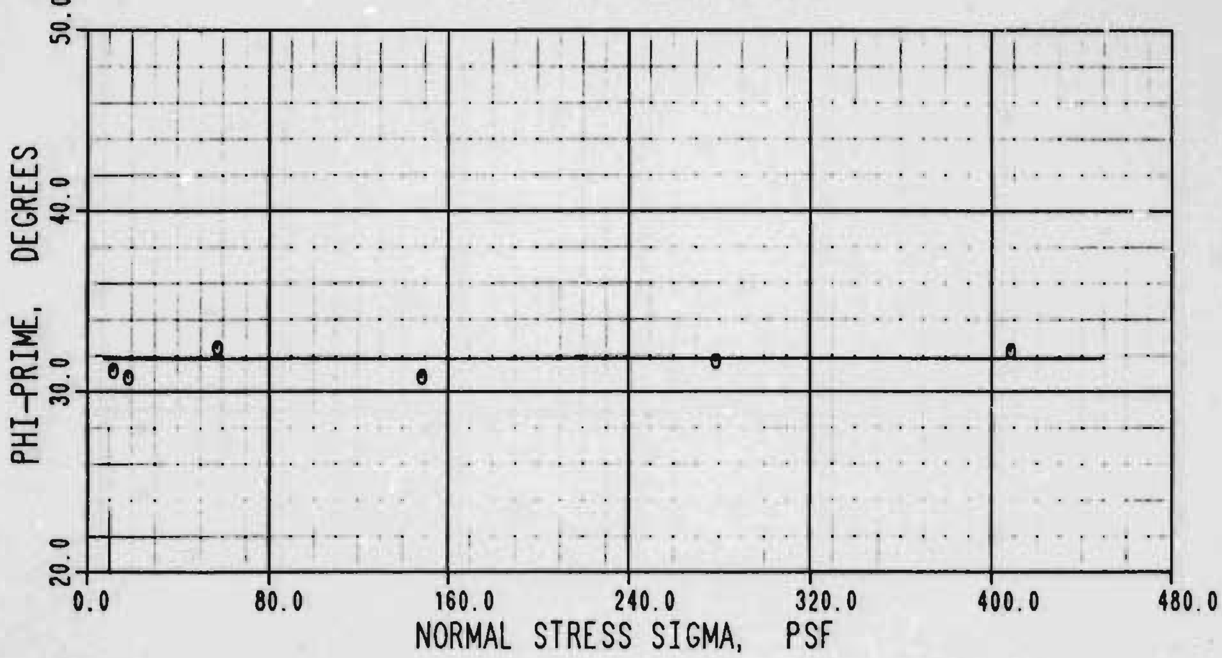
CREATE: 03/03/87
RUN: 03/03/87

JOB#. 871609
ID#: 14288

WALL YIELD LOCUS



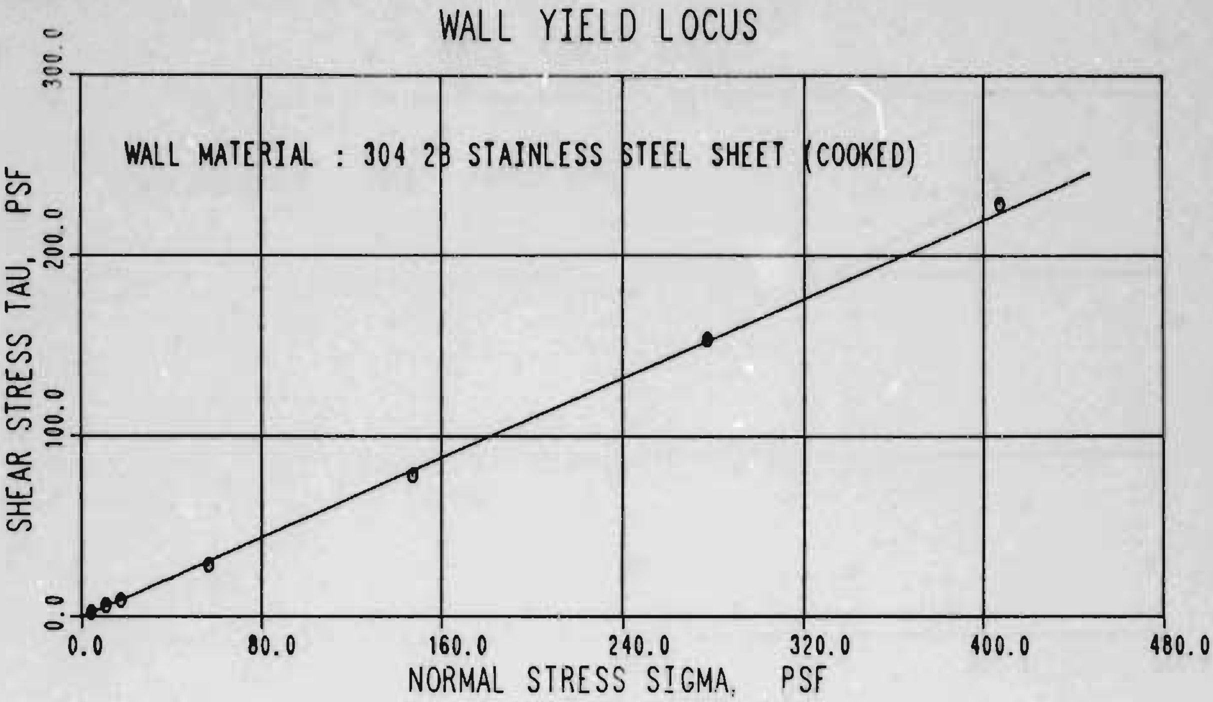
WALL FRICTION ANGLE

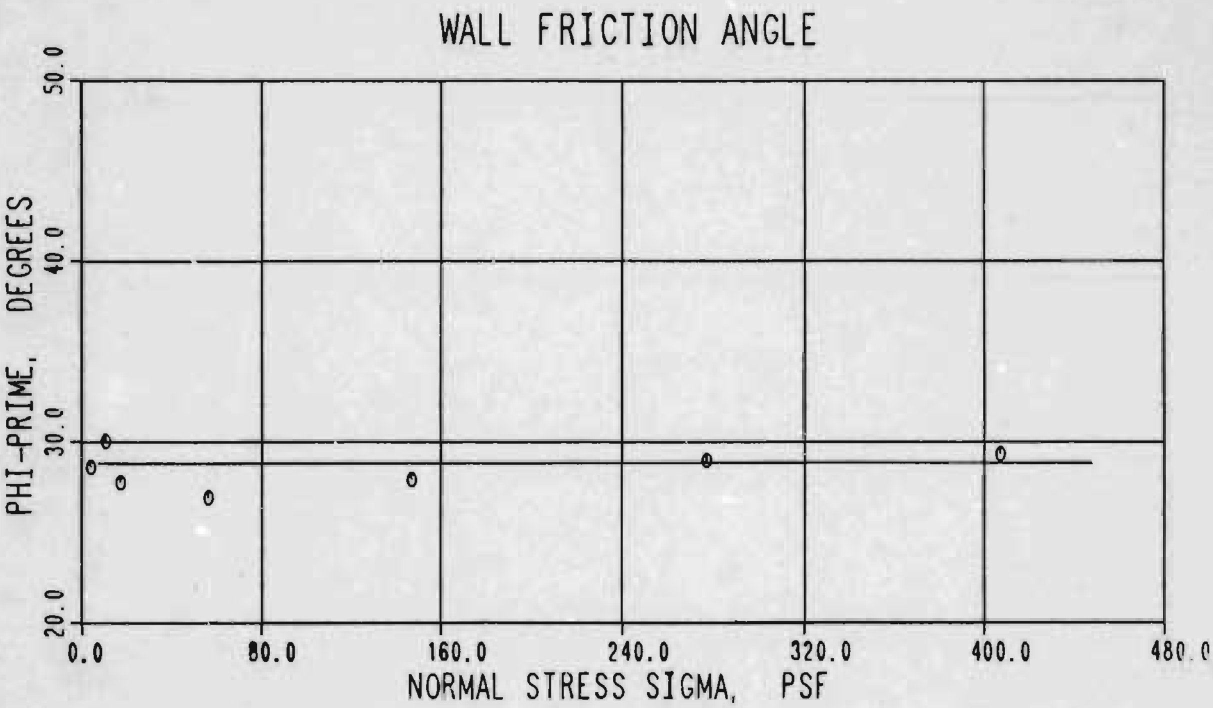


BULK MATERIAL: RETORTED PELLETS
PARTICLE SIZE: AS REC'D
MOISTURE % WT: AS REC'D
TEMPERATURE 72 deg F
STORAGE TIME AT REST 0.0 hrs

CREATE: 03/30/87
RUN: 03/30/87

JOB#: 871609
ID#: 14309

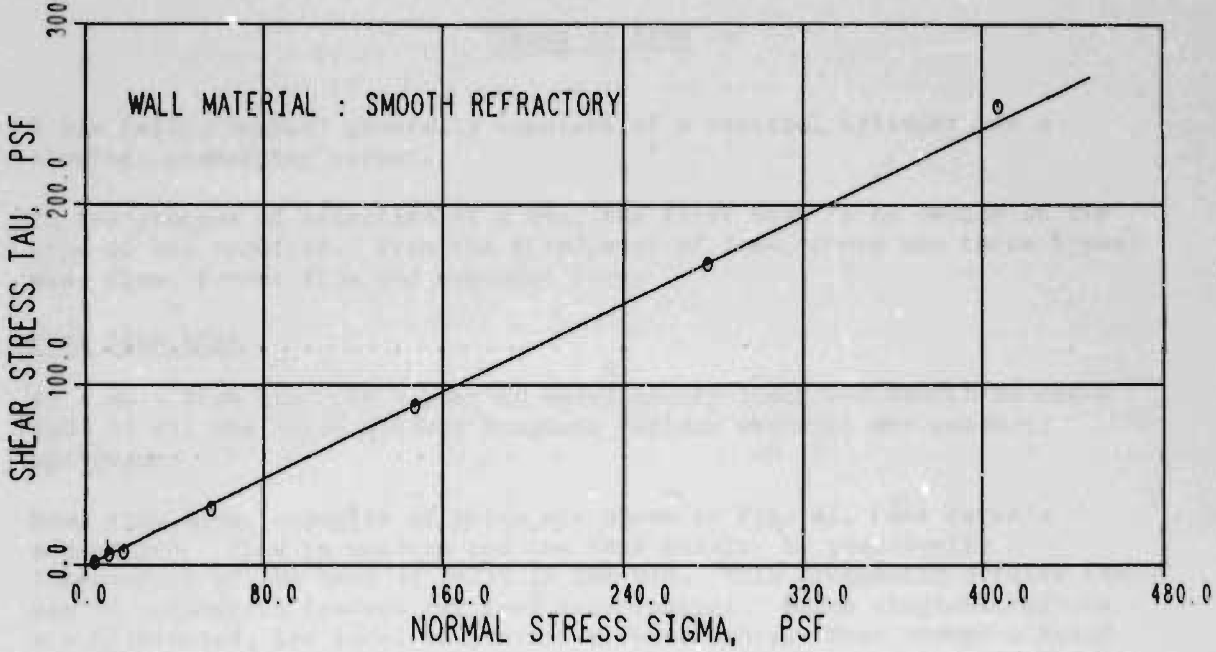




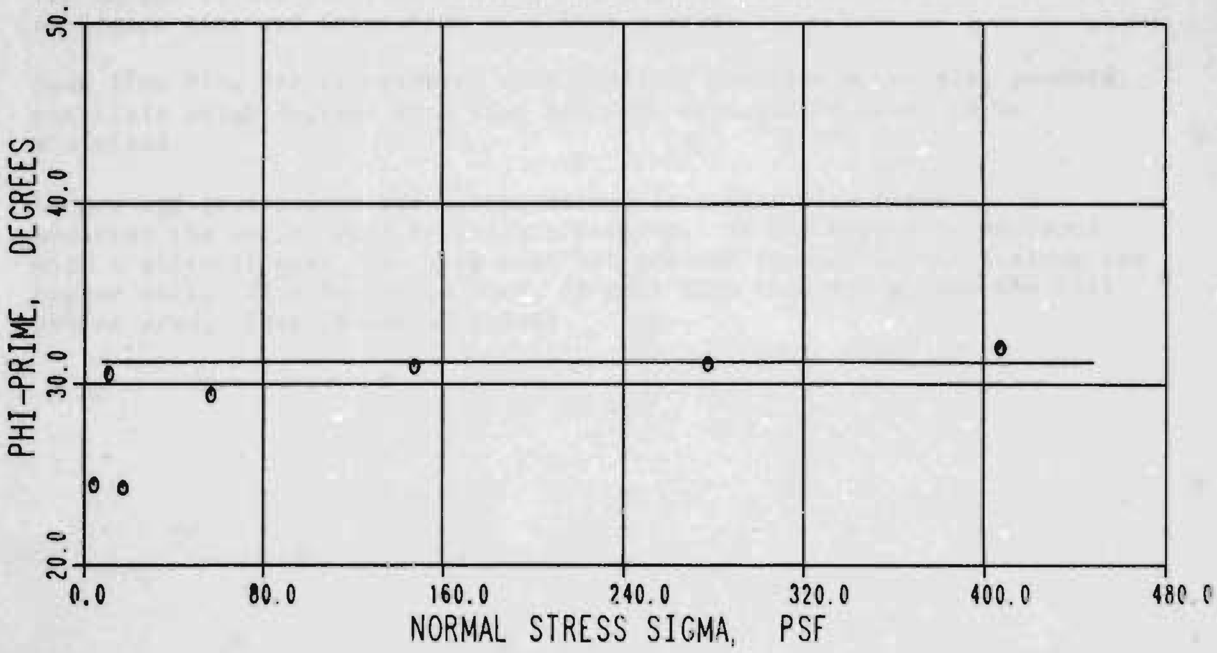
BULK MATERIAL: RETORTED PELLETS
PARTICLE SIZE: AS REC'D
MOISTURE % WT: AS REC'D
TEMPERATURE 72 deg F
STORAGE TIME AT REST 0.0 hrs

CREATE 03/30/87 JOB# 871609
RUN. 03/30/87 ID#: 14309

WALL YIELD LOCUS



WALL FRICTION ANGLE



APPENDIX

SELECTION OF BIN AND FEEDER

Types of Bins

A bin (silo, bunker) generally consists of a vertical cylinder and a sloping, converging hopper.

In the process of selection of a bin, the first step is to decide on the type of bin required. From the standpoint of flow, there are three types: mass flow, funnel flow and expanded flow.

Mass flow bins

In a mass flow bin, the hopper is sufficiently steep and smooth to cause flow of all the solid without stagnant regions whenever any solid is withdrawn.

Mass flow bins, examples of which are shown in Fig. A1, have certain advantages. Flow is uniform and the feed density is practically independent of the head of solid in the bin. This frequently permits the use of volumetric feeders for feed rate control. Since stagnant regions are eliminated, low level indicators work reliably. Even though a solid may segregate at the point of charge into the bin, segregation of the discharge is minimized by the first-in-first-out flow sequence associated with mass flow which enforces the same particle size distribution to exit the hopper as was put into it. This flow sequence also ensures uniform residence time and deaeration of a fine powder.

Mass flow bins are recommended when handling cohesive materials, powders, materials which degrade with time and when segregation needs to be minimized.

Ledges and protrusions are not permitted in a mass flow hopper. In addition the outlet must be fully effective. If the hopper is equipped with a shut-off gate, the gate must not prevent flow of material along the hopper wall. If a feeder is used, it must draw material across the full outlet area. (See "Feeders" below)

Mass flow bins can be used for in-bin blending. Some of the limitations of previous designs have recently been overcome with Jenike & Johanson's patented BINSERT™ bin insert. This device controls the flow pattern of solids in a bin.

Funnel flow bins

Funnel flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls. It also occurs when the outlet of a mass flow bin is not fully effective. Examples of funnel flow bins are shown in Figure A2.

In a funnel flow bin, solid flows toward the outlet through a channel that forms within stagnant material. With a nonfree-flowing solid, this channel expands to a diameter that approximates the largest dimension of the outlet. When the outlet is fully effective, this dimension is its diameter if circular, or the diagonal if it is square or rectangular. The channel will be stable if its diameter is less than the critical rathole diameter.

With a free-flowing solid, the flow channel expands at an angle which depends on the effective angle of friction of the material. The resulting flow channel is generally circular with a diameter in excess of the outlet diameter or diagonal.

When the bin discharge rate is greater than the charge rate, the level of solid within the channel drops causing layers to slough off the top of the stagnant mass and fall into the channel. This spasmodic behavior is detrimental with cohesive solids since the falling solid packs on impact, thereby increasing the chance of arching. With sufficient cohesion sloughing may cease, allowing the channel to empty out completely and form a stable rathole. Aerated solid charged into this empty rathole may overflow the feeder.

When a fluidized powder is charged directly into a funnel flow channel at a sufficiently high rate and is withdrawn at the same time, it has no chance to deaerate. It therefore remains fluidized in the channel and flushes when exiting the bin. A rotary valve is often used under these conditions to contain the material, but a uniform flow rate cannot be ensured because flow into the valve is erratic.

In general funnel flow bins are only suitable for coarse, free-flowing or slightly cohesive, nondegrading solids when segregation is unimportant.

Converting funnel flow bins to mass flow can often be achieved with relatively little expense. It may be done by using the BINSERT™ referred to in the paragraph on blending above.

Expanded flow bins

Examples of expanded flow bins are shown in Figure A3. The lower part of such a bin operates in mass flow while the upper part operates in funnel flow. The mass flow outlet usually requires a smaller feeder than would be the case for a funnel flow bin. The mass flow hopper should expand the flow channel to a diagonal or diameter equal to or greater than the critical rathole diameter. This eliminates the likelihood of ratholing in the funnel flow section.

These bins are used for the storage of large quantities of nondegrading solids. This design is also useful as a modification of existing funnel flow bins to correct erratic flow caused by arching, ratholing or flushing.

The concept can be used with multiple outlets as shown in Fig. A3 (b) where simultaneously flowing mass flow hoppers are placed close enough together to cause a combined flow channel larger than the critical rathole diameter.

With extremely free-flowing solids such as plastic pellets, cement clinker and coarse sand, both funnel flow and expanded flow bins may pulsate. This is caused by the flow pattern suddenly switching from a steady state central channel type flow to a much more extensive secondary flow pattern that may extend to the bin walls. Such a condition may reduce segregation problems, but the shock loads imposed may seriously challenge the structural integrity of the bin.

Feeders

The specified outlet must be fully effective. If flow from the bin is controlled by means of a feeder, the feeder must be so designed as to draw uniformly from the entire cross section of the outlet, a condition which not all feeders satisfy.

This uniformity of draw is especially important when feeding fine powders from slotted outlets. Typical commercial designs tend to draw material either from the front or the back of the slot resulting in a high velocity channel having a diameter of one to two times the width of the outlet. The powder may remain fluidized within this channel and flush on exiting the bin.

To limit high initial loads and starting torque caused by differential settlement between the hopper and the feeder, it is essential that the feeder be either suspended from the bin itself or supported on a flexible frame so as to readily deflect with the bin as solid is added to it. When the feeder is properly designed for uniform flow and when convergence of the hopper extends to the feeder, the effective head EH of solid on the feeder during flow in a mass flow bin is approximately

$$EH = BP \text{ for a transition hopper}$$
$$EH = BC/2 \text{ for a conical hopper} \quad (1)$$

See page A5 for definitions of BP and BC.

Initial loads may be several times these values.

Vibrating Equipment

Vibration has two effects: while it tends to break arches that obstruct flow, it also packs the solid in stagnant regions thereby giving it greater strength. In order to allow for this packing, the recommended outlet dimensions at zero time at rest for a P-FACTOR (described on page A6) of 1.5 may be used as an approximation when calculating critical arching dimensions for use with vibrating equipment.

Vibrators are suitable for materials which are free flowing under conditions of continuous flow but cake and gain strength when stored at rest for hours or days. Hoppers for these materials should be equipped with pads for the mounting of external vibrators. Vibrators should be used only to initiate flow and turned off once flow has started.

Fine powders and wet materials tend to pack severely when vibrated; hence, vibrating equipment is generally not recommended for them.

DISCUSSION OF TEST REPORT DATA

In the discussion which follows, each Section of the test report is explained in general terms. Please refer to Figs. A1, A2, and A3 where many of the symbols are shown. The symbols and other terms used in the text are explained in the Glossary of Terms and Symbols on pages A12 to A15. The concepts of gravity flow of solids and examples of application of solids flow data are presented in greater detail in the attached papers.

Section I - Bin Dimensions for Dependable Flow

This section specifies the bin outlet dimensions necessary for dependable flow in both mass flow and funnel flow bins. These dimensions have been calculated on the basis of the frictional and cohesive properties of the solid given in a subsequent part of the report. In all cases, it is assumed that flow takes place only under the action of gravity, i.e. without internal or external assistance.

In general these dimensions are a function of the time the solid remains in storage at rest, its moisture content, temperature, particle size and overpressure, if any, that is applied to it during storage. The P-FACTORs given in the table are ratios of applied compaction pressure to that pressure resulting from gravity flow only. If there are no overpressures present, the critical dimensions for P-FACTOR = 1.0 should be used. If the P-FACTOR is greater than 1.0, it is assumed that overpressures have been exerted on the solid during storage, but are removed when the solid is required to flow. See page A6 to A8.

Mass flow bins have hopper walls which are smooth and steep enough to cause flow along them; hence, stable channels within the material (ratholes) do not develop. Only two dimensions, both of which are shown in Fig. A1, are specified: BC, the minimum outlet diameter for a conical hopper; and BP, the minimum width for a slotted or oval outlet. The length of the slot or oval should be at least three times its width or the end walls must be vertical and smooth for BP to apply.

A funnel flow bin is created whenever the hopper walls are not steep and smooth enough to cause flow along them. Slotted outlets are recommended for these bins unless the material is quite free flowing. To prevent stable arches from forming, the width of the slot must be at least equal to BF. In a funnel flow bin the solid is held up at the walls and flows only within a circular channel whose diameter is approximately equal to the diameter or length of the effective outlet. If this flow channel diameter is less than the critical rathole diameter DF given in the report, a stable rathole is likely to form and the live capacity of the bin will be essentially only that material which is in the flow channel above the outlet. To prevent stable ratholes from forming, funnel flow bins should be designed with slotted outlets of length at least as long as DF.

In general DF is proportional to the consolidating pressure imposed on the solid during filling of the bin. Hence, in the upper regions of a bin where pressures are low, the critical rathole diameter DF is small and the flow channel diameter may exceed DF. This causes the rathole to be unstable at this point allowing the material to collapse into the stable rathole below. A partial emptying of the bin will result.

