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MINIMUM BED PARAMETERS FOR IN SITU
PROCESSING OF OIL SHALE

FIRST QUARTERLY REPORT
OCTOBER 1 THRU DECEMBER 31, 1979

MASTER

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First Quarterly Report
October 1 thru December 31, 1979

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Introduction and Summary

This document is the first in a series of quarterly reports on the Minimum Bed Parameters for In Situ Processing of Oil Shale Program (FE Control No. 4-79 ET 14165.000). It describes activities during the period October 1, 1979 to December 31, 1979. In addition, because this is the first quarterly report on this program, an appendix has been included which summarizes previous work done in this area by Sandia National Laboratories.

In situ processing of oil shale, because of its limited mining and surface processing and potentially high resource utilization, offers an attractive alternative to surface processing. On a large commercial scale, however, the mining and surface processing requirements and associated costs of even the front running in situ technology, modified in situ (15-30% void), are large. To minimize the costs and environmental impact associated with this material removal, it is extremely important to determine the minimum conditions (of void, permeability, etc.) actually required for a viable in situ process. Investigation of this problem is being accomplished through an integrated program of laboratory studies and mathematical modeling.

The laboratory program this quarter centered around design, fabrication, and initial testing of a new retort vessel and system. The retort can accommodate cores of shale 7.6 cm in diameter by 36 cm long in a number of low-void configurations. The first tests of the system used a core of shale drilled with seven holes in a hexagonal pattern (11% void) to provide flow paths.

Model calculations were made with Sandia's block retorting code in this geometry to determine the most appropriate operating conditions for the run. The calculated yield for the conditions chosen was around 90% FA, with most of the loss due to oil combustion.

The ignition heater design (coiled electric heaters atop core) used in the first attempt to ignite the sample was unsatisfactory, and, as a result, sustained combustion was not achieved. Only a portion of the sample was damaged during that attempt, however, and another attempt to light the same sample will be made in the near future with a newly-developed gas heating system.

Activities

October 1979 - December 1979

A laboratory retort vessel, to allow combustion retorting of 7.6-cm diameter by 36-cm long cylinders of shale in various configurations, has been designed and fabricated. See Figure 1. The retort consists of the oil shale sample sealed in a low-thermal-conductivity castable ceramic inside a thin-walled stainless steel inner liner (10 cm diameter). This assembly is sealed with a silicon sealant/teflon gasket arrangement to the retort bottom plate (to assure that all gas flow is through the sample) and then insulated inside a steel outer vessel. The bottom plate contains ports for gas and product collection as well as for instrumentation (thermocouples). The retort top plate seals the vessel and contains ports for inlet gas flow and electric heaters. The retort can be ignited either with these electric heaters on top of the shale or with hot gas.

Two basic sample geometries will be used in this vessel. One consists of a solid cylinder of shale with one or more axial holes to provide the flow paths. (See Figure 2.) Seven holes (Between 0.6 and 1.2 cm in diameter) will provide an overall void of 5 to 20%. The inner hole in this geometry is additionally insulated by the symmetry of the pattern. The second geometry (Figure 3) consists of competent slices of an axially-sectioned cylinder of shale spaced to the original cylinder diameter with thin zones of rubble. Three rubble sections (~ 50% void) with thickness varying from 0.3 to 0.6 cm will provide an overall void range of 7 to 15%.

Figure 4 shows the retort system schematically. Flow into the retort of the inlet gases (air, N_2 , and CO_2) is individually controlled. A series of cooled condenser/demisters and filters are used to remove condensibles from the product gas stream, which is then routed through a flow meter, an O_2 analyzer, and a gas sampling manifold (for grab samples). Thermal data from the retort as well as flow, pressure, and exit O_2 data are processed, stored, and plotted by the data acquisition system.

The first sample prepared for retorting was a multiple borehole geometry, with seven .95 cm holes drilled in a hexagonal pattern through a solid core of 100 ℓ /tonne Green River shale. A number of

RETORT VESSEL

Figure 1.

Figure 2.

Figure 3.

LAB RETORTING SYSTEM

Figure 4.

retort model calculations (see appendix and ref. A2 for model details) were done to help define appropriate operating conditions for the experiment. As a result of these calculations, undiluted air was selected as the inlet gas, at a total flow rate of between 1 and 2 slm (.006 to .012 kg_{air}/m_{sh}²·sec). The calculated yield at these conditions was around 90% FA, with most of the loss due to oil combustion.

After completion of the retort assembly, air flow was established through the retort and ignition attempted with 310 SS-sheathed electric heaters lying directly on top of the shale cylinder. Although this ignition procedure has worked satisfactorily on previous smaller samples, this ignition attempt was not successful. Apparently, by heating the shale (and not the inlet gas), the primary source of fuel for the process, oil, was depleted in the heated region before gas-phase temperatures were high enough to ignite the oil. (Because of the competent nature of the sample, too little char is available for combustion to sustain the burn.) It is felt that an ignition procedure heating the inlet gas, rather than the shale, will eliminate this problem, since gas temperatures will necessarily be higher (and hence closer to oil ignition temperatures) while retorting is still occurring in adjacent shale.

Because the ignition attempt described above was stopped before the bottom half of the sample was heated, another attempt to ignite the same sample will be made as soon as possible using a hot gas ignition system.

Appendix

Summary of Previous Activities

October 1978 - September 1979

Activities related to the current program were conducted in FY 78-79 as part of Sandia's Fossil Energy Development Program. Those activities are summarized in this appendix.

Modeling: Most in situ retort modeling studies have concentrated on describing modified in situ (packed bed) retorts. Although in recent work^{A1} there has been considerable success in describing most salient features of this type of retort, the results do not apply to the processing of retorts composed of large blocks or seams of shale having significant internal temperature gradients such as would be found in a low void in situ (LVIS) or true in situ (TIS) retort. Thus, a numerical model was developed to simulate the true in situ retorting process.^{A2} In contrast to previous rubblized-bed models, the retort is assumed to be a low porosity, fractured bed composed of large seams of competent oil shale separated at intervals by open fractures through which injected and product gases flow. A two-dimensional rectilinear finite-difference grid is used to simulate this geometry. See Figure A1. Solid-phase reactions considered include kerogen and carbonate decomposition, release of fixed water, oil coking, and reaction of carbonaceous char with oxygen and carbon dioxide. Gas-phase reactions include the shift reaction and combustion of carbon monoxide, hydrogen, methane, and oil. Solid-phase temperature and concentration distributions are coupled to the gas phase by convective and radiative heat transfer and diffusional mass transport. Convective heat and mass transport within the gas stream are included.

Calculations made using thin (less than 0.1 m) shale seams yield results similar to those of rubblized-bed models: complete retorting of the kerogen, effective char utilization as fuel, uniform advance of the thermal wave through the bed, and oil yields as high as 90% Fischer Assay (FA). The results of retorting thick (greater than 1 m) seams are considerably different, however. Thirty to fifty volume percent steam must be injected to keep retort temperatures below shale fusion temperatures (~ 1200 - 1400°C). Air and steam injection rates

Figure A1. Model Geometry

control the extent of retorting, which typically is limited to within 0.5 to 1.0 m of the fractures. Only a small fraction of the char is consumed, with oil being the primary source of fuel for the process. In spite of oil combustion and coking losses and incomplete retorting, however, the amount of retorted shale oil available for recovery from a 2 m seam can be as high as 50% FA.

In addition to the rectilinear geometry originally developed in the code, a number of other geometries have been added in the past year to allow use of the model in guiding operation and predicting behavior of both additional large-block-dominated in situ retorts and certain laboratory block-retorting configurations. The additional geometries now included in the model are shown in Figure A2. The "axisymmetric" geometry shown in Figure A2a retains the same seam/fracture configuration as the original code, except that flow is radial outward from a borehole. This is the geometry of the start-up region (near the injection wellbore) of a wellbore-to-wellbore TIS retort and has been used to study start-up phenomena at the Rock Springs Site 12 TIS field experiment. In the "borehole" geometry of Figure A2b, the fracture has been replaced by a cylindrical hole acting as the flow path. It is being used to model a small laboratory retort setup in

Figure A2. Alternative Model Geometries

that configuration as well as several proposed in situ borehole retort geometries. Finally, Figure A2c illustrates the "cylinder" geometry appropriate for studying the combustion retorting of solid cylinders of shale from their outer surface. An analysis of some experimental results obtained by Lawrence Livermore Laboratory's oil shale group on their retort run L2 (which contained cylinders like this) was done using this geometry.

Finally, the code was used to evaluate a novel retort design, an in situ borehole retort.^{A3} This type of retort is shown schematically in Figure A3. The initial phases of retort preparation are similar to those for an MIS retort. First, rooms are mined at the top, bottom, and, if necessary, middle of the retort. Then, holes are drilled through the formation between rooms, not for the purpose of explosive insertion, but rather (by being drilled entirely through the bed) to provide uniform flow paths through the retort. No explosive rubblization is then necessary. The retort is processed by establishing air flow, igniting at the top, and propagating the combustion zone down the boreholes through the bed. The process could be done equally well in a horizontal geometry.

The primary advantage, in theory, of this type of process over fracturing-type processes is that a controlled, uniform permeability can be established through the retort with minimal void creation. For example, a 300 m high retort, with 5 m high drilling rooms at the

Figure A3. Borehole Retort Schematic

top and one intermediate level, a 3 m high room at the bottom, and 15 cm holes drilled on one meter centers in a hexagonal pattern, would have an overall void fraction of 6.3% (4.3% in rooms and 2.0% in holes). Still, there would be no point in the retort more than 0.5 m from an active flow path. Shale expansion is expected to be less severe a problem in this geometry than in an open fracture TIS geometry. In addition, all the blasting costs and danger are eliminated, as are the flow nonuniformities resulting from such blasts.