Calculation of Effective Head EH

The critical rathole diameter DF is a function of the major consolidating pressure which acts on the solid in the bin. It is convenient to express this pressure in terms of EH, the effective consolidating head of solid in the bin, as follows:

$$EH = [R/(\mu k)]\,[1 - EXP(-\mu k\, H/R)] \quad \text{or} \quad EH = 2R \qquad (2)$$

whichever is larger. The parameters are

- R = hydraulic radius of the cylindrical portion of the bin, i.e. ratio of cross sectional area to circumference.
  - R = D/4 for a circular cylinder of diameter D or a square cylinder of side D.
  - R = W/2 for a long rectangular cylinder of width W.
- μ = tan (PHI-PRIME), coefficient of friction between the stored solid and the cylinder walls (see Section III).
- k = ratio of horizontal to vertical solids pressure. A value of 0.4 is usually acceptable within cylinders.
- H = height of the cylindrical portion of a bin.

Calculation of P-FACTORs

The magnitude of the overpressure factor can be estimated for vibration, impact during charging into the bin, external loading, and fluid flow loading as follows:

Vibration. P-FACTOR = a_y/g or $(1 + a_x/g)$ (3)

whichever is larger, where:

a_x = vertical upward component of acceleration imposed on the solid
a_y = horizontal component of acceleration imposed on the solid
g = gravitational acceleration constant

<u>Impact pressure from fall into a bin</u>. A coarse material compacts as it is charged into a bin under the impact of the falling particles. When the material contains fines and the impact area is close to the outlet, the impact P-FACTOR should be used in the design.

$$\text{P-FACTOR} = (1 + m)\ [w/(A\ B\ \text{GAMMA})]\sqrt{2h/g} \qquad (4)$$

where:

- w = weight flow rate into the bin
- h = height of fall
- m = 0 for a long rectangular outlet
- m = 1 for a circular or square outlet
- A = area impacted by the falling stream of solids
- B = outlet size or bin dimension in the region of impact, i.e. the diameter in a conical hopper or the width in a wedge shaped or transition hopper.
- GAMMA = bulk density of solid

<u>External loading</u>. If the solid has been compacted by an external load F - such as the weight of a tractor passing over an outside stockpile - the overpressure factor at the point of application is given by

$$\text{P-FACTOR} = (1 + m)\ F/(A\ B\ \text{GAMMA}) \qquad (5)$$

where:

A = area of load application.

<u>Liquid or gas flow loading</u>. If the solid has been subjected during storage to fluid or gas flow such as may have been imposed by an air blaster, draining of a saturated solid or the flow of air or gas during drying or chemical processing, the overpressure factor is given by

$$\text{P-FACTOR} = 1 + (dp/dx)/(\text{GAMMA}) \qquad (6)$$

where:

dp/dx = the downward (vertical) liquid or gas pressure gradient at the bin outlet.

In any of the above cases, if the overpressure continues to act during the discharge of the solid and is <u>positive downward,</u> the overpressure factor need not be applied. If the downward pressure acts <u>only</u> during discharge, the dimensions given in Section I A for P-FACTOR = 1.0 may be reduced by dividing them by the appropriate P-FACTOR.

When considering the effect of overpressure which acts on a solid during time of storage at rest, it is not necessary that the overpressure act during the entire time at rest. Soon after an overpressure has been applied, a solid reaches the maximum densification associated with that overpressure. Hence, the critical outlet dimensions will be essentially the same whether the overpressure acts for a short time or continuously during the entire time at rest.

Limits on Bin Sizes

The bin dimensions in part A of this Section I apply to bins of unlimited maximum size. However, some materials will compact in large bins causing large stable arches in the upper part of the hopper while the lower portion may discharge without a problem. This can lead to a very dangerous condition when a large arch is broken high in the hopper. The impact of the falling material may cause structural damage to the bin and possibly tear the hopper from the vertical bin section. If the material is capable of this type of behavior, an additional part B is included which gives the maximum allowable mass flow bin and hopper dimensions.

Often the upper limits on bin size occur only for compaction with time or for significant overpressure conditions. If this is the case, the bin can be designed for an unlimited size provided the critical time and overpressure values are not exceeded during the bin operation.

Section II Bulk Density

The bulk density GAMMA of a material is used in bin load and capacity calculations. Values of bulk density of the sample tested are given in Section II as a function of the effective head of solid EH and the major principal consolidating pressure SIGMA1. The relationship is:

$$\text{SIGMA1} = \text{EH} \times \text{GAMMA} \qquad (7)$$

Within the cylindrical part of a bin, the effective consolidating head EH is given by eq.(2). At the outlet of a mass flow bin, the head is given by eq.(1).

Note that if the sample tested is the fine fraction of a material having a wide range of particle size, inclusion of the coarser particles will usually increase the bulk densities above those given in this section.

Bulk density values have been computed from measured compressibility parameters of the material which are also given in Section II. In general, all materials have a minimum density GAMMA MINIMUM without fluidization. The relationship between bulk density and consolidating pressure only applies when densities are greater than GAMMA MINIMUM.

Section III Maximum Hopper Angles for Mass-Flow

A solid sliding on a bin wall encounters frictional resistance proportional to the tangent of the wall friction angle PHI-PRIME. This angle generally depends not only on the roughness of the wall but also on the pressure which the solid exerts on the wall. For hard wall surfaces, the friction angle decreases as the solids contact pressure increases. This pressure, which varies with position in the bin, is usually smallest at the outlet.

THETA-C and THETA-P are the recommended maximum hopper wall angles, measured from the vertical, for conical and transition mass flow hoppers, respectively. See Fig. A1. These values have been calculated from the friction tests (wall yield loci) included at the end of the report and are tabulated for a series of widths of oval hoppers and diameters of conical hoppers.

To minimize headroom consider changing the slope of the hopper wall as a function of position. For example, if a conical hopper is to be designed with an outlet diameter of 1 ft and the recommended THETA-C is 14° at 1 ft diameter and 23° at 2 ft and larger diameters, use two conical sections. In the lower section where the diameter varies from 1 ft to 2 ft, use a hopper angle of 14°. Above the 2 ft diameter, use a hopper angle of 23°.

Often, both continuous flow and time friction tests are run on a material. If the solid adheres to the wall with time, the time test results will indicate an increase in friction angles. To overcome this time effect, the hopper walls should be made steeper, as recommended, or other means - such as vibration of the bin walls - should be provided to initiate flow.

Section IV Critical Solids Flow Rate

The maximum rate Q at which a coarse solid (say, 95% plus 1/4 inch) flows out of a mass flow hopper is practically independent of the head of solid and is approximately given by

$$Q = (A \ \text{GAMMA}) \sqrt{B\ g/[2(1 + m)\ \tan(\text{THETA})]} \qquad (8)$$

where:

A = area of the outlet.

B = diameter or width of the outlet.

THETA = THETA-P for rectangular or oval outlets, or
= THETA-C for circular outlets.

Predicting the flow rate of fine solids is more complicated because their outflow rate is critically affected by the amount of air entrained in the solid.

Two limiting cases may occur: first, the bin may be charged and discharged at such a rapid rate that a large amount of air is entrained within the solid. As a result the solid may flush and flow uncontrollably from the outlet independent of feeder speeds. The prediction of this critical flushing condition requires an extensive two-phase flow calculation using a Jenike & Johanson proprietary computer program and is not a part of this Standard Test Report.

Second, the bin may be filled intermittently with sufficient retention time before discharging to deaerate the solid. As a result there may be a deficiency of air as the solids expand upon discharging. This generally causes a critical flow rate at the outlet which is tabulated in this section as a function of effective head of solid in the bin. Above this critical rate, flow will be nonsteady.

The critical rates are computed on the assumption that there is no air in-flow or out-flow along the height of the bin, that air pressure at the outlet of the bin is the same as at the top of the bin, and that the feeder outlet is not sealed against air in-flow. Should the operating conditions deviate from these assumptions, a controlled rate different from the critical may be possible.

If the tabulated flow rates are smaller than desired, it may be necessary to: use an air permeation system to increase the rate; increase the outlet size; decrease the bin size; or limit the storage time to prevent deaeration of the solid. Jenike & Johanson can analyze the system and make recommendations.

If the specified flow rate from a bin is close to critical values, it is particularly important that the feeder withdraw uniformly across the entire outlet. If this is not done, localized limiting rate effects may occur at the outlet, especially at the ends of a slotted outlet. This may result in pulsating flow from the bin, the development of fast flowing columns and an uncontrolled rate of withdrawal with flushing.

All the above comments apply as well when a gas other than air is used in the bin. The critical property is the viscosity of the gas. The permeability tests run by Jenike & Johanson are done with air at room temperature. When the gas or the temperature is different, the coefficient of permeability needs to be modified, as discussed below.

Section V   Air Permeability Test Results

Values of air permeability are expressed as a function of the bulk density of the solid. These values are used in the calculation of critical flow rates, given in Section IV, and in the design of air permeation systems.

The equation given in this section and the test method are both based on the assumption of laminar flow of gas. This assumption is generally valid for all powders and for most materials which have a significant portion of particles less than 20 mesh in size.

The permeability factor K has the dimension of velocity and is inversely proportional to the viscosity of the gas. The results can be adjusted to elevated temperatures and to other gases by multiplying the constant KO by the ratio of the viscosity of air at room temperature to that of the gas at the temperature in question.

GLOSSARY OF TERMS AND SYMBOLS

Arching	- a no-flow condition in which material forms a stable arch (dome, bridge) across the bin
Bin	- container for bulk solids with one or more outlets for withdrawal of solids either by gravity alone or by flow-promoting devices which assist gravity
Bunker	- same as bin, often used in reference to storing coal
Cylinder	- vertical part of a bin
Discharger	- device used to enhance material flow from a bin but which is not capable of controlling the rate of withdrawal
Effective head	- convenient way to express consolidating pressure by dividing it by bulk density
Elevator	- same as bin, often used in reference to storing grains
Expanded flow	- flow pattern which is a combination of mass flow and funnel flow
Feeder	- device for controlling the rate of withdrawal of bulk solid from a bin
Flow channel	- space in a bin through which a bulk solid is actually flowing during withdrawal
Flooding & flushing	- conditon where an aerated bulk solid behaves like a fluid and flows uncontrollably through an outlet or feeder
Funnel flow	- flow pattern in which solid flows in a channel formed within stagnant material
Hopper	- converging part of a bin
Mass flow	- flow pattern in which all solid in a bin is in motion whenever any of it is withdrawn

Piping - a no-flow condition in which material forms a stable vertical hole within the bin

P-FACTOR - the ratio of the applied solids compacting pressure to the solids pressure during steady gravity flow.

Ratholing - same as piping

Silo - same as bin

A - area of impact of falling stream of solids, area over which external load is applied, or area of outlet, ft^2

a_x, a_y - vertical and horizontal accelerations respectively, ft/sec^2

B - span across a bin at any elevation of the bin, ft

BC - minimum diameter of a circular outlet in a mass flow bin, ft

BF - minimum width of a rectangular outlet in a funnel flow bin, ft

BP - minimum width of an oval outlet in a mass flow bin, ft

D - diameter of cylindrical portion of a bin, ft

DF - critical piping (ratholing) dimension, ft

EH - effective consolidating head, ft

F - force from an external load on material, lb

f_c - unconfined compressive strength of a solid, psf

g - gravitational constant = 32.2 ft/sec^2

H - height of cylinder, ft

h - height of fall of material, ft

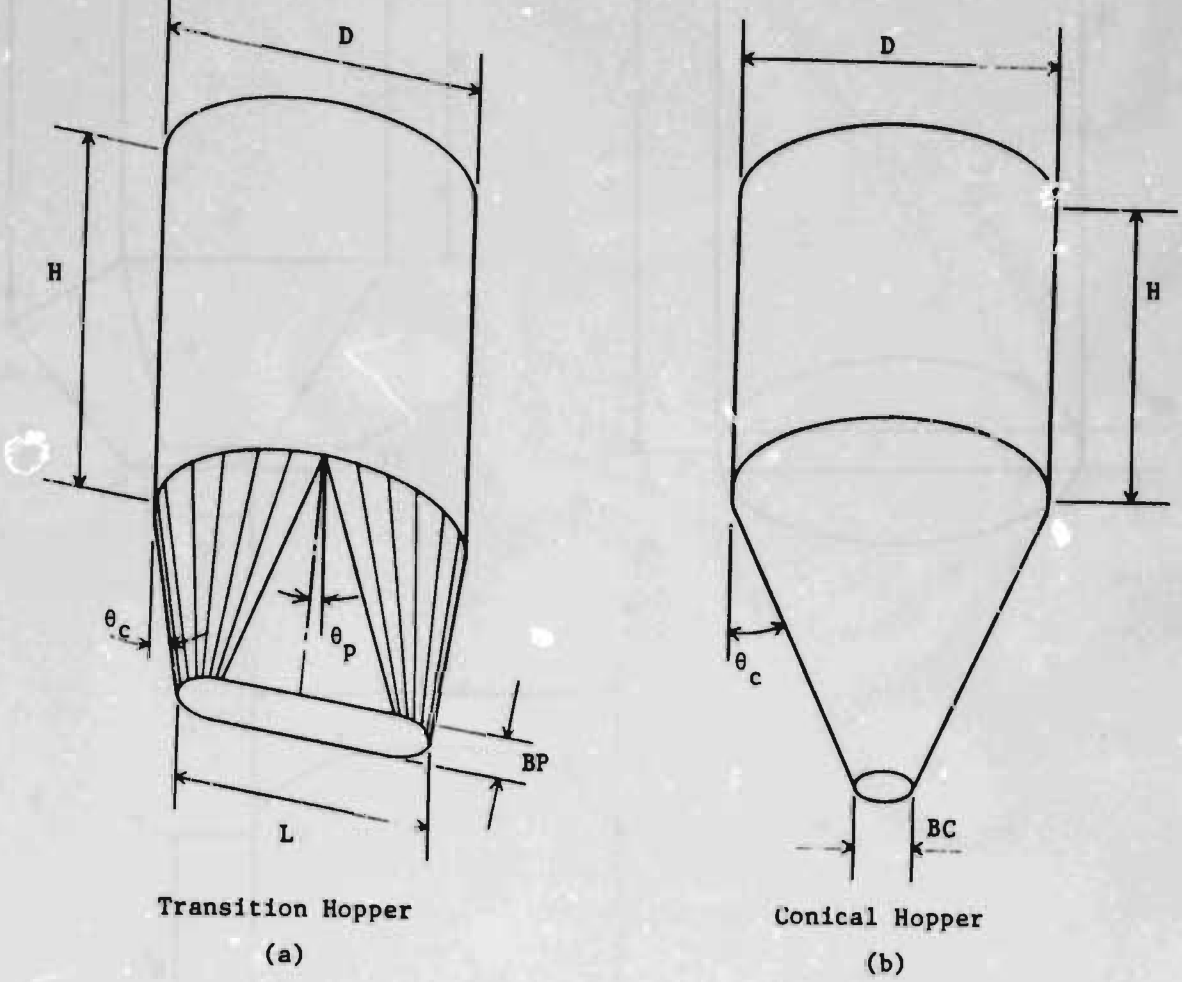
K - permeability factor, ft/sec

k - ratio of horizontal to vertical pressure

KO	- permeability constant, ft/sec
L	- length of hopper outlet, ft
m	- parameter equal to 0 for rectangular outlet and equal to 1 for circular or square outlet
p	- liquid or gas pressure, psf
Q	- maximum discharge rate of a coarse solid, lb/sec
R	- hydraulic radius, ft
S	- shearing force applied to a shear cell, lb
V	- normal force applied to a shear cell, lb
W	- width of rectangular bin cylinder, ft
w	- weight flow rate into the bin, lb/sec
x	- vertical coordinate, ft
y	- horizontal coordinate, ft
γ, GAMMA	- bulk density, pcf
δ, DELTA	- effective angle of internal friction of a solid during flow, degrees
θ_c, THETA-C	- maximum recommended angle (from vertical) of conical hoppers and end walls of transition hoppers for mass flow, degrees
θ_p, THETA-P	- maximum recommended angle (from vertical) of side walls of transition hoppers for mass flow, degrees
μ, MU	- tan (PHI-PRIME)
σ, SIGMA	- normal stress applied to a shear cell, psf
σ_1, SIGMA1	- major consolidating pressure, psf
τ, TAU	- shearing stress applied to a shear cell, psf

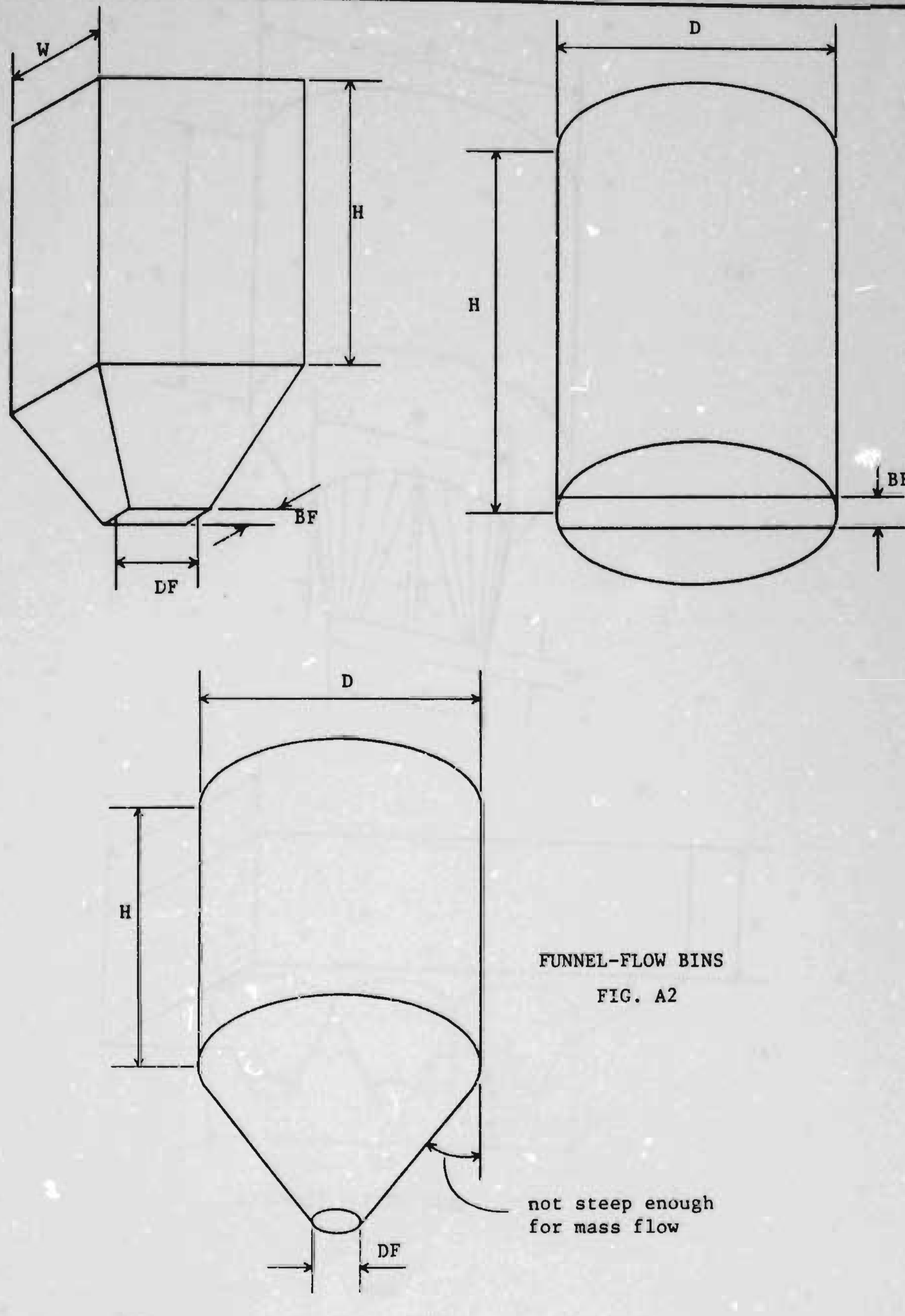
ϕ', PHI-PRIME - kinematic angle of friction between a solid and a wall, degrees

ϕ, PHI - angle of internal friction of a solid in incipient flow, degrees



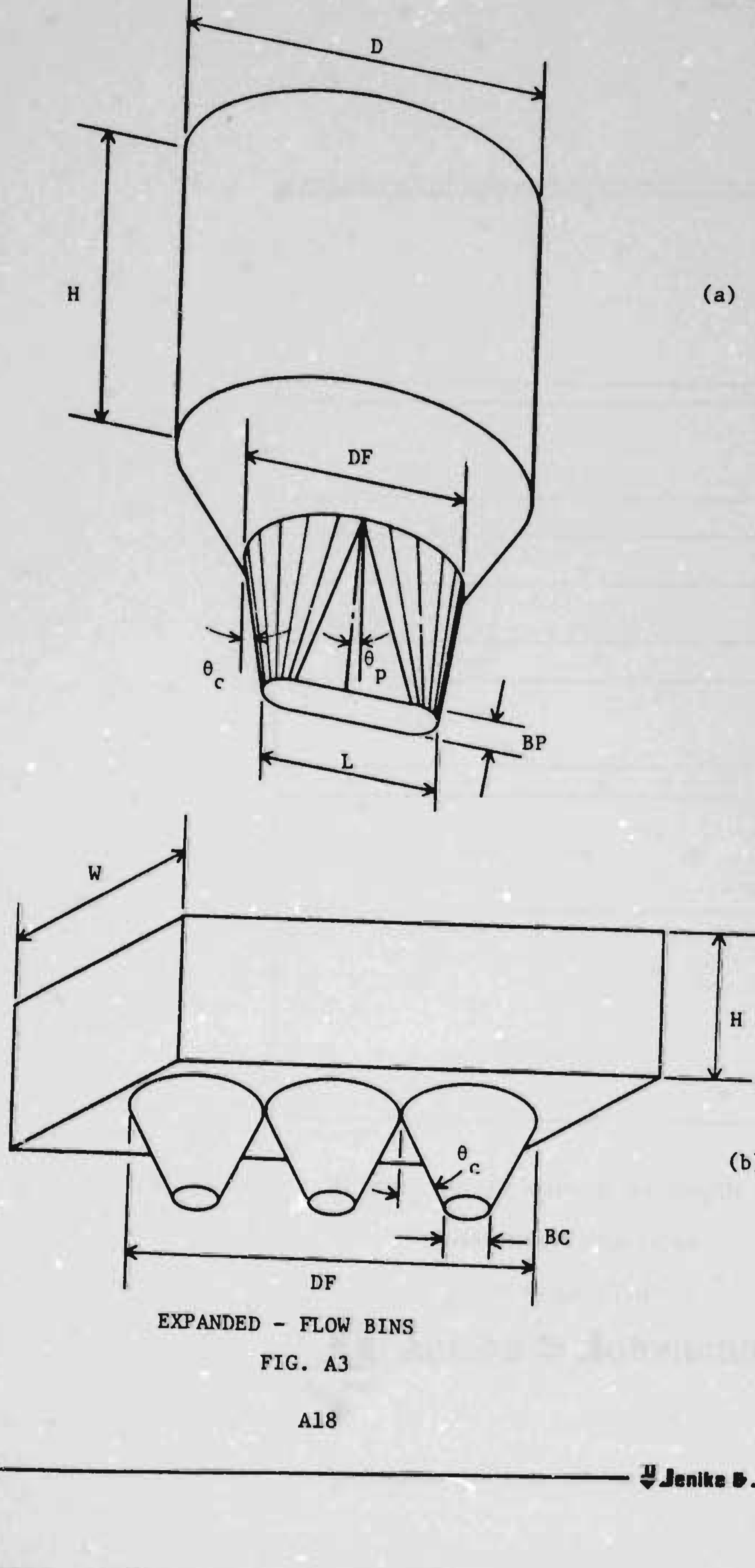
MASS-FLOW BINS

FIG. A1



FUNNEL-FLOW BINS

FIG. A2



EXPANDED - FLOW BINS

FIG. A3

Report on Briquette Strength Tests

Hycrude Corporation

Final Report 871674-1

Jenike & Johanson, inc.