Preliminary model calculations have been done to determine the effect of hole spacing on yield. Operating conditions used for the calculations are given in Table AI. (Calculations to determine the effects of various shale grades, gas fluxes and compositions, hole sizes, etc. will be presented at a later date.) The model geometry shown in Figure A2b was used for these calculations and, because of

Table AI. Conditions for Borehole Retort Calculations

Bed Length	50 m
Hole Spacing	Variable
Hole Diameter	.15 m
Shale Grade	100 l/tonne
Gas Flux	.004 kg _g /m _s ² ·s
Steam Dilution	40 volume %

the symmetry of a hexagonal well pattern, is probably a very good approximation.

Figure A4 shows the calculated yield from the retort versus hole spacing. As in the TIS retort calculations, yield is a strong function of flow path spacing. It would appear from these results that, under the conditions used, a borehole spacing of up to 1.5 m would result in an acceptable yield (> 50%), making this retort concept worthy of further study.

Field Test Applications: The retorting code was also used during the past year to evaluate two field tests. One evaluation, for Geokinetics, Inc.'s retort 18 near Vernal, Utah, looked at the effects of gas flow rate and composition on yield and peak temperatures.^{A4} The results were forwarded to Geokinetics personnel, but are not presented here because they contain proprietary information.

The second was of part of the main burn pattern (well 4 → well W) at LETC's Rock Springs Site 12 (RS12) field test. Calculations of the effect of gas flux and steam injection on yield were similar to the calculations done in September, 1978^{A5} for the sideburn tests. As in the case of the sideburn, the optimal gas flux appears to be around 0.004 kg_{gas}/m_{sh}²·s of 60% air, 40% steam. At this flux and composition, a yield of 50% of FA oil within one meter of a fracture could be expected. Assuming a single fracture as suggested by the flow and tracer logs of Wells 4 and W, the required injection gas flow to maintain the optimal flux during the retort is shown in Figure A5. The retort advance rate at this flow would be about 0.3 m/day. Figure A5 also shows the expected breakthrough of O₂ at Well W because of extinction of the flame behind Well 4. Figure A6 shows, in plan view, the expected location of the burn zone vs. time. This retorting zone,

Figure A4. Effect of Borehole Spacing on yield

Figure A5. Recommended Injection Flow Rate and Expected Exit Gas Oxygen Concentration (assuming 40% steam and 1 fracture) for RS 12 Mainburn, Well 4 → Well W.

Figure A6. RS12 Mainburn Retort: Calculated Extent of Retorting
($0.004 \text{ kg/m}^2\text{-s}$ Gas Flux; 40 vol % Steam)

coupled with a 50% yield, would free about 70 bbl of shale oil for recovery from the single fracture running between Wells 4 and W.

Laboratory Retorting Studies: Laboratory work during the past year has involved several preliminary retorting experiments and initiation of the design and fabrication of a new retort vessel and system.

Each experiment involved retorting of a 4 cm diameter by 15 cm long cylindrical core of shale. A 1 cm hole, drilled axially through the cylinder, served as the flow path. The cylinder was instrumented with thermocouples and sealed in saueriesen in a 5 cm I.D. stainless steel tube which was then insulated and placed in an outer retort vessel. A coiled electric heater, installed atop the sample, was used for ignition.

The primary difference among the three tests was the heater design. The 347-stainless steel heater sheath, used for the first two tests, oxidized and caused heater failure at temperatures too low to ignite the shale. The 310-stainless sheathed heater used for the third test performed very well--essentially no sheath degradation after 2 hours near 1000°C .

During this test, the shale was ignited, with obvious gas phase combustion starting 1-1/2 hours into the run. The exit oxygen

concentration dropped to zero at that point, with both gas and solid temperatures jumping rapidly. The burn continued with the heater on for about 1 hour, at which point the oxygen in the exit gas began to rise rapidly. Some flow adjustment was tried, but the O_2 concentration continued to increase, ending the run. Figure A7 shows typical (a) gas phase and (b) solid phase temperatures; (c) inlet and outlet flow rates; and (d) exit O_2 concentration and inlet pressure during the run.

It appears that combustion was not sustained in the sample because of radial heat losses. Near the top of the retort, the ignition heater was able to compensate for these losses, but as the combustion zone moved down the sample, the heat losses were sufficient to extinguish combustion.

A number of means exist to decrease the radial heat loss, including backheating and increasing sample size. Electrical backheating was tried in a previous run, and, although it did help sustain combustion, it was difficult to insure that the backheating did not control the process. A second backheating technique is to burn a pattern of holes, such that the central hole is "insulated" by symmetry. A new retorting system utilizing this technique, along with an increased core diameter of 8 cm, is being fabricated to help solve the heat loss problem.

RETORT RUN 024

083079

Figure A7. Lab Retort 024 Results

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