3485 Empresa Drive • San Luis Obispo, CA 93401 • (805) 541-0901

October 27, 1987

Report on Briquette Strength Tests

Hycrude Corporation

Final Report 871674-1

1. Introduction

Hycrude Corporation is evaluating the use of beneficiated oil shale pellets in their Hytort process. The pellets will be subjected to high temperature and gas pressure and will also be expected to flow under gravity through a reactor vessel. In December 1982 Jenike & Johanson, Inc. calculated the expected loading on the retort configuration that is proposed and, based on tests on a sample of spent oil shale particles, estimated the total amount of fines that would be generated (see Jenike & Johanson, Inc. Report 820796). In April 1987 we measured the attrition properties of a small sample of pellets prepared by others. (See Jenike & Johanson, Inc. Report 871609-1). As a result of those tests, further work was indicated, including finding the optimum pellet strength with and without binders and determining the appropriate pelletization process to develop that strength.

2. Pellet Strength Tests

A 9 liter sample of oven dried Alabama oil shale flotation concentrate was received from Mineral Resources Institute for testing. Their experience has shown that the best pellets are made at approximately 8 percent moisture content. Therefore, a set of pellets was made with the shale at this moisture content so that the resulting strength could be used as a reference. A set of pellets was made in a pellet press at the highest compacting pressure of the press (54,300 psi) and another set at 50% of that value. The strength of the pellets was measured in a shearing apparatus as shown in Figure 1. All shear strength measurements were made at room temperature.

The average shearing strength of the pellets was 71.4 psi when the compacting pressure was 27,000 psi and 88.4 psi when the compacting pressure was 54,300 psi. This strength was obviously low and the pellets were easily crushed between the fingers.

A series of tests was then run to find a set of conditions under which the pellet strength could be increased substantially over this reference strength. Since the objective was to find a comparative strength, all subsequent sets of pellets were made at the highest compacting pressure only. For each test condition approximately 15 pellets were made and sheared. The results are shown in Table 1.

In general, the results show that curing the pellets for one hour at 220°F increases the strength more than any other curing condition. For example, the strength of pellets made of the shale alone with no binders, and the strength of pellets made with binders, more than doubles with this curing.

The various pozzolanic materials such as refractory cement, fly ash and stove liner mix used as binders did not increase the strength of the pellets significantly, if at all. Various moisture contents, curing times and temperatures were tried but none was found to be effective. At very high temperatures (up to 1000°F) the pellets degraded.

Dolomite clay increased the strength of the pellets by approximately 40% and quicklime by approximately 90%. However, after nine days of curing, the pellets made with dolomite clay increased in strength but the pellets made with quicklime degraded.

Calcium Lignosulphonate (lignosite) was used as a binder and the strength test results were encouraging. With 10% binder in the mix the strength increased by approximately 50%. The strength increased further with extended curing times. A fairly dramatic increase in strength of more than 3 1/2 times over the reference strength of the shale alone was measured when the pellets were cured for one hour at 200°F. This strength decreased only slightly when the same curing conditions were used with 2% binder in the mix.

3. Hot Test

All the work done on pellets and shale particles for Hycrude and IGT thus far has been restricted to tests run at room temperature. However, work done on other oil shales (mostly raw) showed that the shale particles become porous when oil is extracted from them and they lose a significant amount of strength. In other retorts, the fines resulting from degrading particles severely altered the gas flow distribution, and at surfaces where the gas entered the solid resulted in very much higher pressure drops than expected. The higher pressure drops can in turn significantly increase the solids pressures and the system becomes unstable since more fines are produced. The net result has been much lower flow rates than originally designed for because of the problems created by fines and some projects have been abandoned.

A set of pellets was pressed with 2% Lignosite and cured for one hour at 220°F. After cooling they were placed in an oven preheated to 650°F and left for one hour. They were then allowed to cool to room temperature and tested.

The pellets had changed color from dark to light brown. They had lost almost all their strength and were difficult to handle. Those that could be sheared had an average shear strength of 36 psi.

4. Conclusions

It appears that 2% Calcium Lignosulphonate in the oil shale mix can increase the strength of the resulting pellets substantially. This increased strength plus a spherical shape to the pellet will markedly reduce the crushing of the pellets during handling at room temperature. However, once the oil is extracted from the pellets by heating them, they will lose their strength and degrade.

If subjected to the pressures calculated previously for solid in the proposed retort, we expect the pellets weakened by heating will suffer appreciable attrition, and large quantities of fines will be generated. By the time the material has passed through the feed screw we expect that most of the pellets will have turned to dust.

The hot test on the pellets may not accurately reflect the conditions that they will be subjected to in the reactor. If not, it may be advantageous to run a test that more accurately simulates the reactor conditions to determine if the pellets will indeed lose their strength. If they do, we would suggest a retort system, such as a fluidized bed, designed to handle the oil shale as a powder. We have worked on fluidized bed systems recently and have developed efficient and reliable feeding and recirculation systems which we would be happy to discuss with Hycrude for this application.

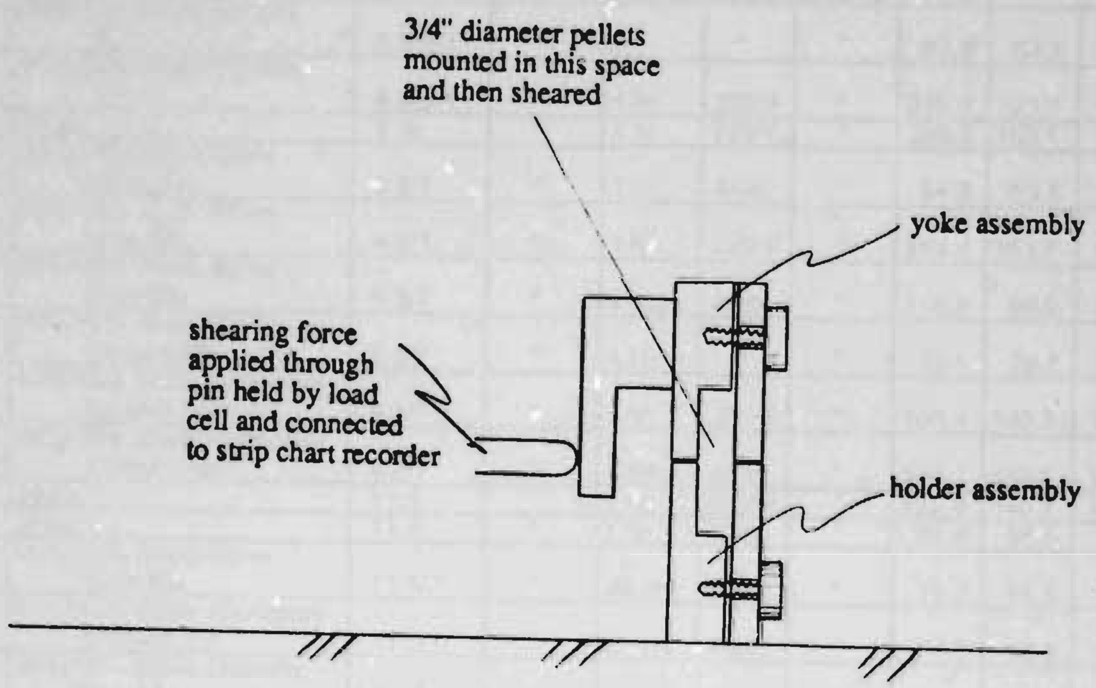


Figure 1

Sketch of Apparatus Used to Shear Pellets

Table 1
Briquette Strength Tests

Test No.	Material Description	% H_2O	Press Temp.	Curing Time	Curing Temp.	σ PSI	S.S. PSI High	S.S. PSI Low	S.S. PSI Average
1.	Shale	8.3	Amb.	0	Amb.	27150	79.0	61.2	71.4
2.	Shale	8.3	"	0	"	54299	109.0	74.9	88.4
3.	90%/10% Shale:Fly Ash Mix	8.3/8.1	"	0	"	"	85.9	54.9	70.3
4.	90%/10% Shale:Fly Ash Mix	8.3/8.1	"	1 hr	220°F	"	215.3	123.7	165.0
5.	Shale	8.3	"	1 hr	220°F	"	209.6	183.1	194.3
6.	90%/10% Shale:Stove - Liner Mix	8.3/?	"	1 hr	Amb.	"	94.8	59.5	76.8
7.	90%/10% Shale:Stove - Liner Mix	8.3/?	"	1 hr	220°F	"	214.4	153.7	180.6
8.	90%/10% Shale:Stove - Liner Mix	8.3/?	"	4 days	Amb.	"	118.0	86.9	104.3
9.	90%/10% Shale:Refractory Cement Mix	8.3/?	"	1.25 hrs	"	"	76.1	76.2	76.2
10.	90%/10% Shale:Refractory Cement Mix	8.3/?	"	1 hr	220°F	"	200.4	143.2	165.1
11.	90%/10% Shale:Refractory Cement Mix	8.3/?	"	4 days	Amb.	"	140.1	103.8	118.7
12.	Shale	11.5	"	1 hr	220°F	"	222.0	140.2	190.5
13.	Shale	11.5	"	1 hr	Amb.	"	78.6	66.5	71.8
14.	90%/10% Shale:Stove - Liner Mix	11.5/?	"	24 hrs	Amb.	"	74.7	65.5	69.2
15.	90%/10% Shale:Refractory Cement Mix	11.5/?	"	24 hrs	Amb.	"	77.9	53.9	64.6
16.	90%/10% Shale:Dolomite Clay Mix	8.3/?	"	0	Amb.	"	147.3	113.1	126.8
17.	90%/10% Shale:Dolomite Clay Mix	8.3/?	"	9 days	Amb	"	176.2	127.0	154.1
18.	90%/10% Shale:Quicklime Mix	8.3/?	"	1 hr	Amb.	"	187.7	146.1	170.8
19.	90%/10% Shale:Quicklime Mix	8.3/?	"	9 days	Amb.	"	All briquettes fractured & broken. Low strength.		
20.	90%/10% Shale:Stove - Liner Mix	11.5/?	"	2 hrs	To 1000°F	"	42.6	31.7	37.2
21.	90%/10% Shale:Stove - Liner Mix	11.5/?	"	6 days	Amb.	"	88.9	40.9	67.6
22.	90%/10% Shale:Refractory Cement Mix	11.5/?	"	2 hrs	To 1000°F	"	Very Fragile		0-10
23.	90%/10% Shale:Refractory Cement Mix	11.5/?	"	6 days	Amb.	"	96.2	46.6	69.7

Where: press temp. = temperature in the pellet press.
σ = pressure in the pellet press.
S.S. = shear strength of the pellets.

DRAFT
12.02.87
12:45 AM

APPENDIX C

1. Material Balance Closure for 87MBU-8
Raw Kentucky New Albany Shale

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

PAGE 1
RUN: 87 MBU-8
DATE: 4/01/87

****

* ADJUST SPENT SHALE FLOW RATE BASED ON MINERAL MATTER BALANCE *

COMPONENT	--RAW SHALE-- UNADJUSTED		------SPENT SHALE------ UNADJUSTED		ADJUSTED
	WEIGHT%	LB/HR	WEIGHT%	LB/HR	LB/HR
ORGANIC CARBON	13.59	.276004	3.08	.050666	.050924
HYDROGEN	1.64	.033307	.34	.005593	.005622
ORG. OXYGEN	1.21	.024574	.00	.000000	.000000
NITROGEN	.47	.009545	.15	.002468	.002480
SULFUR	5.45	.110686	3.19	.052476	.052743
CO2	.59	.011983	.65	.010692	.010747
HIGH TEMP O2	2.82	.057272	1.41	.023194	.023313
MINERAL MATTER	74.23	1.507563	91.18	1.499911	1.507563
TOTAL	100.00	2.030935	100.00	1.645000	1.653392
MOISTURE	.93	.019065			
TOTAL WET SHALE		2.050000			

*** ACCOUNT FOR SOUR WATER CONSTITUENTS ***

REPORTED SOUR WATER PRODUCTION (LB/HR) - .065800

COMPONENT	C	H	S	N	O	TOTAL
	LB/HR					
NH3	-	.000318	-	.001472	-	.001790
H2S	-	.000042	.000669	-	-	.000711
CO2	.000632	-	-	-	.001684	.002316
TOTAL	.000632	.000360	.000669	.001472	.001684	.004817

****

MATERIAL BALANCE CLOSURE — PAGE 2
FOR MINI-BENCH UNIT — RUN: 87 MBU-8
DATE: 4/01/87

****

* DRY PRODUCT GAS (ASSIGNMENT OF COS) *

COMP	MOLE%	MOLES/HR	MOLES/HR C	MOLES/HR H2	MOLES/HR S	MOLES/HR N2	MOLES/HR O2
N2	.0000	.000000	.000000	.000000	.000000	.000000	.000000
CO	.0000	.000000	.000000	.000000	.000000	.000000	.000000
CO2	.1160	.000194	.000194	.000000	.000000	.000000	.000194
H2	97.9524	.163944	.000000	.163944	.000000	.000000	.000000
CH4	.6009	.001006	.001006	.002011	.000000	.000000	.000000
C2H6	.2109	.000353	.000706	.001059	.000000	.000000	.000000
C3H8	.0949	.000159	.000477	.000635	.000000	.000000	.000000
C4H1	.1396	.000234	.000935	.001168	.000000	.000000	.000000
C2H4	.0211	.000035	.000071	.000071	.000000	.000000	.000000
C3H6	.0422	.000071	.000212	.000212	.000000	.000000	.000000
C4H8	.0211	.000035	.000141	.000141	.000000	.000000	.000000
C6H6	.0000	.000000	.000000	.000000	.000000	.000000	.000000
NH3	.0000	.000000	.000000	.000000	.000000	.000000	.000000
H2S	.8011	.001341	.000000	.001341	.001341	.000000	.000000
COS	.0000	.000019	.000019	.000000	.000019	.000000	.000010
TOTAL	100.0002	.167391	.003760	.170583	.001360	.000000	.000204
LB/HR	-	-	.045161	.343861	.043606	.000000	.006519

TOTAL POUNDS OF GAS (ADJUSTED FOR COS)= .439147

*NOTE: THE MOLES/HR OF COS IS ESTIMATED TO BE 1/70TH OF THE REPORTED MOLES OF H2S, THEREFORE COS IS NOT INCLUDED IN THE REPORTED GAS MOLE % COMPOSITION.

****

MATERIAL BALANCE CLOSURE — PAGE 3

FOR MINI-BENCH UNIT — RUN: 87 MBU-8

DATE: 4/01/87

****

* CLOSE CARBON BALANCE BY CALCULATING OIL PRODUCTION *

CARBON IN

INLET GAS	.000000	LB/HR
SHALE ORGANIC CARBON (PG 1)	.276004	LB/HR
SHALE MINERAL CARBON (PG 1)	.003270	LB/HR
TOTAL	.279274	LB/HR

CARBON OUT (EXCLUSIVE OF CARBON IN OIL)

ADJUSTED PRODUCT GAS* (PG 2)	.045161	LB/HR
SHALE ORGANIC CARBON (PG 1)	.050924	LB/HR
SHALE MINERAL CARBON (PG 1)	.002933	LB/HR
SOUR WATER CARBON (PG 1)	.000632	LB/HR
TOTAL	.099651	LB/HR

CALCULATED CARBON IN OIL PRODUCED------ .179624 LB/HR

---------------------- OIL YIELD ADJUSTMENT ----------------------

ELEMENT	WEIGHT%	LB/HR REPORTED	LB/HR CALCULATED**
C	85.54	.156453	.179624
H	10.07	.018418	.021146
S	1.03	.001884	.002163
N	2.05	.003749	.004305
O	1.31	.002396	.002751
TOTAL	100.00	.182900	.209988

UNADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)--- .090057

ADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)----- .103395

* GAS ADJUSTED FOR COS (SEE PAGE 2).

** BASED ON EXISTING ELEMENTAL BALANCE AND CALCULATED CARBON IN OIL.

****

MATERIAL BALANCE CLOSURE — PAGE 4
FOR MINI-BENCH UNIT — RUN: 87 MBU-8
DATE: 4/01/87

****

* CLOSE OXYGEN BALANCE BY CALCULATING WATER PRODUCTION *

OXYGEN IN

SHALE MOISTURE (PG 1)	.016932	LB/HR
SHALE ORG. OXYGEN (PG 1)	.024574	LB/HR
SHALE CARBON DIOXIDE (PG 1)	.008712	LB/HR
SHALE HIGH TEMP. O (PG 1)	.057272	LB/HR
OXYGEN IN INLET GAS	.000000	LB/HR
TOTAL	.107491	LB/HR

OXYGEN OUT (EXCLUDING O2 IN REPORTED WATER PRODUCTION)

SHALE ORG. OXYGEN (PG 1)	.000000	LB/HR
SHALE CO2 OXYGEN (PG 1)	.007814	LB/HR
SHALE HIGH TEMP. O (PG 1)	.023313	LB/HR
SOUR WATER CO2 O (PG 1)	.001684	LB/HR
OXYGEN IN PROD GAS (PG 2)	.006519	LB/HR **
OXYGEN IN OIL (PG 3)	.002751	LB/HR
TOTAL	.042081	LB/HR

O2 ASSIGNED TO WATER PRODUCTION---	.065410	LB/HR
TOTAL CALCULATED H2O PRODUCTION---	.073651	LB/HR *
TOTAL REPORTED H2O PRODUCTION-----	.060983	LB/HR *
ADJUSTMENT TO H2O PRODUCTION------	.012668	LB/HR

* REPORTED AND CALCULATED WATER PRODUCTIONS INCLUDE RAW SHALE MOISTURE.

** OXYGEN IN PRODUCT GAS IS ADJUSTED TO INCLUDE CARBONYL SULFIDE OXYGEN, WHICH IS ASSIGNED TO THE PRODUCT GAS (SEE PG 2).

CLOSE SULFUR BALANCE BY CALCULATING HYDROGEN SULFIDE PRODUCTION

SULFUR IN

SHALE SULFUR (PG 1)	.110686	LB/HR
INLET GAS SULFUR	.000000	LB/HR
TOTAL	.110686	LB/HR

SULFUR OUT

SHALE SULFUR (PG 1)	.052743	LB/HR
OIL SULFUR (PG 3)	.002163	LB/HR
SOUR WATER H2S (PG 1)	.000669	LB/HR
PRODUCT GAS H2S (PG 2)	.043606	LB/HR
TOTAL	.099181	LB/HR

SULFUR ADJUSTMENT------- .011505 LB/HR

------------------HYDROGEN SULFIDE ADJUSTMENT------------------

REPORTED HYDROGEN SULFIDE*		
GAS	.045695	LB/HR
SOUR WATER	.000711	LB/HR
TOTAL	.046405	LB/HR
H2S ADJUSTMENT	.012229	LB/HR
CALCULATED H2S (TOTAL)	.058634	LB/HR

* SULFUR ALSO EXISTS AS COS IN PRODUCT GAS.

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

PAGE 6
RUN: 87 MBU-8
DATE: 4/01/87

****

* CLOSE NITROGEN BALANCE BY CALCULATING AMMONIA PRODUCTION *

NITROGEN IN

NITROGEN IN GAS	.000000	LB/HR
SHALE NITROGEN (PG 1)	.009545	LB/HR
TOTAL	.009545	LB/HR

NITROGEN OUT

ELEMENTAL NITROGEN IN GAS	.000000	LB/HR
AMMONIA NITROGEN IN GAS	.000000	LB/HR
SHALE NITROGEN (PG 1)	.002480	LB/HR
OIL NITROGEN (PG 3)	.004305	LB/HR
SOUR WATER NH3 (PG 1)	.001472	LB/HR
TOTAL	.008257	LB/HR

NITROGEN ADJUSTMENT	.001289	LB/HR

AMMONIA ADJUSTMENT

REPORTED AMMONIA

GAS	.000000	LB/HR
SOUR WATER	.001790	LB/HR
TOTAL	.001790	LB/HR
AMMONIA ADJUSTMENT	.001567	LB/HR
CALCULATED AMMONIA (TOTAL)	.003356	LB/HR

2444 HYCRUDE CORPORATION

BENEFICIATION- HYDRORETORTING OF U.S. OIL SHALES PROGRAM YEAR 2

* CLOSE HYDROGEN BALANCE TO CALCULATE HYDROGEN CONSUMPTION *

HYDROGEN IN

FEED GAS	.000000	LB/HR *
DRY RAW SHALE (PG 1)	.033307	LB/HR
RAW SHALE MOISTURE (PG 1)	.002133	LB/HR
TOTAL	.035441	LB/HR

HYDROGEN OUT

PRODUCT GAS (PG 2)	.013382	LB/HR *
OIL (PG 3)	.021146	LB/HR
SPENT SHALE (PG 1)	.005622	LB/HR
WATER PRODUCTION (PG 4)	.008241	LB/HR
SOUR WATER NH3 (PG 6)	.000596	LB/HR
SOUR WATER H2S (PG 5)	.000765	LB/HR
TOTAL	.049752	LB/HR

HYDROGEN CONSUMED .014311 LB/HR

CALCULATED HYDROGEN CONSUMPTION = 2646.24 SCF/TON DRS

* FEED AND PRODUCT GAS COMBINED HYDROGEN ONLY.
NO MOLECULAR (FREE) HYDROGEN IS REPORTED.

DRAFT
12.02.87
12:45 AM

APPENDIX C

2. Material Balance Closure for 87MBU-14
Beneficiated Kentucky New Albany Shale
(Low Sulfur)

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

PAGE 1
RUN: 87 MBU-14
DATE: 6/29/87

* ADJUST SPENT SHALE FLOW RATE BASED ON MINERAL MATTER BALANCE *

COMPONENT	--RAW SHALE-- UNADJUSTED		------SPENT SHALE------ UNADJUSTED		ADJUSTED
	WEIGHT%	LB/HR	WEIGHT%	LB/HR	LB/HR
ORGANIC CARBON	45.71	.523118	17.08	.093086	.105342
HYDROGEN	4.72	.054017	.90	.004905	.005551
ORG. OXYGEN	.00	.000000	1.76	.009592	.010855
NITROGEN	1.28	.014649	.75	.004088	.004626
SULFUR	4.55	.052072	6.41	.034935	.039534
CO2	.05	.000572	.08	.000436	.000493
HIGH TEMP O2	5.06	.057908	1.34	.007303	.008265
MINERAL MATTER	38.63	.442093	71.68	.390656	.442093
TOTAL	100.00	1.144429	100.00	.545000	.616759
MOISTURE	1.85	.021571			
TOTAL WET SHALE		1.166000			

*** ACCOUNT FOR SOUR WATER CONSTITUENTS ***

REPORTED SOUR WATER PRODUCTION (LB/HR) - .078700

COMPONENT	C	H	S	N	O	TOTAL
	LB/HR					
NH3	-	.000377	-	.001747	-	.002124
H2S	-	.000010	.000165	-	-	.000176
CO2	.001574	-	-	-	.004193	.005767
TOTAL	.001574	.000388	.000165	.001747	.004193	.008067

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

RUN: 87 MBU-14
DATE: 6/29/87

****

* DRY PRODUCT GAS (ASSIGNMENT OF COS) *

COMP	MOLE%	MOLES/HR	MOLES/HR C	MOLES/HR H2	MOLES/HR S	MOLES/HR N2	MOLES/HR O2
N2	.0000	.000000	.000000	.000000	.000000	.000000	.000000
CO	.0734	.000123	.000123	.000000	.000000	.000000	.000062
CO2	.0734	.000123	.000123	.000000	.000000	.000000	.000123
H2	97.7627	.164143	.000000	.164143	.000000	.000000	.000000
CH4	1.0478	.001759	.001759	.003519	.000000	.000000	.000000
C2H6	.3773	.000633	.001267	.001900	.000000	.000000	.000000
C3H8	.1676	.000281	.000844	.001126	.000000	.000000	.000000
C4H1	.1939	.000326	.001302	.001628	.000000	.000000	.000000
C2H4	.0419	.000070	.000141	.000141	.000000	.000000	.000000
C3H6	.0734	.000123	.000370	.000370	.000000	.000000	.000000
C4H8	.0524	.000088	.000352	.000352	.000000	.000000	.000000
C6H6	.0000	.000000	.000000	.000000	.000000	.000000	.000000
NH3	.0000	.000000	.000000	.000000	.000000	.000000	.000000
H2S	.1362	.000229	.000000	.000229	.000229	.000000	.000000
COS	.0000	.000003	.000003	.000000	.000003	.000000	.000002
TOTAL	100.0000	.167903	.006285	.173407	.000232	.000000	.000186
LB/HR	-	-	.075487	.349553	.007437	.000000	.005967

TOTAL POUNDS OF GAS (ADJUSTED FOR COS)= .438445

*NOTE: THE MOLES/HR OF COS IS ESTIMATED TO BE 1/70TH OF THE REPORTED MOLES OF H2S, THEREFORE COS IS NOT INCLUDED IN THE REPORTED GAS MOLE % COMPOSITION.

****

MATERIAL BALANCE CLOSURE — PAGE 3
FOR MINI-BENCH UNIT — RUN: 87 MBU-14
DATE: 6/29/87

****

* CLOSE CARBON BALANCE BY CALCULATING OIL PRODUCTION *

CARBON IN

INLET GAS	.000000	LB/HR
SHALE ORGANIC CARBON (PG 1)	.523118	LB/HR
SHALE MINERAL CARBON (PG 1)	.000156	LB/HR
TOTAL	.523275	LB/HR

CARBON OUT (EXCLUSIVE OF CARBON IN OIL)

ADJUSTED PRODUCT GAS* (PG 2)	.075487	LB/HR
SHALE ORGANIC CARBON (PG 1)	.105342	LB/HR
SHALE MINERAL CARBON (PG 1)	.000135	LB/HR
SOUR WATER CARBON (PG 1)	.001574	LB/HR
TOTAL	.182538	LB/HR

CALCULATED CARBON IN OIL PRODUCED------ .340736 LB/HR

---------------------- OIL YIELD ADJUSTMENT ---------------------

ELEMENT	WEIGHT%	LB/HR REPORTED	LB/HR CALCULATED**
C	84.13	.326593	.340736
H	10.01	.038859	.040542
S	.93	.003610	.003767
N	1.99	.007725	.008060
O	2.94	.011413	.011907
TOTAL	100.00	.388200	.405012

UNADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)--- .339208

ADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)----- .353899

* GAS ADJUSTED FOR COS (SEE PAGE 2).
** BASED ON EXISTING ELEMENTAL BALANCE AND CALCULATED CARBON IN OIL.

* CLOSE OXYGEN BALANCE BY CALCULATING WATER PRODUCTION *

OXYGEN IN

SHALE MOISTURE (PG 1)	.019157	LB/HR
SHALE ORG. OXYGEN (PG 1)	.000000	LB/HR
SHALE CARBON DIOXIDE (PG 1)	.000416	LB/HR
SHALE HIGH TEMP. O (PG 1)	.057908	LB/HR
OXYGEN IN INLET GAS	.000000	LB/HR
TOTAL	.077481	LB/HR

OXYGEN OUT (EXCLUDING O2 IN REPORTED WATER PRODUCTION)

SHALE ORG. OXYGEN (PG 1)	.010855	LB/HR
SHALE CO2 OXYGEN (PG 1)	.000359	LB/HR
SHALE HIGH TEMP. O (PG 1)	.008265	LB/HR
SOUR WATER CO2 O (PG 1)	.004193	LB/HR
OXYGEN IN PROD GAS (PG 2)	.005967	LB/HR **
OXYGEN IN OIL (PG 3)	.011907	LB/HR
TOTAL	.041546	LB/HR

O2 ASSIGNED TO WATER PRODUCTION---	.035935	LB/HR
TOTAL CALCULATED H2O PRODUCTION---	.040463	LB/HR *
TOTAL REPORTED H2O PRODUCTION-----	.070633	LB/HR *
ADJUSTMENT TO H2O PRODUCTION------	-.030171	LB/HR

* REPORTED AND CALCULATED WATER PRODUCTIONS INCLUDE RAW SHALE MOISTURE.

** OXYGEN IN PRODUCT GAS IS ADJUSTED TO INCLUDE CARBONYL SULFIDE OXYGEN, WHICH IS ASSIGNED TO THE PRODUCT GAS (SEE PG 2).

****

MATERIAL BALANCE CLOSURE — PAGE 3
FOR MINI-BENCH UNIT — RUN: 87 MBU-14
DATE: 6/29/87

****

CLOSE SULFUR BALANCE BY CALCULATING HYDROGEN SULFIDE PRODUCTION

SULFUR IN

SHALE SULFUR (PG 1)	.052072	LB/HR
INLET GAS SULFUR	.000000	LB/HR
TOTAL	.052072	LB/HR

SULFUR OUT

SHALE SULFUR (PG 1)	.039534	LB/HR
OIL SULFUR (PG 3)	.003767	LB/HR
SOUR WATER H2S (PG 1)	.000165	LB/HR
PRODUCT GAS H2S (PG 2)	.007437	LB/HR
TOTAL	.050903	LB/HR

SULFUR ADJUSTMENT------- .001168 LB/HR

-------------------HYDROGEN SULFIDE ADJUSTMENT-------------------

REPORTED HYDROGEN SULFIDE*

GAS	.007793	LB/HR
SOUR WATER	.000176	LB/HR
TOTAL	.007969	LB/HR
H2S ADJUSTMENT	.001242	LB/HR
CALCULATED H2S (TOTAL)	.009211	LB/HR

* SULFUR ALSO EXISTS AS COS IN PRODUCT GAS.

* CLOSE NITROGEN BALANCE BY CALCULATING AMMONIA PRODUCTION *

NITROGEN IN

NITROGEN IN GAS	.000000	LB/HR
SHALE NITROGEN (PG 1)	.014649	LB/HR
TOTAL	.014649	LB/HR

NITROGEN OUT

ELEMENTAL NITROGEN IN GAS	.000000	LB/HR
AMMONIA NITROGEN IN GAS	.000000	LB/HR
SHALE NITROGEN (PG 1)	.004626	LB/HR
OIL NITROGEN (PG 3)	.008060	LB/HR
SOUR WATER NH3 (PG 1)	.001747	LB/HR
TOTAL	.014432	LB/HR

NITROGEN ADJUSTMENT .000216 LB/HR

AMMONIA ADJUSTMENT

REPORTED AMMONIA

GAS	.000000	LB/HR
SOUR WATER	.002124	LB/HR
TOTAL	.002124	LB/HR

AMMONIA ADJUSTMENT .000263 LB/HR

CALCULATED AMMONIA (TOTAL)------ .002387 LB/HR

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

RUN: 87 MBU-14
DATE: 6/29/87

****

* CLOSE HYDROGEN BALANCE TO CALCULATE HYDROGEN CONSUMPTION *

HYDROGEN IN

FEED GAS	.000000	LB/HR *
DRY RAW SHALE (PG 1)	.054017	LB/HR
RAW SHALE MOISTURE (PG 1)	.002414	LB/HR
TOTAL	.056431	LB/HR

HYDROGEN OUT

PRODUCT GAS (PG 2)	.018673	LB/HR *
OIL (PG 3)	.040542	LB/HR
SPENT SHALE (PG 1)	.005551	LB/HR
WATER PRODUCTION (PG 4)	.004528	LB/HR
SOUR WATER NH3 (PG 6)	.000424	LB/HR
SOUR WATER H2S (PG 5)	.000084	LB/HR
TOTAL	.069801	LB/HR

HYDROGEN CONSUMED .013370 LB/HR

CALCULATED HYDROGEN CONSUMPTION = 4387.26 SCF/TON DRS

* FEED AND PRODUCT GAS COMBINED HYDROGEN ONLY.
NO MOLECULAR (FREE) HYDROGEN IS REPORTED.

****

****

*** ADJUSTED MASS BALANCE CHECK ***

EXIT STREAMS

SHALE (PG 1)	.616759	LB/HR
OIL (PG 3)	.405012	LB/HR
GAS (PG 2)	.107565	LB/HR *
TOTAL WATER (PG 4)	.040463	LB/HR
SOUR WATER NH3 (PG 6)	.002387	LB/HR
SOUR WATER H2S (PG 5)	.001417	LB/HR
SOUR WATER CO2 (PG 1)	.005767	LB/HR
TOTAL	1.179370	LB/HR

FEED STREAMS

SHALE (PG 1)	1.144429	LB/HR
HYDROGEN CONSUMED (PG 7)	.013370	LB/HR
RAW SHALE MOISTURE (PG 1)	.021571	LB/HR
TOTAL	1.179370	LB/HR

* NOT INCLUDING MOLECULAR (FREE) HYDROGEN

* CARBON DISTRIBUTION DATA *

ORGANIC CARBON IN OIL	65.14
ORGANIC CARBON IN GAS	14.73
ORGANIC CARBON IN SPENT SHALE	20.14
TOTAL	100.00

TOTAL ORGANIC CARBON CONVERSION--- 79.86

SELECTIVITY TO OIL---------------- 81.56

NOTE: SELECTIVITY TO OIL IS DEFINED AS THE PERCENTAGE OF CONVERTED ORGANIC CARBON CONTAINED IN THE PRODUCT OIL

APPENDIX C

3. Material Balance Closure for 87MBU-15 Beneficiated Kentucky New Albany Shale (High Sulfur)

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

RUN: 87 MBU-15
DATE: 7/02/87

****

* ADJUST SPENT SHALE FLOW RATE BASED ON MINERAL MATTER BALANCE *

COMPONENT	--RAW SHALE-- UNADJUSTED		------SPENT SHALE------ UNADJUSTED		ADJUSTED
	WEIGHT%	LB/HR	WEIGHT%	LB/HR	LB/HR
ORGANIC CARBON	29.52	.402092	8.77	.078579	.079094
HYDROGEN	3.21	.043723	.61	.005466	.005501
ORG. OXYGEN	2.05	.027923	1.45	.012992	.013077
NITROGEN	.80	.010897	.39	.003494	.003517
SULFUR	6.02	.081998	5.01	.044890	.045184
CO2	.08	.001090	.04	.000358	.000361
HIGH TEMP O2	3.96	.053939	1.63	.014605	.014701
MINERAL MATTER	54.36	.740437	82.10	.735616	.740437
TOTAL	100.00	1.362099	100.00	.896000	.901872
MOISTURE	1.44	.019901			
TOTAL WET SHALE		1.382000			

*** ACCOUNT FOR SOUR WATER CONSTITUENTS ***

REPORTED SOUR WATER PRODUCTION (LB/HR) - .073000

COMPONENT	C	H	S	N	O	TOTAL
	---LB/HR---					
NH3	-	.000388	-	.001796	-	.002183
H2S	-	.000015	.000241	-	-	.000256
CO2	.001241	-	-	-	.003306	.004547
TOTAL	.001241	.000403	.000241	.001796	.003306	.006987

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

RUN: 87 MBU-15
DATE: 7/02/87

****

* DRY PRODUCT GAS (ASSIGNMENT OF COS) *

			MOLES/HR				
COMP	MOLE%	MOLES/HR	C	H2	S	N2	O2
N2	.0000	.000000	.000000	.000000	.000000	.000000	.000000
CO	.0524	.000088	.000088	.000000	.000000	.000000	.000044
CO2	.0629	.000105	.000105	.000000	.000000	.000000	.000105
H2	97.6871	.163629	.000000	.163629	.000000	.000000	.000000
CH4	.8277	.001386	.001386	.002773	.000000	.000000	.000000
C2H6	.2828	.000474	.000947	.001421	.000000	.000000	.000000
C3H8	.1258	.000211	.000632	.000843	.000000	.000000	.000000
C4H1	.1126	.000189	.000754	.000943	.000000	.000000	.000000
C2H4	.0524	.000088	.000176	.000176	.000000	.000000	.000000
C3H6	.0524	.000088	.000263	.000263	.000000	.000000	.000000
C4H8	.1991	.000333	.001334	.001334	.000000	.000000	.000000
C6H6	.0000	.000000	.000000	.000000	.000000	.000000	.000000
NH3	.0000	.000000	.000000	.000000	.000000	.000000	.000000
H2S	.5448	.000913	.000000	.000913	.000913	.000000	.000000
COS	.0000	.000013	.000013	.000000	.000013	.000000	.000007
TOTAL	100.0000	.167516	.005699	.172294	.000926	.000000	.000156
LB/HR	-	-	.068457	.347311	.029678	.000000	.004984

TOTAL POUNDS OF GAS (ADJUSTED FOR COS)= .450431

*NOTE: THE MOLES/HR OF COS IS ESTIMATED TO BE 1/70TH OF THE REPORTED MOLES OF H2S, THEREFORE COS IS NOT INCLUDED IN THE REPORTED GAS MOLE % COMPOSITION.

****

MATERIAL BALANCE CLOSURE — PAGE 3
FOR MINI-BENCH UNIT — RUN: 87 MBU-15
DATE: 7/02/87

****

* CLOSE CARBON BALANCE BY CALCULATING OIL PRODUCTION *

CARBON IN

INLET GAS	.000000	LB/HR
SHALE ORGANIC CARBON (PG 1)	.402092	LB/HR
SHALE MINERAL CARBON (PG 1)	.000297	LB/HR
TOTAL	.402389	LB/HR

CARBON OUT (EXCLUSIVE OF CARBON IN OIL)

ADJUSTED PRODUCT GAS* (PG 2)	.068457	LB/HR
SHALE ORGANIC CARBON (PG 1)	.079094	LB/HR
SHALE MINERAL CARBON (PG 1)	.000098	LB/HR
SOUR WATER CARBON (PG 1)	.001241	LB/HR
TOTAL	.148891	LB/HR

CALCULATED CARBON IN OIL PRODUCED------ .253498 LB/HR

OIL YIELD ADJUSTMENT

ELEMENT	WEIGHT%	LB/HR REPORTED	LB/HR CALCULATED**
C	84.33	.258556	.253498
H	9.90	.030353	.029760
S	1.11	.003403	.003337
N	2.04	.006255	.006132
O	2.62	.008033	.007876
TOTAL	100.00	.306600	.300603

UNADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)--- .225094

ADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)----- .220691

* GAS ADJUSTED FOR COS (SEE PAGE 2).
** BASED ON EXISTING ELEMENTAL BALANCE AND CALCULATED CARBON IN OIL.

* CLOSE OXYGEN BALANCE BY CALCULATING WATER PRODUCTION *

OXYGEN IN

SHALE MOISTURE (PG 1)	.017674	LB/HR
SHALE ORG. OXYGEN (PG 1)	.027923	LB/HR
SHALE CARBON DIOXIDE (PG 1)	.000792	LB/HR
SHALE HIGH TEMP. O (PG 1)	.053939	LB/HR
OXYGEN IN INLET GAS	.000000	LB/HR
TOTAL	.100328	LB/HR

OXYGEN OUT (EXCLUDING O2 IN REPORTED WATER PRODUCTION)

SHALE ORG. OXYGEN (PG 1)	.013077	LB/HR
SHALE CO2 OXYGEN (PG 1)	.000262	LB/HR
SHALE HIGH TEMP. O (PG 1)	.014701	LB/HR
SOUR WATER CO2 O (PG 1)	.003306	LB/HR
OXYGEN IN PROD GAS (PG 2)	.004984	LB/HR **
OXYGEN IN OIL (PG 3)	.007876	LB/HR
TOTAL	.044206	LB/HR

O2 ASSIGNED TO WATER PRODUCTION---	.056122	LB/HR
TOTAL CALCULATED H2O PRODUCTION---	.063193	LB/HR *
TOTAL REPORTED H2O PRODUCTION-----	.066013	LB/HR *
ADJUSTMENT TO H2O PRODUCTION-----	-.002820	LB/HR

* REPORTED AND CALCULATED WATER PRODUCTIONS INCLUDE RAW SHALE MOISTURE.

** OXYGEN IN PRODUCT GAS IS ADJUSTED TO INCLUDE CARBONYL SULFIDE OXYGEN, WHICH IS ASSIGNED TO THE PRODUCT GAS (SEE PG 2).

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

PAGE 5
RUN: 87 MBU-15
DATE: 7/02/87

****

CLOSE SULFUR BALANCE BY CALCULATING HYDROGEN SULFIDE PRODUCTION

SULFUR IN

SHALE SULFUR (PG 1)	.081998	LB/HR
INLET GAS SULFUR	.000000	LB/HR
TOTAL	.081998	LB/HR

SULFUR OUT

SHALE SULFUR (PG 1)	.045184	LB/HR
OIL SULFUR (PG 3)	.003337	LB/HR
SOUR WATER H2S (PG 1)	.000241	LB/HR
PRODUCT GAS H2S (PG 2)	.029678	LB/HR
TOTAL	.078440	LB/HR

SULFUR ADJUSTMENT------- .003559 LB/HR

-------------------HYDROGEN SULFIDE ADJUSTMENT-------------------

REPORTED HYDROGEN SULFIDE*

GAS	.031100	LB/HR
SOUR WATER	.000256	LB/HR
TOTAL	.031356	LB/HR
H2S ADJUSTMENT	.003782	LB/HR
CALCULATED H2S (TOTAL)	.035138	LB/HR

* SULFUR ALSO EXISTS AS COS IN PRODUCT GAS.

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

RUN: 87 MBU-15
DATE: 7/02/87

****

* CLOSE NITROGEN BALANCE BY CALCULATING AMMONIA PRODUCTION *

NITROGEN IN

NITROGEN IN GAS	.000000	LB/HR
SHALE NITROGEN (PG 1)	.010897	LB/HR
TOTAL	.010897	LB/HR

NITROGEN OUT

ELEMENTAL NITROGEN IN GAS	.000000	LB/HR
AMMONIA NITROGEN IN GAS	.000000	LB/HR
SHALE NITROGEN (PG 1)	.003517	LB/HR
OIL NITROGEN (PG 3)	.006132	LB/HR
SOUR WATER NH3 (PG 1)	.001796	LB/HR
TOTAL	.011445	LB/HR

NITROGEN ADJUSTMENT -.000549 LB/HR

------------------------AMMONIA ADJUSTMENT------------------------

REPORTED AMMONIA

GAS	.000000	LB/HR
SOUR WATER	.002183	LB/HR
TOTAL	.002183	LB/HR

AMMONIA ADJUSTMENT -.000667 LB/HR

CALCULATED AMMONIA (TOTAL)------ .001516 LB/HR

****

MATERIAL BALANCE CLOSURE — PAGE 7
FOR MINI-BENCH UNIT — RUN: 87 MBU-15
DATE: 7/02/87

****

* CLOSE HYDROGEN BALANCE TO CALCULATE HYDROGEN CONSUMPTION *

HYDROGEN IN

FEED GAS	.000000	LB/HR *
DRY RAW SHALE (PG 1)	.043723	LB/HR
RAW SHALE MOISTURE (PG 1)	.002227	LB/HR
TOTAL	.045950	LB/HR

HYDROGEN OUT

PRODUCT GAS (PG 2)	.017468	LB/HR *
OIL (PG 3)	.029760	LB/HR
SPENT SHALE (PG 1)	.005501	LB/HR
WATER PRODUCTION (PG 4)	.007071	LB/HR
SOUR WATER NH3 (PG 6)	.000269	LB/HR
SOUR WATER H2S (PG 5)	.000239	LB/HR
TOTAL	.060308	LB/HR

HYDROGEN CONSUMED .014358 LB/HR

CALCULATED HYDROGEN CONSUMPTION = 3958.39 SCF/TON DRS

* FEED AND PRODUCT GAS COMBINED HYDROGEN ONLY.
NO MOLECULAR (FREE) HYDROGEN IS REPORTED.

```
****************************************************************
   MATERIAL BALANCE CLOSURE                    PAGE  8
   FOR MINI-BENCH UNIT                         RUN: 87 MBU-15
                                               DATE: 7/02/87
****************************************************************
```

*** ADJUSTED MASS BALANCE CHECK ***

EXIT STREAMS

SHALE (PG 1)	.901872	LB/HR
OIL (PG 3)	.300603	LB/HR
GAS (PG 2)	.120587	LB/HR *
TOTAL WATER (PG 4)	.063193	LB/HR
SOUR WATER NH3 (PG 6)	.001516	LB/HR
SOUR WATER H2S (PG 5)	.004038	LB/HR
SOUR WATER CO2 (PG 1)	.004547	LB/HR
TOTAL	1.396357	LB/HR

FEED STREAMS

SHALE (PG 1)	1.362099	LB/HR
HYDROGEN CONSUMED (PG 7)	.014358	LB/HR
RAW SHALE MOISTURE (PG 1)	.019901	LB/HR
TOTAL	1.396358	LB/HR

* NOT INCLUDING MOLECULAR (FREE) HYDROGEN

* CARBON DISTRIBUTION DATA *

ORGANIC CARBON IN OIL	63.04
ORGANIC CARBON IN GAS	17.28
ORGANIC CARBON IN SPENT SHALE	19.67
TOTAL	100.00

TOTAL ORGANIC CARBON CONVERSION--- 80.33

SELECTIVITY TO OIL--------------- 78.48

NOTE: SELECTIVITY TO OIL IS DEFINED AS THE PERCENTAGE OF CONVERTED ORGANIC CARBON CONTAINED IN THE PRODUCT OIL

DRAFT
12.02.87
12:45 AM

APPENDIX C

4. Material Balance Closure for 87MBU-20
Beneficiated Alabama Shale
(Low Sulfur)

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

PAGE 1
RUN: 87 MBU-20
DATE: 9/28/87

****

* ADJUST SPENT SHALE FLOW RATE BASED ON MINERAL MATTER BALANCE *

COMPONENT	--RAW SHALE-- UNADJUSTED		------SPENT SHALE------ UNADJUSTED		ADJUSTED
	WEIGHT%	LB/HR	WEIGHT%	LB/HR	LB/HR
ORGANIC CARBON	43.29	.509401	21.17	.138028	.144559
HYDROGEN	4.25	.050010	1.09	.007107	.007443
ORG. OXYGEN	.54	.006354	1.08	.007042	.007375
NITROGEN	.84	.009884	.42	.002738	.002868
SULFUR	9.27	.109082	10.75	.070090	.073406
CO2	.00	.000000	.00	.000000	.000000
HIGH TEMP O2	4.81	.056600	1.73	.011280	.011813
MINERAL MATTER	37.00	.435385	63.76	.415715	.435385
TOTAL	100.00	1.176717	100.00	.652000	.682850
MOISTURE	1.53	.018284			
TOTAL WET SHALE		1.195000			

*** ACCOUNT FOR SOUR WATER CONSTITUENTS ***

REPORTED SOUR WATER PRODUCTION (LB/HR) - .055200

COMPONENT	C	H	S	N	O	TOTAL
	LB/HR					
NH3	-	.000220	-	.001021	-	.001241
H2S	-	.000069	.001104	-	-	.001173
CO2	.000304	-	-	-	.000809	.001112
TOTAL	.000304	.000290	.001104	.001021	.000809	.003527

****

MATERIAL BALANCE CLOSURE
FOR MINI-BENCH UNIT

RUN: 87 MBU-20
DATE: 9/28/87

****

* DRY PRODUCT GAS (ASSIGNMENT OF COS) *

COMP	MOLE%	MOLES/HR	MOLES/HR C	H2	S	N2	O2
N2	.0000	.000000	.000000	.000000	.000000	.000000	.000000
CO	.0000	.000000	.000000	.000000	.000000	.000000	.000000
CO2	.0211	.000032	.000032	.000000	.000000	.000000	.000032
H2	96.2166	.144897	.000000	.144897	.000000	.000000	.000000
CH4	1.7191	.002589	.002589	.005178	.000000	.000000	.000000
C2H6	.6117	.000921	.001842	.002764	.000000	.000000	.000000
C3H8	.2320	.000349	.001048	.001398	.000000	.000000	.000000
C4H1	.2292	.000345	.001381	.001726	.000000	.000000	.000000
C2H4	.0844	.000127	.000254	.000254	.000000	.000000	.000000
C3H6	.0949	.000143	.000429	.000429	.000000	.000000	.000000
C4H8	.0633	.000095	.000381	.000381	.000000	.000000	.000000
C6H6	.0000	.000000	.000000	.000000	.000000	.000000	.000000
NH3	.0000	.000000	.000000	.000000	.000000	.000000	.000000
H2S	.7277	.001096	.000000	.001096	.001096	.000000	.000000
COS	.0000	.000016	.000016	.000000	.000016	.000000	.000008
TOTAL	100.0000	.150610	.007972	.158122	.001112	.000000	.000040
LB/HR	-	-	.095750	.318742	.035640	.000000	.001267

TOTAL POUNDS OF GAS (ADJUSTED FOR COS)= .451399

*NOTE: THE MOLES/HR OF COS IS ESTIMATED TO BE 1/70TH OF THE REPORTED MOLES OF H2S, THEREFORE COS IS NOT INCLUDED IN THE REPORTED GAS MOLE % COMPOSITION.

* CLOSE CARBON BALANCE BY CALCULATING OIL PRODUCTION *

CARBON IN

INLET GAS	.000000	LB/HR
SHALE ORGANIC CARBON (PG 1)	.509401	LB/HR
SHALE MINERAL CARBON (PG 1)	.000000	LB/HR
TOTAL	.509401	LB/HR

CARBON OUT (EXCLUSIVE OF CARBON IN OIL)

ADJUSTED PRODUCT GAS* (PG 2)	.095750	LB/HR
SHALE ORGANIC CARBON (PG 1)	.144559	LB/HR
SHALE MINERAL CARBON (PG 1)	.000000	LB/HR
SOUR WATER CARBON (PG 1)	.000304	LB/HR
TOTAL	.240613	LB/HR

CALCULATED CARBON IN OIL PRODUCED------ .268788 LB/HR

OIL YIELD ADJUSTMENT

ELEMENT	WEIGHT%	LB/HR REPORTED	LB/HR CALCULATED**
C	86.03	.287254	.268788
H	9.98	.033323	.031181
S	1.82	.006077	.005686
N	1.91	.006377	.005968
O	.26	.000868	.000812
TOTAL	100.00	.333900	.312435

UNADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)--- .283756

ADJUSTED OIL YIELD (LB OIL/LB DRY SHALE)----- .265514

* GAS ADJUSTED FOR COS (SEE PAGE 2).
** BASED ON EXISTING ELEMENTAL BALANCE AND CALCULATED CARBON IN OIL.

****

MATERIAL BALANCE CLOSURE — PAGE 4
FOR MINI-BENCH UNIT — RUN: 87 MBU-20
DATE: 9/28/87

****

* CLOSE OXYGEN BALANCE BY CALCULATING WATER PRODUCTION *

OXYGEN IN

SHALE MOISTURE (PG 1)	.016238	LB/HR
SHALE ORG. OXYGEN (PG 1)	.006354	LB/HR
SHALE CARBON DIOXIDE (PG 1)	.000000	LB/HR
SHALE HIGH TEMP. O (PG 1)	.056600	LB/HR
OXYGEN IN INLET GAS	.000000	LB/HR
TOTAL	.079192	LB/HR

OXYGEN OUT (EXCLUDING O2 IN REPORTED WATER PRODUCTION)

SHALE ORG. OXYGEN (PG 1)	.007375	LB/HR
SHALE CO2 OXYGEN (PG 1)	.000000	LB/HR
SHALE HIGH TEMP. O (PG 1)	.011813	LB/HR
SOUR WATER CO2 O (PG 1)	.000809	LB/HR
OXYGEN IN PROD GAS (PG 2)	.001267	LB/HR **
OXYGEN IN OIL (PG 3)	.000812	LB/HR
TOTAL	.022076	LB/HR

O2 ASSIGNED TO WATER PRODUCTION---	.057116	LB/HR
TOTAL CALCULATED H2O PRODUCTION---	.064312	LB/HR *
TOTAL REPORTED H2O PRODUCTION-----	.051673	LB/HR *
ADJUSTMENT TO H2O PRODUCTION------	.012638	LB/HR

* REPORTED AND CALCULATED WATER PRODUCTIONS INCLUDE RAW SHALE MOISTURE.

** OXYGEN IN PRODUCT GAS IS ADJUSTED TO INCLUDE CARBONYL SULFIDE OXYGEN, WHICH IS ASSIGNED TO THE PRODUCT GAS (SEE PG 2).

****

MATERIAL BALANCE CLOSURE — PAGE 5
FOR MINI-BENCH UNIT — RUN: 87 MBU-20
DATE: 9/28/87

****

CLOSE SULFUR BALANCE BY CALCULATING HYDROGEN SULFIDE PRODUCTION

SULFUR IN

SHALE SULFUR (PG 1)	.109082	LB/HR
INLET GAS SULFUR	.000000	LB/HR
TOTAL	.109082	LB/HR

SULFUR OUT

SHALE SULFUR (PG 1)	.073406	LB/HR
OIL SULFUR (PG 3)	.005686	LB/HR
SOUR WATER H2S (PG 1)	.001104	LB/HR
PRODUCT GAS H2S (PG 2)	.035640	LB/HR
TOTAL	.115836	LB/HR

SULFUR ADJUSTMENT------- -.006755 LB/HR

--------------------HYDROGEN SULFIDE ADJUSTMENT--------------------

REPORTED HYDROGEN SULFIDE*

GAS	.037347	LB/HR
SOUR WATER	.001173	LB/HR
TOTAL	.038520	LB/HR
H2S ADJUSTMENT	-.007179	LB/HR
CALCULATED H2S (TOTAL)	.031341	LB/HR

* SULFUR ALSO EXISTS AS COS IN PRODUCT GAS.

```
*************************************************************************
   MATERIAL BALANCE CLOSURE                          PAGE  6
   FOR MINI-BENCH UNIT                               RUN: 87 MBU-20
                                                     DATE: 9/28/87
*************************************************************************

  * CLOSE NITROGEN BALANCE BY CALCULATING AMMONIA PRODUCTION *
-------------------------------------------------------------------------

  NITROGEN IN
  -----------
       NITROGEN IN GAS                  .000000  LB/HR
       SHALE NITROGEN (PG 1)            .009884  LB/HR
       -------------------------------------------
                            TOTAL       .009884  LB/HR

  NITROGEN OUT
  ------------
       ELEMENTAL NITROGEN IN GAS        .000000  LB/HR
       AMMONIA NITROGEN IN GAS          .000000  LB/HR
       SHALE NITROGEN (PG 1)            .002868  LB/HR
       OIL NITROGEN (PG 3)              .005968  LB/HR
       SOUR WATER NH3 (PG 1)            .001021  LB/HR
       -------------------------------------------
                            TOTAL       .009857  LB/HR

 NITROGEN ADJUSTMENT                    .000028  LB/HR


-----------------------AMMONIA ADJUSTMENT-------------------------


 REPORTED AMMONIA
        GAS                             .000000  LB/HR
        SOUR WATER                      .001241  LB/HR
                            ------------------------
                            TOTAL       .001241  LB/HR

 AMMONIA ADJUSTMENT                     .000034  LB/HR
                            ------------------------

 CALCULATED AMMONIA (TOTAL)------       .001275  LB/HR
```

****

MATERIAL BALANCE CLOSURE — PAGE 7

FOR MINI-BENCH UNIT — RUN: 87 MBU-20

DATE: 9/28/87

****

* CLOSE HYDROGEN BALANCE TO CALCULATE HYDROGEN CONSUMPTION *

HYDROGEN IN

FEED GAS	.000000	LB/HR *
DRY RAW SHALE (PG 1)	.050010	LB/HR
RAW SHALE MOISTURE (PG 1)	.002046	LB/HR
TOTAL	.052056	LB/HR

HYDROGEN OUT

PRODUCT GAS (PG 2)	.026658	LB/HR *
OIL (PG 3)	.031181	LB/HR
SPENT SHALE (PG 1)	.007443	LB/HR
WATER PRODUCTION (PG 4)	.007196	LB/HR
SOUR WATER NH3 (PG 6)	.000226	LB/HR
SOUR WATER H2S (PG 5)	-.000355	LB/HR
TOTAL	.072350	LB/HR

HYDROGEN CONSUMED	.020294	LB/HR

CALCULATED HYDROGEN CONSUMPTION = 6476.41 SCF/TON DRS

* FEED AND PRODUCT GAS COMBINED HYDROGEN ONLY.
NO MOLECULAR (FREE) HYDROGEN IS REPORTED.

****

MATERIAL BALANCE CLOSURE — PAGE 8
FOR MINI-BENCH UNIT — RUN: 87 MBU-20
DATE: 9/28/87

****

*** ADJUSTED MASS BALANCE CHECK ***

EXIT STREAMS

SHALE (PG 1)	.682850	LB/HR
OIL (PG 3)	.312435	LB/HR
GAS (PG 2)	.159316	LB/HR *
TOTAL WATER (PG 4)	.064312	LB/HR
SOUR WATER NH3 (PG 6)	.001275	LB/HR
SOUR WATER H2S (PG 5)	-.006006	LB/HR
SOUR WATER CO2 (PG 1)	.001112	LB/HR
TOTAL	1.215294	LB/HR

FEED STREAMS

SHALE (PG 1)	1.176717	LB/HR
HYDROGEN CONSUMED (PG 7)	.020294	LB/HR
RAW SHALE MOISTURE (PG 1)	.018284	LB/HR
TOTAL	1.215294	LB/HR

* NOT INCLUDING MOLECULAR (FREE) HYDROGEN

* CARBON DISTRIBUTION DATA *

ORGANIC CARBON IN OIL	52.77
ORGANIC CARBON IN GAS	18.86
ORGANIC CARBON IN SPENT SHALE	28.38
TOTAL	100.00

TOTAL ORGANIC CARBON CONVERSION--- 71.62

SELECTIVITY TO OIL---------------- 73.67

NOTE: SELECTIVITY TO OIL IS DEFINED AS THE PERCENTAGE OF CONVERTED ORGANIC CARBON CONTAINED IN THE PRODUCT OIL

DRAFT
12.02.87
12:45 AM

APPENDIX D

1. Retort Design* for Beneficiated Alabama Shale
Based on 86MBU-11

* This design is slightly different from the one reported in Program Year 1 Annual Report, because the subroutine for calculating the shale enthalpy has been revised to account for shale composition.

```
                         HYTORT RETORT CALCULATIONS      DATE: 09/11/86
                        BASIS: HOUR                     RUN: MBU11-86
                        PRESSURE:  620.PSIA

    >>>>>>>>>>>>V    >>>>>>>>>>>>>>>>>> WET RECYCLE GAS
    RAW SHALE   V    ^                    2777180. LB
      (DRY)     V    ^                    295.F
   9334098. LB  V    ^                  SAT. TEMP. = 270. F
        60. F   V    ^                  MOLE % H20 = 6.8 %
    MOISTURE    V    ^  STREAM 6
    560046. LB  V    ^
                V    ^
    STREAM A    V    ^
              **********
 HEAT OF      *        *
 REACTION     * PREHEAT*
 21.47 BTU/LB *        *
    @ 60. F   **********
                V    ^
                V    ^  5
                V    ^  710.F
                V    ^<<<<<<<<
    STREAM B    V           ^                             754401. LB OIL
                V           ^                            3283608. LB GAS
                V    >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
        700.F   V    ^ 891.F ^
                V    ^       ^
                V    ^  4    ^
                V    ^       ^
                V    ^       ^
              **********     ^                       RECYCLE GAS
 HEAT OF      *        *     ^                V<<<<<
 REACTION     * RETORT *     ^                V     3219664. LB
-74.43 BTU/LB *        *     ^     .          V
    @ 60. F   **********     ^    ***         V STREAM 9
                V    ^       ^    *.*  1971142. LB V
                V    ^ 3     ^<<<<<<<<<<<<<<<<<<<<<<V
                V    ^ 1075.F   *   *     7       V
    STREAM C    V    ^        *     *             V
                V    ^        *     *             V
       1065.F   V    ^  1095.F *    * 1248522. LB V
                V    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
                V    ^      2 *     *     8
                V    ^        *     *                  OVERALL HEAT
                V    ^ 1A     *******                  OF REACTION
                V    ^ 1055.F                           -51.0 BTU/LB
                V    ^                                 DRY RAW SHALE
              **********                                 @   60. F
              *        *
              * COOLING*
              *        *
              **********
                V    ^
    STREAM D    V    ^        STREAM 1
                V    ^                                RECYCLE GAS
     <<<<<<<<        ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<  162. F
      SPENT SHALE                                     1251278. LB
      7549897. LB
          172. F
```

PREHEAT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
 STREAM A                      STREAM 6
 DRY RAW SHALE                 WET RECYCLE GAS

9334098.4 LBS/HR             2777180.3 LBS/HR
     60.0 F                      295.4 F
     0.00 BTU/LB                321.13 BTU/LB
    0.000 MMBTU/HR             891.835 MMBTU/HR

   V  *****************************  ^
   V         PREHEAT ZONE            ^
   V       OUTLET ENTHALPY           ^
   V       STREAMS 6 AND B           ^
   V     2118.417 MMBTU/HR           ^
   V  *****************************  ^

  STREAM B                     STREAM  5
  PREHEATED SHALE              HOT RECYCLE GAS

9088106.4 LBS/HR             1971142.4 LBS/HR
    700.0 F                      710.0 F
   134.97 BTU/LB               1176.38 BTU/LB
 1226.582 MMBTU/HR            2318.803 MMBTU/HR
```

ADDITIONAL PREHEAT ZONE HEAT BALANCE DATA

STREAM A SHALE MOISTURE	HEATS OF REACTION HIGH TEMP WATER	HEATS OF REACTION HYDROGEN SULFIDE
560045.9 LBS/HR	50460.8 LBS/HR	207823.8 LBS/HR
60.0 F	700.0 F	700.0 F
0.00 BTU/LB	1500.00 BTU/LB	600.00 BTU/LB
0.000 MMBTU/HR	75.691 MMBTU/HR	124.694 MMBTU/HR

HEAT OF REACTION - 21.47 BTU/LB
(PREHEAT ZONE) @ 60. F
(DRY RAW SHALE)

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

HYTORT RETORT CALCULATIONS DATE: 09/11/86
RUN: MBU11-86
PRESSURE: 620.PSIA

RETORT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM B                                       STREAM 4
RAW PREHEATED SHALE          PRODUCT GAS                     OIL

 9088106.4 LBS/HR        3283607.6 LBS/HR      754401.0 LBS/HR
     700.0 F                 891.1 F              891.1 F
    134.97 BTU/LB          1193.08 BTU/LB        528.41 BTU/LB
  1226.582 MMBTU/HR       3917.611 MMBTU/HR     398.631 MMBTU/HR

     V   ****************************   ^
     V           RETORT ZONE            ^
     V         HEAT OF REACTION         ^
     V    -74.43 BTU/LB DRY PREHEATED   ^
     V          SHALE @  60.0 F         ^
     V          -676.425 MMBTU/HR       ^
     V   ****************************   ^

STREAM C                  STREAM 3
HOT SPENT SHALE           COMBINED RECYCYLE GAS

 7549897.0 LBS/HR           2499799.6 LBS/HR
    1065.0 F                   1075.0 F
    300.11 BTU/LB             1871.87 BTU/LB
  2265.794 MMBTU/HR          4679.305 MMBTU/HR

                                    ^         STREAM 2
                                    ^         HOT RECYCLE GAS
                                    ^
                                    ^<<<<<<<< 1248521.9 LBS/HR
                                    ^                1095.0 F
                                    ^                1910.8 BTU/LB
                                    ^             2385.665 MMBTU/HR
                          STREAM 1A
                          PREHEATED RECYCLE GAS

                           1251277.7 LBS/HR
                              1055.0 F
                             1833.04 BTU/LB
                            2293.639 MMBTU/HR
```

NOTE-HEAT OF REACTION CORRECTED FOR HIGH TEMPERATURE WATER AND H2S REMOVED IN PREHEAT ZONE.
THE OVERALL HEAT OF REACTION IS -51.0 BTU/LB DRY RAW SHALE @ 60.0 F

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

COOLING ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM C                         STREAM 1A
HOT SPENT SHALE                  PREHEATED RECYCLE GAS

 7549897.0 LBS/HR                 1251277.7 LBS/HR
    1065.0 F                         1055.0 F
    300.11 BTU/LB                   1833.04 BTU/LB
  2265.794 MMBTU/HR                2293.639 MMBTU/HR

      V    *****************************    ^
      V            COOLING ZONE             ^
      V          HEAT EXCHANGED             ^
      V        2065.330 MMBTU/HR            ^
      V    *****************************    ^

STREAM D                            STREAM 1
COOL SPENT SHALE                    RECYCLE GAS

 7549897.0 LBS/HR                 1251277.7 LBS/HR
     172.4 F                          162.4 F
     26.55 BTU/LB                    182.46 BTU/LB
   200.464 MMBTU/HR                 228.309 MMBTU/HR
```

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

PREHEAT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 5		GAS MAKE		STREAM 6		
MOL WT	4.125				5.426		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	690.3	12435.5	33888.4	610506.7	34578.7	622942.2	6.757
H2	430105.5	867006.8	-6098.2	-12292.7	424007.4	854714.1	82.849
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	12486.8	349763.4	0.0	0.0	12486.8	349763.4	2.440
CO2	19.2	843.8	0.0	0.0	19.2	843.8	0.004
H2S	1.8	60.9	6098.2	207823.8	6099.9	207884.7	1.192
COS	114.8	6897.6	0.0	0.0	114.8	6897.6	0.022
NH3	8.6	147.0	0.0	0.0	8.6	147.0	0.002
CH4	26813.3	430160.8	0.0	0.0	26813.3	430160.8	5.239
C2H6	4276.4	128589.9	0.0	0.0	4276.4	128589.9	0.836
C2H4	458.3	12856.9	0.0	0.0	458.3	12856.9	0.090
C3H8	1204.6	53120.5	0.0	0.0	1204.6	53120.5	0.235
C3H6	567.1	23862.5	0.0	0.0	567.1	23862.5	0.111
C4H10	846.8	49219.8	0.0	0.0	846.8	49219.8	0.165
C4H8	165.2	9268.9	0.0	0.0	165.2	9268.9	0.032
C5+	134.5	26908.3	0.0	0.0	134.5	26908.3	0.026
TOTAL	477893.3	1971142.4	33888.4	806037.9	511781.7	2777180.3	100.000

RETORT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 3		GAS MAKE		STREAM 4		
MOL WT	4.125				5.456		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	875.4	15770.6	11204.1	201843.3	12079.5	217613.9	2.007
H2	545459.2	1099536.6	-40745.6	-82134.9	504713.6	1017401.7	83.865
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	15835.8	443569.4	300.3	8411.0	16136.0	451980.4	2.681
CO2	24.3	1070.1	486.8	21422.9	511.1	22492.9	0.085
H2S	2.3	77.2	6098.2	207823.8	6100.4	207901.1	1.014
COS	145.6	8747.5	191.1	11478.4	336.7	20225.9	0.056
NH3	10.9	186.4	1191.7	20294.9	1202.6	20481.3	0.200
CH4	34004.6	545529.2	10678.8	171317.3	44683.4	716846.6	7.425
C2H6	5423.3	163077.5	3164.2	95145.8	8587.5	258223.3	1.427
C2H4	581.2	16305.1	308.0	8641.3	889.2	24946.4	0.148
C3H8	1527.7	67367.3	1054.6	46503.0	2582.3	113870.3	0.429
C3H6	719.1	30262.4	483.0	20326.8	1202.2	50589.2	0.200
C4H10	1073.9	62420.4	1133.2	65863.5	2207.1	128284.0	0.367
C4H8	209.5	11754.8	374.2	20995.8	583.7	32750.6	0.097
TOTAL	605892.9	2465674.6	-4077.6	817933.0	601815.3	3283607.6	100.000

OIL DATA

OIL PRODUCTION : 720276.0 LB/HR
0.0772 LB OIL/LB DRY RAW SHALE

CHARACTERISTICS : API - 15.7
MBP - 484.0 F

CHEMICAL HYDROGEN CONSUMPTION

	SCF/TON*	SCF/BBL**
PREHEAT	494.56	1079.72
RETORT	3304.49	7214.28
	3799.05	8294.00

* TON OF DRY RAW SHALE ENTERING PREHEAT ZONE
** BBL OF OIL PRODUCED IN RETORT ZONE

PRESSURE: 620.PSIA

PREHEAT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STREAM A				
DRY RAW SHALE	9334098.4	60.0	0.0	0.000
SHALE MOISTURE	560045.9	60.0	0.0	0.000
STREAM 5 (HOT RECY GAS)	1971142.4	710.0	1176.4	2318.803
TOTAL	11865286.7			2318.803
OUTLET STREAMS				
STRM B (PREHEATED SHALE)	9088106.4	700.0	135.0	1226.582
STRM 6 (WET RECYCLE GAS)	2777180.3	295.4	321.1	891.835
TOTAL	11865286.7			2118.417
INLET-OUTLET=	0.0			200.386
HEAT OF REACTION @ 60. F				
HIGH TEMPERATURE WATER	50460.8		1500.0	75.691
HYDROGEN SULFIDE	207823.8		600.0	124.694
TOTAL	258284.7		21.5	200.386

RETORT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
STRM 1A (HEATED RECY GAS)	1251277.7	1055.0	1833.0	2293.639
STRM 2 (HOT RECYCLE GAS)	1248521.9	1095.0	1910.8	2385.665
TOTAL (STREAM 3)	2499799.6	1075.0		4679.305
INLET STREAMS				
STRM B (PREHEATED SHALE)	9088106.4	700.0	135.0	1226.582
STRM 3 (STREAMS 1A & 2)	2499799.6	1075.0	1871.9	4679.305
TOTAL	11587906.1			5905.886
OUTLET STREAMS				
STRM C (RETORTED SHALE)	7549897.0	1065.0	300.1	2265.794
STRM 4 (GAS & OIL PROD)				
GAS	3283607.6	891.1	1193.1	3917.611
OIL	754401.0	891.1	528.4	398.631
TOTAL	11587905.6			6582.036
INLET-OUTLET=	0.5			-676.150
HEAT OF REACTION @ 60. F (BASED ON PREHEATED SHALE)	9088106.4		-74.4	-676.425

COOLING ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
********************				
INLET STREAMS				
STRM C (RETORTED SHALE)	7549897.0	1065.0	300.1	2265.794
STRM 1 (WARM RECY GAS)	1251277.7	162.4	182.5	228.309
TOTAL	8801174.7			2494.103
OUTLET STREAMS				
STRM 1A (HEATED RECY GAS)	1251277.7	1055.0	1833.0	2293.639
STRM D (SPENT SHALE)	7549897.0	172.4	26.6	200.464
TOTAL	8801174.7			2494.103
INLET-OUTLET=	0.0			0.000
HEAT TRANSFERRED IN COOLING ZONE				2065.330

DRAFT
12.02.87
12:45 AM

APPENDIX D

2. Retort Design* for Beneficiated Alabama Shale (High Sulfur) Based on 86MBU-12

* This design is slightly different from the one reported in Program Year 1 Annual Report, because the subroutine for calculating the shale enthalpy has been revised to account for shale composition.

HYTORT RETORT CALCULATIONS

DATE: 09/15/86

BASIS: HOUR

RUN: MBU12-86

PRESSURE: 620.PSIA

```
   >>>>>>>>>>>>V    >>>>>>>>>>>>>>>>>> WET RECYCLE GAS
   RAW SHALE   V    ^                    1318900. LB
    (DRY)      V    ^                    285.F
  3761440. LB  V    ^                 SAT. TEMP. = 260. F
       60. F   V    ^                 MOLE % H2O = 5.7 %
   MOISTURE    V    ^  STREAM 6
   210922. LB  V    ^
               V    ^
   STREAM A    V    ^
             **********
HEAT OF      *        *
REACTION     * PREHEAT*
30.46 BTU/LB *        *
   @ 60. F   **********
               V    ^
               V    ^  5
               V    ^  710.F
               V    ^<<<<<<<<
   STREAM B    V          ^                              735291. LB OIL
               V          ^                             1394404. LB GAS
               V    >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
       700.F   V    ^ 891.F ^
               V    ^       ^
               V    ^  4    ^
               V    ^       ^
               V    ^       ^
             **********     ^                           RECYCLE GAS
HEAT OF      *        *     ^                     V<<<<<
REACTION     * RETORT *     ^                     V     1436261. LB
-84.31 BTU/LB *       *     ^      .              V
   @ 60. F   **********     ^     ***             V STREAM 9
               V    ^       ^     *.*    980816. LB V
               V    ^ 3     ^<<<<<<<<<<<<<<<<<<<<<<<V
               V    ^ 1110.F    *   *     7         V
   STREAM C    V    ^          *     *              V
               V    ^          *     *              V
      1100.F   V    ^  1130.F  *     *  455445. LB  V
               V    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
               V    ^       2  *     *    8
               V    ^          *     *                 OVERALL HEAT
               V    ^ 1A       *******                 OF REACTION
               V    ^ 1090.F                            -51.0 BTU/LB
               V    ^                                  DRY RAW SHALE
             **********                                  @   60. F
             *        *
             * COOLING*
             *        *
             **********
               V    ^
   STREAM D    V    ^     STREAM 1
               V    ^                              RECYCLE GAS
        <<<<<<<<    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< 174. F
     SPENT SHALE                                   456481. LB
     2416510. LB
         184. F
```

PREHEAT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM A DRY RAW SHALE	STREAM 6 WET RECYCLE GAS
3761440.3 LBS/HR	1318899.9 LBS/HR
60.0 F	285.0 F
0.00 BTU/LB	316.82 BTU/LB
0.000 MMBTU/HR	417.849 MMBTU/HR

```
V   *****************************   ^
V          PREHEAT ZONE             ^
V        OUTLET ENTHALPY            ^
V        STREAMS 6 AND B            ^
V      1034.024 MMBTU/HR            ^
V   *****************************   ^
```

STREAM B PREHEATED SHALE	STREAM 5 HOT RECYCLE GAS
3634278.5 LBS/HR	980816.2 LBS/HR
700.0 F	710.0 F
169.54 BTU/LB	1171.06 BTU/LB
616.139 MMBTU/HR	1148.590 MMBTU/HR

ADDITIONAL PREHEAT ZONE HEAT BALANCE DATA

STREAM A	HEATS OF REACTION	
SHALE MOISTURE	HIGH TEMP WATER	HYDROGEN SULFIDE
210921.9 LBS/HR	38818.5 LBS/HR	93897.3 LBS/HR
60.0 F	700.0 F	700.0 F
0.00 BTU/LB	1500.00 BTU/LB	600.00 BTU/LB
0.000 MMBTU/HR	58.228 MMBTU/HR	56.338 MMBTU/HR

HEAT OF REACTION - 30.46 BTU/LB
(PREHEAT ZONE) @ 60. F
(DRY RAW SHALE)

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

RETORT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM B                                         STREAM 4
RAW PREHEATED SHALE            PRODUCT GAS                   OIL

 3634278.5 LBS/HR          1394404.0 LBS/HR        735290.6 LBS/HR
     700.0 F                   890.9 F                 890.9 F
    169.54 BTU/LB            1035.25 BTU/LB           536.11 BTU/LB
   616.139 MMBTU/HR         1443.559 MMBTU/HR        394.198 MMBTU/HR

     V   *****************************   ^
     V          RETORT ZONE              ^
     V        HEAT OF REACTION           ^
     V   -84.31 BTU/LB DRY PREHEATED     ^
     V         SHALE @  60.0 F           ^
     V        -306.400 MMBTU/HR          ^
     V   *****************************   ^

STREAM C                  STREAM 3
HOT SPENT SHALE           COMBINED RECYCYLE GAS

 2416510.3 LBS/HR           911926.3 LBS/HR
    1100.0 F                  1110.0 F
    350.16 BTU/LB            1931.31 BTU/LB
   846.163 MMBTU/HR         1761.211 MMBTU/HR

                                      ^         STREAM 2
                                      ^         HOT RECYCLE GAS
                                      ^
                                      ^<<<<<<<<<  455445.1 LBS/HR
                                      ^                  1130.0 F
                                      ^                  1970.2 BTU/LB
                                      ^                 897.333 MMBTU/HR
                          STREAM 1A
                          PREHEATED RECYCLE GAS

                            456481.2 LBS/HR
                              1090.0 F
                             1892.47 BTU/LB
                             863.879 MMBTU/HR
```

NOTE-HEAT OF REACTION CORRECTED FOR HIGH TEMPERATURE
WATER AND H2S REMOVED IN PREHEAT ZONE.
THE OVERALL HEAT OF REACTION IS -51.0 BTU/LB
DRY RAW SHALE @ 60.0 F

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

HYTORT RETORT CALCULATIONS DATE: 09/15/86
RUN: MBU12-86
PRESSURE: 620.PSIA

COOLING ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM C                       STREAM 1A
HOT SPENT SHALE                PREHEATED RECYCLE GAS

 2416510.3 LBS/HR               456481.2 LBS/HR
    1100.0 F                      1090.0 F
    350.16 BTU/LB                1892.47 BTU/LB
   846.163 MMBTU/HR              863.879 MMBTU/HR

     V   *****************************   ^
     V           COOLING ZONE            ^
     V          HEAT EXCHANGED           ^
     V         771.310 MMBTU/HR          ^
     V   *****************************   ^

STREAM D                          STREAM 1
COOL SPENT SHALE                  RECYCLE GAS

 2416510.3 LBS/HR                 456481.2 LBS/HR
     183.5 F                         173.5 F
     30.98 BTU/LB                   202.79 BTU/LB
    74.853 MMBTU/HR                 92.568 MMBTU/HR
```

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

PREHEAT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 5		GAS MAKE		STREAM 6		
MOL WT	4.167				5.291		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	323.7	5831.2	13862.8	249740.4	14186.4	255571.6	5.691
H2	211858.4	427064.2	-2755.2	-5554.0	209103.2	421510.2	83.889
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	5929.1	166077.8	0.0	0.0	5929.1	166077.8	2.379
CO2	8.4	371.1	0.0	0.0	8.4	371.1	0.003
H2S	0.7	25.2	2755.2	93897.3	2756.0	93922.5	1.106
COS	34.4	2064.4	0.0	0.0	34.4	2064.4	0.014
NH3	8.4	142.7	0.0	0.0	8.4	142.7	0.003
CH4	13302.8	213414.0	0.0	0.0	13302.8	213414.0	5.337
C2H6	2184.6	65691.4	0.0	0.0	2184.6	65691.4	0.876
C2H4	210.5	5906.2	0.0	0.0	210.5	5906.2	0.084
C3H8	695.7	30678.2	0.0	0.0	695.7	30678.2	0.279
C3H6	245.7	10338.7	0.0	0.0	245.7	10338.7	0.099
C4H10	386.7	22474.0	0.0	0.0	386.7	22474.0	0.155
C4H8	77.6	4354.3	0.0	0.0	77.6	4354.3	0.031
C5+	131.9	26382.8	0.0	0.0	131.9	26382.8	0.053
TOTAL	235398.6	980816.2	13862.8	338083.8	249261.4	1318899.9	100.000

RETORT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 3		GAS MAKE		STREAM 4		
MOL WT	4.167				6.529		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	300.9	5421.7	8619.1	155274.0	8920.0	160695.7	4.176
H2	196978.0	397068.3	-29505.1	-59476.5	167472.9	337591.9	78.413
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	5512.7	154412.9	0.0	0.0	5512.7	154412.9	2.581
CO2	7.8	345.0	163.9	7211.1	171.7	7556.1	0.080
H2S	0.7	23.4	2755.2	93897.3	2755.9	93920.8	1.290
COS	32.0	1919.4	68.1	4090.6	100.0	6010.1	0.047
NH3	7.8	132.7	1019.1	17356.4	1026.9	17489.0	0.481
CH4	12368.4	198424.3	7238.9	116132.4	19607.3	314556.7	9.180
C2H6	2031.2	61077.5	2306.4	69351.8	4337.5	130429.3	2.031
C2H4	195.7	5491.4	208.1	5838.3	403.9	11329.7	0.189
C3H8	646.8	28523.4	832.8	36723.4	1479.6	65246.8	0.693
C3H6	228.4	9612.5	288.3	12133.2	516.8	21745.7	0.242
C4H10	359.5	20895.4	640.8	37244.6	1000.3	58140.1	0.468
C4H8	72.2	4048.5	200.2	11230.9	272.3	15279.3	0.128
TOTAL	218742.2	887396.5	-5164.3	507007.5	213577.9	1394404.0	100.000

OIL DATA

OIL PRODUCTION : 710760.8 LB/HR
0.1890 LB OIL/LB DRY RAW SHALE

CHARACTERISTICS : API - 19.5
MBP - 437.0 F

CHEMICAL HYDROGEN CONSUMPTION

	SCF/TON*	SCF/BBL**
PREHEAT	554.50	481.92
RETORT	5937.99	5160.79
	6492.48	5642.71

* TON OF DRY RAW SHALE ENTERING PREHEAT ZONE
** BBL OF OIL PRODUCED IN RETORT ZONE

PRESSURE: 620.PSIA

PREHEAT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STREAM A				
DRY RAW SHALE	3761440.3	60.0	0.0	0.000
SHALE MOISTURE	210921.9	60.0	0.0	0.000
STREAM 5 (HOT RECY GAS)	980816.2	710.0	1171.1	1148.590
TOTAL	4953178.4			1148.590
OUTLET STREAMS				
STRM B (PREHEATED SHALE)	3634278.5	700.0	169.5	616.139
STRM 6 (WET RECYCLE GAS)	1318899.9	285.0	316.8	417.849
TOTAL	4953178.4			1033.987
INLET-OUTLET=	0.0			114.603
HEAT OF REACTION @ 60. F				
HIGH TEMPERATURE WATER	38818.5		1500.0	58.228
HYDROGEN SULFIDE	93897.3		600.0	56.338
TOTAL	132715.8		30.5	114.566

RETORT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
STRM 1A (HEATED RECY GAS)	456481.2	1090.0	1892.5	863.879
STRM 2 (HOT RECYCLE GAS)	455445.1	1130.0	1970.2	897.333
TOTAL (STREAM 3)	911926.3	1110.0		1761.211
INLET STREAMS				
STRM B (PREHEATED SHALE)	3634278.5	700.0	169.5	616.139
STRM 3 (STREAMS 1A & 2)	911926.3	1110.0	1931.3	1761.211
TOTAL	4546204.8			2377.350
OUTLET STREAMS				
STRM C (RETORTED SHALE)	2416510.3	1100.0	350.2	846.163
STRM 4 (GAS & OIL PROD)				
GAS	1394404.0	890.9	1035.3	1443.559
OIL	735290.6	890.9	536.1	394.198
TOTAL	4546204.9			2683.920
INLET-OUTLET=	-0.2			-306.570
HEAT OF REACTION @ 60. F (BASED ON PREHEATED SHALE)	3634278.5		-84.3	-306.400

COOLING ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STRM C (RETORTED SHALE)	2416510.3	1100.0	350.2	846.163
STRM 1 (WARM RECY GAS)	456481.2	173.5	202.8	92.568
TOTAL	2872991.5			938.732
OUTLET STREAMS				
STRM 1A (HEATED RECY GAS)	456481.2	1090.0	1892.5	863.879
STRM D (SPENT SHALE)	2416510.3	183.5	31.0	74.853
TOTAL	2872991.5			938.732
INLET-OUTLET=	0.0			0.000
HEAT TRANSFERRED IN COOLING ZONE				771.310

DRAFT
12.02.87
12:45 AM

APPENDIX D

3. Retort Design for Raw Kentucky New Albany Shale Based on 87MBU-8

HYTORT RETORT CALCULATIONS
BASIS: HOUR
PRESSURE: 600.PSIA

DATE: 4/01/87
RUN: MBU8-87

```
   >>>>>>>>>>>>V    >>>>>>>>>>>>>>>>>> WET RECYCLE GAS
   RAW SHALE   V    ^                    2332710. LB
     (DRY)     V    ^                    293.F
  8431405. LB  V    ^                  SAT. TEMP. = 268. F
       60. F   V    ^                  MOLE % H20 = 6.7 %
   MOISTURE    V    ^  STREAM 6
   472789. LB  V    ^
               V    ^
   STREAM A    V    ^
             ***********
HEAT OF      *         *
REACTION     * PREHEAT*
15.64 BTU/LB *         *
   @ 60. F   ***********
               V    ^
               V    ^  5
               V    ^  710.F
               V    ^<<<<<<<<
   STREAM B    V           ^                              764599. LB OIL
               V           ^                             2764658. LB GAS
               V    >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
       700.F   V    ^ 849.F ^
               V    ^       ^
               V    ^  4    ^
               V    ^       ^
               V    ^       ^
             ***********    ^                            RECYCLE GAS
HEAT OF      *        *     ^                      V<<<<<
REACTION     * RETORT *     ^                      V     2846472. LB
-67.84 BTU/LB*        *     ^     .                V
   @ 60. F   ***********    ^    ***               V STREAM 9
               V    ^       ^    *.*   1710501. LB V
               V    ^ 3     ^<<<<<<<<<<<<<<<<<<<<<<V
               V    ^ 1010.F   *     *     7       V
   STREAM C    V    ^          *     *             V
               V    ^          *     *             V
      1000.F   V    ^  1030.F  *     * 1135971. LB V
               V    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
               V    ^       2  *     *     8
               V    ^          *     *                   OVERALL HEAT
               V    ^ 1A       *******                   OF REACTION
               V    ^  990.F                              -51.0 BTU/LB
               V    ^                                    DRY RAW SHALE
             ***********                                   @   60. F
             *         *
             * COOLING*
             *         *
             ***********
               V    ^
   STREAM D    V    ^       STREAM 1
               V    ^                               RECYCLE GAS
        <<<<<<<<    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<  153. F
     SPENT SHALE                                    1138532. LB
     7027232. LB
         163. F
```

PREHEAT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM A DRY RAW SHALE	STREAM 6 WET RECYCLE GAS
8431405.1 LBS/HR	2332709.6 LBS/HR
60.0 F	293.0 F
0.00 BTU/LB	323.75 BTU/LB
0.000 MMBTU/HR	755.204 MMBTU/HR

```
V   ****************************   ^
V          PREHEAT ZONE            ^
V        OUTLET ENTHALPY           ^
V        STREAMS 6 AND B           ^
V       1856.342 MMBTU/HR          ^
V   ****************************   ^
```

STREAM B PREHEATED SHALE	STREAM 5 HOT RECYCLE GAS
8281985.7 LBS/HR	1710501.1 LBS/HR
700.0 F	710.0 F
132.96 BTU/LB	1162.34 BTU/LB
1101.138 MMBTU/HR	1988.190 MMBTU/HR

ADDITIONAL PREHEAT ZONE HEAT BALANCE DATA

STREAM A	HEATS OF REACTION	
SHALE MOISTURE	HIGH TEMP WATER	HYDROGEN SULFIDE
472789.1 LBS/HR	42399.6 LBS/HR	113747.9 LBS/HR
60.0 F	700.0 F	700.0 F
0.00 BTU/LB	1500.00 BTU/LB	600.00 BTU/LB
0.000 MMBTU/HR	63.599 MMBTU/HR	68.249 MMBTU/HR

HEAT OF REACTION - 15.64 BTU/LB
(PREHEAT ZONE) @ 60. F
(DRY RAW SHALE)

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

HYTORT RETORT CALCULATIONS DATE: 4/01/87
RUN: MBU8-87
PRESSURE: 600.PSIA

RETORT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM B                                STREAM 4
RAW PREHEATED SHALE          PRODUCT GAS              OIL

 8281985.7 LBS/HR        2764657.7 LBS/HR      764599.4 LBS/HR
     700.0 F                 849.2 F              849.2 F
    132.96 BTU/LB          1193.63 BTU/LB        503.62 BTU/LB
  1101.133 MMBTU/HR       3299.966 MMBTU/HR     385.070 MMBTU/HR

    V   ******************************   ^
    V          RETORT ZONE               ^
    V        HEAT OF REACTION            ^
    V    -67.84 BTU/LB DRY PREHEATED     ^
    V         SHALE @  60.0 F            ^
    V        -561.850 MMBTU/HR           ^
    V   ******************************   ^

STREAM C                     STREAM 3
HOT SPENT SHALE              COMBINED RECYCYLE GAS

 7027231.5 LBS/HR             2274502.7 LBS/HR
    1000.0 F                     1010.0 F
    270.92 BTU/LB               1725.93 BTU/LB
  1903.798 MMBTU/HR            3925.643 MMBTU/HR

                                         ^        STREAM 2
                                         ^        HOT RECYCLE GAS
                                         ^
                                         ^<<<<<<<< 1135970.9 LBS/HR
                                         ^                1030.0 F
                                         ^                1764.2 BTU/LB
                                         ^            2004.066 MMBTU/HR
                             STREAM 1A
                             PREHEATED RECYCLE GAS

                              1138531.8 LBS/HR
                                  990.0 F
                                1687.77 BTU/LB
                               1921.578 MMBTU/HR
```

NOTE-HEAT OF REACTION CORRECTED FOR HIGH TEMPERATURE
WATER AND H2S REMOVED IN PREHEAT ZONE.
THE OVERALL HEAT OF REACTION IS -51.0 BTU/LB
DRY RAW SHALE @ 60.0 F

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

COOLING ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM C                          STREAM 1A
HOT SPENT SHALE                   PREHEATED RECYCLE GAS

 7027231.5 LBS/HR                 1138531.8 LBS/HR
    1000.0 F                          990.0 F
    270.92 BTU/LB                   1687.77 BTU/LB
  1903.798 MMBTU/HR                1921.578 MMBTU/HR

      V    ******************************    ^
      V           COOLING ZONE               ^
      V          HEAT EXCHANGED              ^
      V        1734.289 MMBTU/HR             ^
      V    ******************************    ^

STREAM D                             STREAM 1
COOL SPENT SHALE                     RECYCLE GAS

 7027231.5 LBS/HR                 1138531.8 LBS/HR
     163.2 F                          153.2 F
     24.12 BTU/LB                    164.50 BTU/LB
   169.509 MMBTU/HR                 187.289 MMBTU/HR
```

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

PREHEAT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 5		GAS MAKE		STREAM 6		
MOL WT	4.198				5.349		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	647.0	11656.6	28597.4	515188.6	29244.5	526845.3	6.706
H2	366731.4	739257.1	-3337.7	-6728.1	363393.7	732529.0	83.332
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	10608.9	297162.7	0.0	0.0	10608.9	297162.7	2.433
CO2	18.0	791.7	0.0	0.0	18.0	791.7	0.004
H2S	1.7	58.8	3337.7	113747.9	3339.4	113806.8	0.766
COS	59.1	3548.6	0.0	0.0	59.1	3548.6	0.014
NH3	5.8	99.4	0.0	0.0	5.8	99.4	0.001
CH4	22035.4	353509.6	0.0	0.0	22035.4	353509.6	5.053
C2H6	3718.5	111813.3	0.0	0.0	3718.5	111813.3	0.853
C2H4	435.7	12224.2	0.0	0.0	435.7	12224.2	0.100
C3H8	1302.6	57441.4	0.0	0.0	1302.6	57441.4	0.299
C3H6	603.4	25392.8	0.0	0.0	603.4	25392.8	0.138
C4H10	1076.2	62550.2	0.0	0.0	1076.2	62550.2	0.247
C4H8	86.5	4852.5	0.0	0.0	86.5	4852.5	0.020
C5+	150.7	30142.3	0.0	0.0	150.7	30142.3	0.035
TOTAL	407481.0	1710501.1	28597.4	622208.4	436078.4	2332709.6	100.000

RETORT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 3		GAS MAKE		STREAM 4		
MOL WT	4.198				5.116		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	860.4	15500.1	9414.2	169598.3	10274.6	185098.4	1.901
H2	487653.3	983011.5	-24207.6	-48797.7	463445.6	934213.7	85.765
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	14107.0	395145.8	0.0	0.0	14107.0	395145.8	2.611
CO2	23.9	1052.7	957.6	42142.0	981.5	43194.7	0.182
H2S	2.3	78.2	3337.7	113747.9	3340.0	113826.1	0.618
COS	78.5	4718.7	74.5	4473.4	153.0	9192.1	0.028
NH3	7.8	132.1	764.7	13023.8	772.5	13155.9	0.143
CH4	29301.1	470071.9	4455.8	71483.5	33756.9	541555.4	6.247
C2H6	4944.5	148681.4	1564.0	47028.8	6508.5	195710.1	1.204
C2H4	579.4	16254.9	156.4	4388.0	735.8	20643.0	0.136
C3H8	1732.1	76381.5	703.6	31026.0	2435.7	107407.5	0.451
C3H6	802.4	33765.6	312.8	13164.1	1115.2	46929.7	0.206
C4H10	1431.0	83174.8	1035.4	60181.9	2466.4	143356.7	0.456
C4H8	115.0	6452.5	156.4	8776.1	271.4	15228.6	0.050
TOTAL	541638.8	2234421.6	-1274.6	530236.1	540364.2	2764657.7	100.000

OIL DATA

OIL PRODUCTION : 724518.4 LB/HR
0.0859 LB OIL/LB DRY RAW SHALE

CHARACTERISTICS : API - 13.3
MBP - 561.0 F

CHEMICAL HYDROGEN CONSUMPTION

	SCF/TON*	SCF/BBL**
PREHEAT	299.67	597.24
RETORT	2173.44	4331.65
	2473.11	4928.89

* TON OF DRY RAW SHALE ENTERING PREHEAT ZONE
** BBL OF OIL PRODUCED IN RETORT ZONE

PRESSURE: 600.PSIA

PREHEAT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STREAM A				
DRY RAW SHALE	8431405.1	60.0	0.0	0.000
SHALE MOISTURE	472789.1	60.0	0.0	0.000
STREAM 5 (HOT RECY GAS)	1710501.1	710.0	1162.3	1988.190
TOTAL	10614695.3			1988.190
OUTLET STREAMS				
STRM B (PREHEATED SHALE)	8281985.7	700.0	133.0	1101.138
STRM 6 (WET RECYCLE GAS)	2332709.6	293.0	323.7	755.204
TOTAL	10614695.3			1856.342
INLET-OUTLET=	0.0			131.848
HEAT OF REACTION @ 60. F				
HIGH TEMPERATURE WATER	42399.6		1500.0	63.599
HYDROGEN SULFIDE	113747.9		600.0	68.249
TOTAL	156147.5		15.6	131.848

RETORT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
STRM 1A (HEATED RECY GAS)	1138531.8	990.0	1687.8	1921.578
STRM 2 (HOT RECYCLE GAS)	1135970.9	1030.0	1764.2	2004.066
TOTAL (STREAM 3)	2274502.7	1010.0		3925.643
INLET STREAMS				
STRM B (PREHEATED SHALE)	8281985.7	700.0	133.0	1101.138
STRM 3 (STREAMS 1A & 2)	2274502.7	1010.0	1725.9	3925.643
TOTAL	10556488.4			5026.781
OUTLET STREAMS				
STRM C (RETORTED SHALE)	7027231.5	1000.0	270.9	1903.798
STRM 4 (GAS & OIL PROD)				
GAS	2764657.7	849.2	1193.6	3299.966
OIL	764599.4	649.2	503.6	385.070
TOTAL	10556488.7			5588.833
INLET-OUTLET=	-0.3			-562.052
HEAT OF REACTION @ 60. F (BASED ON PREHEATED SHALE)	8281985.7		-67.8	-561.850

COOLING ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
*********************				
INLET STREAMS				
STRM C (RETORTED SHALE)	7027231.5	1000.0	270.9	1903.798
STRM 1 (WARM RECY GAS)	1138531.8	153.2	164.5	187.289
TOTAL	8165763.4			2091.087
OUTLET STREAMS				
STRM 1A (HEATED RECY GAS)	1138531.8	990.0	1687.8	1921.578
STRM D (SPENT SHALE)	7027231.5	163.2	24.1	169.509
TOTAL	8165763.4			2091.087
INLET-OUTLET=	0.0			0.000
HEAT TRANSFERRED IN COOLING ZONE				1734.289

DRAFT
12.02.87
12:45 AM

APPENDIX D

4. Retort Design for Beneficiated Kentucky New Albany Shale
(Low Sulfur)
Based on 87MBU-14

HYTORT RETORT CALCULATIONS
BASIS: HOUR
PRESSURE: 620.PSIA

DATE: 6/29/87
RUN: MBU14-87

```
 >>>>>>>>>>>>>V    >>>>>>>>>>>>>>>>>> WET RECYCLE GAS
 RAW SHALE    V    ^                     823853. LB
   (DRY)      V    ^                    280.F
 2496999. LB  V    ^                  SAT. TEMP. = 255. F
      60. F   V    ^                  MOLE % H2O = 5.3 %
 MOISTURE     V    ^  STREAM 6
 140019. LB   V    ^
              V    ^
 STREAM A     V    ^
           **********
HEAT OF    *        *
REACTION   * PREHEAT*
 6.89 BTU/LB *      *
 @ 60. F   **********
              V
              V    ^  5
              V    ^  710.F
              V    ^<<<<<<<<
 STREAM B     V          ^                                 758961. LB OIL
              V          ^                                 800143. LB GAS
              V    >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
     700.F    V    ^ 767.F ^
              V    ^       ^
              V    ^  4    ^
              V    ^       ^
              V    ^       ^
           **********      ^                             RECYCLE GAS
HEAT OF    *        *      ^                         V<<<<<
REACTION   * RETORT *      ^                         V     948133. LB
-58.27 BTU/LB *     *      ^                         V
 @ 60. F   **********      ^     ***                 V STREAM 9
              V    ^       ^     *.*     667293. LB  V
              V    ^ 3     ^<<<<<<<<<<<<<<<<<<<<<<<<<V
              V    ^  960.F   *    *       7         V
 STREAM C     V    ^         *    *                  V
              V    ^         *    *                  V
     950.F    V    ^   980.F *    *  280840. LB      V
              V    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
              V    ^      2  *    *      8
              V    ^         *    *                          OVERALL HEAT
              V    ^ 1A      *******                         OF REACTION
              V    ^  940.F                                   -51.0 BTU/LB
              V    ^                                         DRY RAW SHALE
           **********                                          @   60. F
           *        *
           * COOLING*
           *        *
           **********
              V    ^
 STREAM D     V    ^        STREAM 1
              V    ^                                    RECYCLE GAS
     <<<<<<<<      ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<  171. F
  SPENT SHALE                                           281516. LB
  1483709. LB
       181. F
```

PREHEAT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM A DRY RAW SHALE	STREAM 6 WET RECYCLE GAS
2496998.8 LBS/HR	823853.3 LBS/HR
60.0 F	280.3 F
0.00 BTU/LB	323.10 BTU/LB
0.000 MMBTU/HR	266.191 MMBTU/HR

```
V   ******************************   ^
V           PREHEAT ZONE             ^
V          OUTLET ENTHALPY           ^
V          STREAMS 6 AND B           ^
V         734.295 MMBTU/HR           ^
V   ******************************   ^
```

STREAM B PREHEATED SHALE	STREAM 5 HOT RECYCLE GAS
2480457.4 LBS/HR	667293.2 LBS/HR
700.0 F	710.0 F
188.71 BTU/LB	1126.17 BTU/LB
468.077 MMBTU/HR	751.488 MMBTU/HR

ADDITIONAL PREHEAT ZONE HEAT BALANCE DATA

STREAM A	HEATS OF REACTION	
SHALE MOISTURE	HIGH TEMP WATER	HYDROGEN SULFIDE
140018.6 LBS/HR	7704.9 LBS/HR	9392.1 LBS/HR
60.0 F	700.0 F	700.0 F
0.00 BTU/LB	1500.00 BTU/LB	600.00 BTU/LB
0.000 MMBTU/HR	11.557 MMBTU/HR	5.635 MMBTU/HR

HEAT OF REACTION - 6.89 BTU/LB
(PREHEAT ZONE) @ 60. F
(DRY RAW SHALE)

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

HYTORT RETORT CALCULATIONS DATE: 6/29/87
RUN: MBU14-87
PRESSURE: 620.PSIA

RETORT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM B RAW PREHEATED SHALE	STREAM 4 PRODUCT GAS	OIL
2480457.4 LBS/HR	800142.8 LBS/HR	758961.1 LBS/HR
700.0 F	767.5 F	767.5 F
188.71 BTU/LB	909.09 BTU/LB	458.80 BTU/LB
468.077 MMBTU/HR	727.398 MMBTU/HR	348.213 MMBTU/HR

V ****************************** ^
V RETORT ZONE ^
V HEAT OF REACTION ^
V -58.27 BTU/LB DRY PREHEATED ^
V SHALE @ 60.0 F ^
V -144.540 MMBTU/HR ^
V ****************************** ^

STREAM C HOT SPENT SHALE	STREAM 3 COMBINED RECYCYLE GAS
1483708.8 LBS/HR	562355.4 LBS/HR
950.0 F	960.0 F
286.86 BTU/LB	1580.17 BTU/LB
425.613 MMBTU/HR	888.618 MMBTU/HR

^ STREAM 2
^ HOT RECYCLE GAS
^
^<<<<<<<< 280839.7 LBS/HR
^ 980.0 F
^ 1617.1 BTU/LB
^ 454.142 MMBTU/HR

STREAM 1A
PREHEATED RECYCLE GAS

281515.7 LBS/HR
940.0 F
1543.35 BTU/LB
434.476 MMBTU/HR

NOTE-HEAT OF REACTION CORRECTED FOR HIGH TEMPERATURE
WATER AND H2S REMOVED IN PREHEAT ZONE.
THE OVERALL HEAT OF REACTION IS -51.0 BTU/LB
DRY RAW SHALE @ 60.0 F

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

COOLING ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM C                           STREAM 1A
HOT SPENT SHALE                    PREHEATED RECYCLE GAS

 1483708.8 LBS/HR                   281515.7 LBS/HR
     950.0 F                           940.0 F
    286.86 BTU/LB                    1543.35 BTU/LB
   425.613 MMBTU/HR                  434.476 MMBTU/HR

     V    ****************************    ^
     V          COOLING ZONE              ^
     V        HEAT EXCHANGED              ^
     V       380.393 MMBTU/HR             ^
     V    ****************************    ^

STREAM D                              STREAM 1
COOL SPENT SHALE                      RECYCLE GAS

 1483708.8 LBS/HR                   281515.7 LBS/HR
     180.8 F                           170.8 F
     30.48 BTU/LB                     192.11 BTU/LB
    45.220 MMBTU/HR                   54.083 MMBTU/HR
```

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

PREHEAT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 5		GAS MAKE		STREAM 6		
MOL WT	4.397				5.150		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	200.6	3613.4	8199.9	147723.5	8400.5	151336.9	5.252
H2	136585.2	275328.4	-275.6	-555.5	136309.6	274772.9	85.214
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	4066.3	113900.2	0.0	0.0	4066.3	113900.2	2.542
CO2	5.4	239.4	0.0	0.0	5.4	239.4	0.003
H2S	0.5	16.9	275.6	9392.1	276.1	9409.0	0.173
COS	3.7	219.7	0.0	0.0	3.7	219.7	0.002
NH3	1.6	26.5	0.0	0.0	1.6	26.5	0.001
CH4	7566.5	121387.5	0.0	0.0	7566.5	121387.5	4.730
C2H6	1543.5	46414.1	0.0	0.0	1543.5	46414.1	0.965
C2H4	183.2	5140.5	0.0	0.0	183.2	5140.5	0.115
C3H8	603.2	26597.8	0.0	0.0	603.2	26597.8	0.377
C3H6	269.5	11341.9	0.0	0.0	269.5	11341.9	0.168
C4H10	500.8	29105.9	0.0	0.0	500.8	29105.9	0.313
C4H8	86.4	4847.7	0.0	0.0	86.4	4847.7	0.054
C5+	145.6	29113.2	0.0	0.0	145.6	29113.2	0.091
TOTAL	151761.9	667293.2	8199.9	156560.1	159961.8	823853.3	100.000

RETORT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 3		GAS MAKE		STREAM 4		
MOL WT	4.397				6.386		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	169.0	3045.2	1710.7	30819.5	1879.8	33864.7	1.500
H2	115105.9	232030.6	-13249.2	-26707.7	101856.8	205322.9	81.288
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	3426.9	95988.4	251.2	7036.7	3678.1	103025.1	2.935
CO2	4.6	201.8	518.6	22821.8	523.1	23023.5	0.418
H2S	0.4	14.2	275.6	9392.1	276.0	9406.4	0.220
COS	3.1	185.2	6.7	403.8	9.8	588.9	0.008
NH3	1.3	22.3	285.9	4868.9	287.2	4891.2	0.229
CH4	6376.6	102298.2	4144.8	66494.7	10521.4	168792.9	8.397
C2H6	1300.8	39115.0	1492.5	44878.6	2793.3	83993.7	2.229
C2H4	154.4	4332.1	165.6	4646.3	320.0	8978.4	0.255
C3H8	508.3	22415.1	663.0	29234.6	1171.3	51649.7	0.935
C3H6	227.1	9558.3	290.3	12214.4	517.4	21772.6	0.413
C4H10	422.0	24528.7	767.1	44586.3	1189.1	69115.0	0.949
C4H8	72.8	4085.4	207.3	11632.4	280.1	15717.8	0.224
TOTAL	127773.3	537820.5	-2469.9	262322.4	125303.5	800142.8	100.000

OIL DATA

OIL PRODUCTION : 734426.2 LB/HR
0.2941 LB OIL/LB DRY RAW SHALE

CHARACTERISTICS : API - 14.5
MBP - 554.0 F

CHEMICAL HYDROGEN CONSUMPTION

	SCF/TON*	SCF/BBL**
PREHEAT	83.55	48.25
RETORT	4016.67	2319.56
	4100.22	2367.81

* TON OF DRY RAW SHALE ENTERING PREHEAT ZONE
** BBL OF OIL PRODUCED IN RETORT ZONE

PRESSURE: 620.PSIA

PREHEAT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STREAM A				
DRY RAW SHALE	2496998.8	60.0	0.0	0.000
SHALE MOISTURE	140018.6	60.0	0.0	0.000
STREAM 5 (HOT RECY GAS)	667293.2	710.0	1126.2	751.488
TOTAL	3304310.6			751.488
OUTLET STREAMS				
STRM B (PREHEATED SHALE)	2480457.4	700.0	188.7	468.077
STRM 6 (WET RECYCLE GAS)	823853.3	280.3	323.1	266.191
TOTAL	3304310.6			734.268
INLET-OUTLET=	0.0			17.220
HEAT OF REACTION @ 60. F				
HIGH TEMPERATURE WATER	7704.9		1500.0	11.557
HYDROGEN SULFIDE	9392.1		600.0	5.635
TOTAL	17097.0		6.9	17.193

RETORT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
STRM 1A (HEATED RECY GAS)	281515.7	940.0	1543.3	434.476
STRM 2 (HOT RECYCLE GAS)	280839.7	980.0	1617.1	454.142
TOTAL (STREAM 3)	562355.4	960.0		888.618
INLET STREAMS				
STRM B (PREHEATED SHALE)	2480457.4	700.0	188.7	468.077
STRM 3 (STREAMS 1A & 2)	562355.4	960.0	1580.2	888.618
TOTAL	3042812.8			1356.695
OUTLET STREAMS				
STRM C (RETORTED SHALE)	1483708.8	950.0	286.9	425.613
STRM 4 (GAS & OIL PROD)				
GAS	800142.8	767.5	909.1	727.398
OIL	758961.1	767.5	458.8	348.213
TOTAL	3042812.7			1501.224
INLET-OUTLET=	0.1			-144.529
HEAT OF REACTION @ 60. F (BASED ON PREHEATED SHALE)	2480457.4		-58.3	-144.540

COOLING ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STRM C (RETORTED SHALE)	1483708.8	950.0	286.9	425.613
STRM 1 (WARM RECY GAS)	281515.7	170.8	192.1	54.083
TOTAL	1765224.5			479.696
OUTLET STREAMS				
STRM 1A (HEATED RECY GAS)	281515.7	940.0	1543.3	434.476
STRM D (SPENT SHALE)	1483708.8	180.8	30.5	45.220
TOTAL	1765224.5			479.696
INLET-OUTLET=	0.0			0.000
HEAT TRANSFERRED IN COOLING ZONE				380.393

DRAFT
12.02.87
12:45 AM

APPENDIX D

5. Retort Design for Beneficiated Kentucky New Albany Shale
(High Sulfur)
Based on 87MBU-015

```
                           HYTORT RETORT CALCULATIONS        DATE: 7/02/87
                          BASIS: HOUR                       RUN: MBU15-87
                          PRESSURE:  620.PSIA

    >>>>>>>>>>>>>V   >>>>>>>>>>>>>>>>>> WET RECYCLE GAS
    RAW SHALE    V   ^                   1264191. LB
      (DRY)      V   ^                   287.F
   3979327. LB   V   ^                 SAT. TEMP. = 262. F
        60. F    V   ^                 MOLE % H2O = 5.9 %
    MOISTURE     V   ^  STREAM 6
    223140. LB   V   ^
                 V   ^
    STREAM A     V   ^
              **********
 HEAT OF      *        *
 REACTION     * PREHEAT*
 16.14 BTU/LB *        *
     @ 60. F  **********
                 V   ^
                 V   ^  5
                 V   ^  710.F
                 V   ^<<<<<<<<<
    STREAM B     V            ^                            760191. LB OIL
                 V            ^                           1337740. LB GAS
                 V   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
        700.F    V   ^ 809.F  ^
                 V   ^        ^
                 V   ^  4     ^
                 V   ^        ^
                 V   ^        ^
              **********      ^                           RECYCLE GAS
 HEAT OF      *        *      ^                     V<<<<<
 REACTION     * RETORT *      ^                     V     1459353. LB
-68.33 BTU/LB *        *      ^     .               V
     @ 60. F  **********      ^   ***               V STREAM 9
                 V   ^        ^   *.*     972276. LB V
                 V   ^ 3      ^<<<<<<<<<<<<<<<<<<<<<V
                 V   ^  960.F    *   *     7        V
    STREAM C     V   ^          *     *             V
                 V   ^          *     *             V
        950.F    V   ^   980.F  *     *  487076. LB V
                 V   ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
                 V   ^        2 *     *    8
                 V   ^          *     *                    OVERALL HEAT
                 V   ^ 1A       *******                    OF REACTION
                 V   ^  940.F                               -51.0 BTU/LB
                 V   ^                                     DRY RAW SHALE
              **********                                     @ 60. F
              *        *
              * COOLING*
              *        *
              **********
                 V   ^
    STREAM D     V   ^        STREAM 1
                 V   ^                                RECYCLE GAS
         <<<<<<<<    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< 164. F
      SPENT SHALE                                     488202. LB
      2787900. LB
          174. F
```

PREHEAT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
   STREAM A                     STREAM 6
   DRY RAW SHALE                WET RECYCLE GAS

  3979327.0 LBS/HR           1264190.6 LBS/HR
       60.0 F                    287.3 F
       0.00 BTU/LB              319.85 BTU/LB
      0.000 MMBTU/HR           404.348 MMBTU/HR

     V    ****************************    ^
     V           PREHEAT ZONE             ^
     V         OUTLET ENTHALPY            ^
     V         STREAMS 6 AND B            ^
     V       1035.247 MMBTU/HR            ^
     V    ****************************    ^

   STREAM B                     STREAM 5
   PREHEATED SHALE              HOT RECYCLE GAS

  3910552.5 LBS/HR            972276.2 LBS/HR
      700.0 F                    710.0 F
     161.33 BTU/LB             1130.84 BTU/LB
    630.898 MMBTU/HR          1099.490 MMBTU/HR
```

ADDITIONAL PREHEAT ZONE HEAT BALANCE DATA

```
   STREAM A                        HEATS OF REACTION
   SHALE MOISTURE             HIGH TEMP WATER     HYDROGEN SULFIDE

  223139.8 LBS/HR            23640.5 LBS/HR       47971.5 LBS/HR
      60.0 F                   700.0 F              700.0 F
      0.00 BTU/LB            1500.00 BTU/LB        600.00 BTU/LB
     0.000 MMBTU/HR           35.461 MMBTU/HR      28.783 MMBTU/HR

                        HEAT OF REACTION - 16.14 BTU/LB
                         (PREHEAT ZONE)       @ 60. F
                                            (DRY RAW SHALE)
```

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

HYTORT RETORT CALCULATIONS   DATE: 7/02/87
RUN: MBU15-87
PRESSURE: 620.PSIA

RETORT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM B                                        STREAM 4
RAW PREHEATED SHALE            PRODUCT GAS                     OIL

 3910552.5 LBS/HR          1337740.1 LBS/HR      760190.5 LBS/HR
     700.0 F                   809.1 F              809.1 F
    161.33 BTU/LB             996.74 BTU/LB        482.24 BTU/LB
   630.898 MMBTU/HR         1333.376 MMBTU/HR     366.594 MMBTU/HR

     V   ****************************    ^
     V          RETORT ZONE              ^
     V        HEAT OF REACTION           ^
     V   -68.33 BTU/LB DRY PREHEATED     ^
     V         SHALE @  60.0 F           ^
     V        -267.189 MMBTU/HR          ^
     V   ****************************    ^

STREAM C                  STREAM 3
HOT SPENT SHALE           COMBINED RECYCYLE GAS

 2787900.0 LBS/HR           975278.0 LBS/HR
     950.0 F                   960.0 F
    267.37 BTU/LB            1586.37 BTU/LB
   745.396 MMBTU/HR         1547.155 MMBTU/HR

                                 ^      STREAM 2
                                 ^      HOT RECYCLE GAS
                                 ^
                                 ^<<<<<<<<  487076.3 LBS/HR
                                 ^               980.0 F
                                 ^              1623.4 BTU/LB
                                 ^             790.713 MMBTU/HR
                          STREAM 1A
                          PREHEATED RECYCLE GAS

                            488201.6 LBS/HR
                               940.0 F
                             1549.44 BTU/LB
                             756.441 MMBTU/HR
```

NOTE-HEAT OF REACTION CORRECTED FOR HIGH TEMPERATURE
WATER AND H2S REMOVED IN PREHEAT ZONE.
THE OVERALL HEAT OF REACTION IS -51.0 BTU/LB
DRY RAW SHALE @ 60.0 F

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

COOLING ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM C HOT SPENT SHALE	STREAM 1A PREHEATED RECYCLE GAS
2787900.0 LBS/HR	488201.6 LBS/HR
950.0 F	940.0 F
267.37 BTU/LB	1549.44 BTU/LB
745.396 MMBTU/HR	756.441 MMBTU/HR

```
V   ******************************   ^
V          COOLING ZONE              ^
V        HEAT EXCHANGED              ^
V       668.821 MMBTU/HR             ^
V   ******************************   ^
```

STREAM D COOL SPENT SHALE	STREAM 1 RECYCLE GAS
2787900.0 LBS/HR	488201.6 LBS/HR
173.7 F	163.7 F
27.47 BTU/LB	179.48 BTU/LB
76.575 MMBTU/HR	87.621 MMBTU/HR

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

PREHEAT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 5		GAS MAKE		STREAM 6		
MOL WT	4.345				5.324		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	317.3	5716.7	13698.5	246780.4	14015.8	252497.1	5.902
H2	201388.2	405958.3	-1407.6	-2837.5	199980.6	403120.8	84.215
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	6385.6	178863.1	0.0	0.0	6385.6	178863.1	2.689
CO2	8.8	386.8	0.0	0.0	8.8	386.8	0.004
H2S	0.8	27.9	1407.6	47971.5	1408.4	47999.3	0.593
COS	22.8	1366.9	0.0	0.0	22.8	1366.9	0.010
NH3	1.5	26.4	0.0	0.0	1.5	26.4	0.001
CH4	11060.7	177445.1	0.0	0.0	11060.7	177445.1	4.658
C2H6	2001.1	60172.2	0.0	0.0	2001.1	60172.2	0.843
C2H4	405.2	11366.9	0.0	0 0	405.2	11366.9	0.171
C3H8	759.9	33511.2	0.0	0.0	759.9	33511.2	0.320
C3H6	325.0	13674.7	0.0	0.0	325.0	13674.7	0.137
C4H10	454.8	26432.0	0.0	0.0	454.8	26432.0	0.192
C4H8	483.0	27100.0	0.0	0.0	483.0	27100.0	0.203
C5+	151.1	30228.0	0.0	0.0	151.1	30228.0	0.064
TOTAL	223765.8	972276.2	13698.5	291914.4	237464.2	1264190.6	100.000

2444 HYCRUDE CORPORATION

BENEFICIATION- HYDRORETORTING OF U.S. OIL SHALES PROGRAM YEAR 2

RETORT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 3		GAS MAKE		STREAM 4		
MOL WT	4.345				6.014		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	318.3	5734.4	5249.0	94562.2	5567.3	100296.6	2.503
H2	202009.9	407211.6	-18039.2	-36363.5	183970.7	370848.1	82.705
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	6405.3	179415.4	239.7	6714.9	6645.0	186130.2	2.987
CO2	8.8	388.0	569.8	25078.0	578.6	25466.0	0.260
H2S	0.8	27.9	1407.6	47971.5	1408.4	47999.4	0.633
COS	22.8	1371.1	35.5	2131.4	58.3	3502.5	0.026
NH3	1.6	26.4	243.0	4138.4	244.6	4164.8	0.110
CH4	11094.9	177993.0	4222.5	67740.3	15317.4	245733.3	6.886
C2H6	2007.3	60358.0	1442.7	43382.0	3450.0	103740.0	1.551
C2H4	406.4	11402.0	267.4	7501.5	673.8	18903.5	0.303
C3H8	762.3	33614.7	641.7	28297.5	1404.0	61912.2	0.631
C3H6	326.0	13716.9	267.4	11252.3	593.4	24969.2	0.267
C4H10	456.2	26513.6	574.4	33386.3	1030.6	59899.9	0.463
C4H8	484.5	27183.7	1015.7	56990.7	1500.2	84174.4	0.674
TOTAL	224305.0	944956.7	-1862.7	392783.4	222442.3	1337740.1	100.000

OIL DATA

OIL PRODUCTION : 729869.2 LB/HR
0.1834 LB OIL/LB DRY RAW SHALE

CHARACTERISTICS : API - 14.1
MBP - 559.0 F

CHEMICAL HYDROGEN CONSUMPTION

	SCF/TON*	SCF/BBL**
PREHEAT	267.78	248.66
RETORT	3431.66	3186.62
	3699.44	3435.28

* TON OF DRY RAW SHALE ENTERING PREHEAT ZONE
** BBL OF OIL PRODUCED IN RETORT ZONE

PRESSURE: 620.PSIA

PREHEAT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STREAM A				
DRY RAW SHALE	3979327.0	60.0	0.0	0.000
SHALE MOISTURE	223139.8	60.0	0.0	0.000
STREAM 5 (HOT RECY GAS)	972276.2	710.0	1130.8	1099.490
TOTAL	5174743.1			1099.490
OUTLET STREAMS				
STRM B (PREHEATED SHALE)	3910552.5	700.0	161.3	630.898
STRM 6 (WET RECYCLE GAS)	1264190.6	287.3	319.8	404.348
TOTAL	5174743.1			1035.247
INLET-OUTLET=	0.0			64.244
HEAT OF REACTION @ 60. F				
HIGH TEMPERATURE WATER	23640.5		1500.0	35.461
HYDROGEN SULFIDE	47971.5		600.0	28.783
TOTAL	71612.0		16.1	64.244

RETORT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
STRM 1A (HEATED RECY GAS)	488201.6	940.0	1549.4	756.441
STRM 2 (HOT RECYCLE GAS)	487076.3	980.0	1623.4	790.713
TOTAL (STREAM 3)	975278 0	960.0		1547.155
INLET STREAMS				
STRM B (PREHEATED SHALE)	3910552.5	700.0	161.3	630.898
STRM 3 (STREAMS 1A & 2)	975278.0	960.0	1586.4	1547.155
TOTAL	4885830.5			2178.053
OUTLET STREAMS				
STRM C (RETORTED SHALE)	2787900.0	950.0	267.4	745.396
STRM 4 (GAS & OIL PROD)				
GAS	1337740.1	809.1	996.7	1333.376
OIL	780190.5	809.1	462.2	366.594
TOTAL	4885830.6			2445.367
INLET-OUTLET=	-0.1			-267.314
HEAT OF REACTION @ 60. F (BASED ON PREHEATED SHALE)	3910552.5		-68.3	-267.189

COOLING ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
********************				
INLET STREAMS				
STRM C (RETORTED SHALE)	2787900.0	950.0	267.4	745.396
STRM 1 (WARM RECY GAS)	488201.6	163.7	179.5	87.621
TOTAL	3276101.6			833.017
OUTLET STREAMS				
STRM 1A (HEATED RECY GAS)	488201.6	940.0	1549.4	756.441
STRM D (SPENT SHALE)	2787900.0	173.7	27.5	76.575
TOTAL	3276101.6			833.017
INLET-OUTLET=	0.0			0.000
HEAT TRANSFERRED IN COOLING ZONE				668.821

DRAFT
12.02.87
12:45 AM

APPENDIX D

6. Retort Design for Beneficiated Alabama Shale
(Low Sulfur)
Based on 87MBU-20

```
                           HYTORT RETORT CALCULATIONS       DATE: 9/28/87
                          BASIS: HOUR                      RUN: MBU20-87
                          PRESSURE:  620.PSIA

    >>>>>>>>>>>>V    >>>>>>>>>>>>>>>>> WET RECYCLE GAS
    RAW SHALE   V    ^                   1131331. LB
      (DRY)     V    ^                   283.F
   3340549. LB  V    ^                 SAT. TEMP. = 258. F
        60. F   V    ^                 MOLE % H2O = 5.5 %
    MOISTURE    V    ^  STREAM 6
    187320. LB  V    ^
                V    ^
    STREAM A    V    ^
              ***********
 HEAT OF      *         *
 REACTION     * PREHEAT*
 18.41 BTU/LB *         *
    @ 60. F   ***********
                V    ^
                V    ^  5
                V    ^  710.F
                V    ^<<<<<<<<<
    STREAM B    V            ^                             761216. LB OIL
                V            ^                            1208454. LB GAS
                V    >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
        700.F   V    ^ 812.F ^
                V    ^       ^
                V    ^  4    ^
                V    ^       ^
                V    ^       ^
              ***********    ^                            RECYCLE GAS
 HEAT OF      *         *    ^                      V<<<<<
 REACTION     * RETORT  *    ^                      V     1281565. LB
-70.76 BTU/LB *         *    ^     .                V
    @ 60. F   ***********    ^    ***               V STREAM 9
                V    ^       ^    *.*    880519. LB V
                V    ^ 3     ^<<<<<<<<<<<<<<<<<<<<<<V
                V    ^  960.F    *   *     7        V
    STREAM C    V    ^          *     *             V
                V    ^          *     *             V
        950.F   V    ^   980.F  *     *  401046. LB V
                V    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
                V    ^       2  *     *    8
                V    ^          *     *                    OVERALL HEAT
                V    ^ 1A       *******                    OF REACTION
                V    ^  940.F                               -51.0 BTU/LB
                V    ^                                     DRY RAW SHALE
              ***********                                   @  60. F
              *         *
              * COOLING*
              *         *
              ***********
                V    ^
    STREAM D    V    ^        STREAM 1
                V    ^                                RECYCLE GAS
         <<<<<<<<    ^<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< 175. F
      SPENT SHALE                                      401993. LB
      2110426. LB
          185. F
```

PREHEAT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM A DRY RAW SHALE	STREAM 6 WET RECYCLE GAS
3340548.8 LBS/HR	1131331.4 LBS/HR
60.0 F	282.9 F
0.00 BTU/LB	323.38 BTU/LB
0.000 MMBTU/HR	365.853 MMBTU/HR

```
V  ****************************  ^
V          PREHEAT ZONE          ^
V        OUTLET ENTHALPY         ^
V       STREAMS 6 AND B          ^
V      958.632 MMBTU/HR          ^
V  ****************************  ^
```

STREAM B PREHEATED SHALE	STREAM 5 HOT RECYCLE GAS
3277056.6 LBS/HR	880518.7 LBS/HR
700.0 F	710.0 F
180.89 BTU/LB	1158.57 BTU/LB
592.779 MMBTU/HR	1020.142 MMBTU/HR

ADDITIONAL PREHEAT ZONE HEAT BALANCE DATA

STREAM A	HEATS OF REACTION	
SHALE MOISTURE	HIGH TEMP WATER	HYDROGEN SULFIDE
187320.5 LBS/HR	24376.5 LBS/HR	41574.8 LBS/HR
60.0 F	700.0 F	700.0 F
0.00 BTU/LB	1500.00 BTU/LB	600.00 BTU/LB
0.000 MMBTU/HR	36.565 MMBTU/HR	24.945 MMBTU/HR

HEAT OF REACTION - 18.41 BTU/LB
(PREHEAT ZONE) @ 60. F
(DRY RAW SHALE)

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

HYTORT RETORT CALCULATIONS DATE: 9/28/87
RUN: MBU20-87
PRESSURE: 620.PSIA

RETORT ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

```
STREAM B                                      STREAM 4
RAW PREHEATED SHALE          PRODUCT GAS                 OIL

 3277056.6 LBS/HR         1208453.8 LBS/HR     761215.9 LBS/HR
     700.0 F                  812.2 F             812.2 F
    180.89 BTU/LB            943.22 BTU/LB       481.07 BTU/LB
   592.779 MMBTU/HR        1139.839 MMBTU/HR    366.199 MMBTU/HR

    V   ******************************   ^
    V          RETORT ZONE               ^
    V        HEAT OF REACTION            ^
    V    -70.76 BTU/LB DRY PREHEATED     ^
    V         SHALE @  60.0 F            ^
    V        -231.878 MMBTU/HR           ^
    V   ******************************   ^

STREAM C                 STREAM 3
HOT SPENT SHALE          COMBINED RECYCYLE GAS

 2110426.4 LBS/HR           803039.6 LBS/HR
     950.0 F                   960.0 F
    295.85 BTU/LB            1625.93 BTU/LB
   624.377 MMBTU/HR         1305.686 MMBTU/HR

                                 ^         STREAM 2
                                 ^         HOT RECYCLE GAS
                                 ^
                                 ^<<<<<<<<<  401046.2 LBS/HR
                                 ^                 980.0 F
                                 ^                1663.9 BTU/LB
                                 ^              667.308 MMBTU/HR
                         STREAM 1A
                         PREHEATED RECYCLE GAS

                           401993.3 LBS/HR
                              940.0 F
                            1588.03 BTU/LB
                            638.378 MMBTU/HR
```

NOTE-HEAT OF REACTION CORRECTED FOR HIGH TEMPERATURE
WATER AND H2S REMOVED IN PREHEAT ZONE.
THE OVERALL HEAT OF REACTION IS -51.0 BTU/LB
DRY RAW SHALE @ 60.0 F

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

COOLING ZONE SCHEMATIC
HEAT AND MATERIAL BALANCE

STREAM C HOT SPENT SHALE	STREAM 1A PREHEATED RECYCLE GAS
2110426.4 LBS/HR	401993.3 LBS/HR
950.0 F	940.0 F
295.85 BTU/LB	1588.03 BTU/LB
624.377 MMBTU/HR	638.378 MMBTU/HR

```
V   ****************************   ^
V          COOLING ZONE            ^
V         HEAT EXCHANGED           ^
V        556.659 MMBTU/HR          ^
V   ****************************   ^
```

STREAM D COOL SPENT SHALE	STREAM 1 RECYCLE GAS
2110426.4 LBS/HR	401993.3 LBS/HR
185.1 F	175.1 F
32.09 BTU/LB	203.28 BTU/LB
67.718 MMBTU/HR	81.719 MMBTU/HR

*NOTE. SEE PAGE 7 OF THIS REPORT FOR ITEMIZED LISTING OF STREAMS

PREHEAT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 5		GAS MAKE		STREAM 6		
MOL WT	4.247				5.164		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	275.9	4971.1	11751.0	211697.0	12027.0	216668.1	5.489
H2	186613.5	376175.5	-1219.9	-2459.1	185393.6	373716.4	84.617
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	4757.4	133257.9	0.0	0.0	4757.4	133257.9	2.171
CO2	7.2	316.6	0.0	0.0	7.2	316.6	0.003
H2S	0.6	21.5	1219.9	41574.8	1220.6	41596.3	0.557
COS	19.6	1177.6	0.0	0.0	19.6	1177.6	0.009
NH3	1.3	21.9	0.0	0.0	1.3	21.9	0.001
CH4	11386.6	182673.1	0.0	0.0	11386.6	182673.1	5.197
C2H6	2171.9	65308.1	0.0	0.0	2171.9	65308.1	0.991
C2H4	318.6	8938.4	0.0	0.0	318.6	8938.4	0.145
C3H8	731.1	32240.9	0.0	0.0	731.1	32240.9	0.334
C3H6	304.6	12819.1	0.0	0.0	304.6	12819.1	0.139
C4H10	530.7	30843.5	0.0	0.0	530.7	30843.5	0.242
C4H8	95.7	5367.2	0.0	0.0	95.7	5367.2	0.044
C5+	131.9	26386.4	0.0	0.0	131.9	26386.4	0.060
TOTAL	207346.7	880518.7	11751.0	250812.7	219097.7	1131331.4	100.000

HYTORT RETORT CALCULATIONS   DATE: 9/28/87
RUN: MBU20-87
PRESSURE: 620.PSIA

RETORT ZONE
HEAT AND MATERIAL BALANCE

	STREAM 3		GAS MAKE		STREAM 4		
MOL WT	4.247				6 600		
COMP	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL/HR	LBS/HR	MOL %
H2O	251.7	4533.6	5412.4	97506.2	5664.1	102039.8	3.094
H2	170192.9	343074.8	-25489.9	-51382.6	144703.0	291692.2	79.033
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.000
CO	4338.8	121532.2	0.0	0.0	4338.8	121532.2	2.370
CO2	6.6	288.7	151.2	6655.6	157.8	6944.3	0.086
H2S	0.6	19.6	1219.9	41574.8	1220.5	41594.4	0.667
COS	17.9	1074.0	41.6	2502.0	59.5	3575.9	0.033
NH3	1.2	20.0	198.7	3384.2	199.9	3404.2	0.109
CH4	10384.7	166599.2	7124.9	114303.7	17509.6	280902.9	9.563
C2H6	1980.8	59561.4	2535.3	76234.7	4516.0	135796.1	2.467
C2H4	290.6	8151.9	349.8	9813.0	640.4	17964.9	0.350
C3H8	666.8	29403.9	961.6	42402.5	1628.4	71806.5	0.889
C3H6	277.8	11691.1	393.3	16549.6	671.1	28240.7	0.367
C4H10	484.0	28129.5	950.0	55219.2	1434.0	83348.7	0.783
C4H8	87.2	4894.9	262.3	14716.0	349.5	19610.9	0.191
TOTAL	188981.4	778974.9	-5888.8	429478.9	183092.5	1208453.8	100.000

OIL DATA

OIL PRODUCTION : 737151.3 LB/HR
0.2207 LB OIL/LB DRY RAW SHALE

CHARACTERISTICS : API - 14.5
MBP - 520.0 F

CHEMICAL HYDROGEN CONSUMPTION

	SCF/TON*	SCF/BBL**
PREHEAT	276.45	212.79
RETORT	5776.26	4446.09
	6052.70	4658.87

* TON OF DRY RAW SHALE ENTERING PREHEAT ZONE
** BBL OF OIL PRODUCED IN RETORT ZONE

PRESSURE: 820.PSIA

PREHEAT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STREAM A				
DRY RAW SHALE	3340548.6	60.0	0.0	0.000
SHALE MOISTURE	187320.5	60.0	0.0	0.000
STREAM 5 (HOT RECY GAS)	880518.7	710.0	1158.6	1020.142
TOTAL	4408388.1			1020.142
OUTLET STREAMS				
STRM B (PREHEATED SHALE)	3277056.6	700.0	180.9	592.779
STRM 8 (WET RECYCLE GAS)	1131331.4	282.9	323.4	365.853
TOTAL	4408388.1			958.632
INLET-OUTLET=	0.0			61.510
HEAT OF REACTION @ 80. F				
HIGH TEMPERATURE WATER	24376.5		1500.0	36.565
HYDROGEN SULFIDE	41574.8		600.0	24.945
TOTAL	65951.3		18.4	61.510

RETORT ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
STRM 1A (HEATED RECY GAS)	401993.3	940.0	1588.0	638.378
STRM 2 (HOT RECYCLE GAS)	401046.2	980.0	1663.9	667.308
TOTAL (STREAM 3)	803039.6	960.0		1305.686
INLET STREAMS				
STRM B (PREHEATED SHALE)	3277056.6	700.0	180.9	592.779
STRM 3 (STREAMS 1A & 2)	803039.6	960.0	1625.9	1305.686
TOTAL	4080096.2			1898.466
OUTLET STREAMS				
STRM C (RETORTED SHALE)	2110426.4	950.0	295.9	624.377
STRM 4 (GAS & OIL PROD)				
GAS	1208453.8	812.2	943.2	1139.839
OIL	761215.9	812.2	481.1	366.199
TOTAL	4080096.2			2130.415
INLET-OUTLET=	0.0			-231.950
HEAT OF REACTION @ 80. F (BASED ON PREHEATED SHALE)	3277056.6		-70.8	-231.878

COOLING ZONE	LB/HR	DEG F	BTU/LB	MMBTU/HR
INLET STREAMS				
STRM C (RETORTED SHALE)	2110426.4	950.0	295.9	624.377
STRM 1 (WARM RECY GAS)	401993.3	175.1	203.3	81.719
TOTAL	2512419.8			706.096
OUTLET STREAMS				
STRM 1A (HEATED RECY GAS)	401993.3	940.0	1588.0	638.378
STRM D (SPENT SHALE)	2110426.4	185.1	32.1	67.718
TOTAL	2512419.8			706.096
INLET-OUTLET=	0.0			0.000
HEAT TRANSFERRED IN COOLING ZONE				556.659

END OF PAPER