C. Chemistry and Physics of Retorting

INSTRUMENTATION AND DATA ANALYSIS FROM OCCIDENTAL RETORTS MR-3 AND MR-4, SAND82-0138, P. J. Hommert, Sandia National Laboratories, Proceedings, 15th Oil Shale Symposium, Colorado School of Mines, April 27-30, 1982, Golden, Colorado.

During 1981, Occidental Oil Shale, Inc., conducted two approximately 12 m x 12 m x 16 m vertical modified in situ retorting experiments designated MR-3 and MR-4. These retorts were run to develop ignition technology for their commercial size retorts 7 and 8. Sandia National Laboratories participated in the experiments by providing both thermal instrumentation and a computer based data acquisition and analysis system. An analysis approach utilizing both thermal data and material balance calculations based on offgas composition was applied to both retorts. Results indicate that the analysis tools used can provide a detailed assessment of retort performance. Thermal instrumentation provides detail about the structure of the retort front. Material balance calculations permit estimates of retorting rates and oil loss mechanisms such as coking and combustion. The sweep efficiencies were estimated to be 76% for MR-3 and 48% for MR-4. Oil loss to combustion in the two retorts were 35% and 29% of Fischer Assay, respectively. Material balance results also permitted detailed energy balances to be performed on the retorts.

ANALYSIS OF HORIZONTAL AND VERTICAL IN SITU OIL SHALE RETORTING: COMPARISON OF FIELD EXPERIMENTS, SAND82-0972, T. C. Bickel and C. E. Tyner, Sandia National Laboratories.

Currently there are two different processing techniques being utilized in in situ oil shale retorting. Horizontal In Situ (HIS), in which the retort front moves parallel to the shale bedding planes, is being utilized on relatively thin, near surface oil shale. Vertical Modified In Situ (VMIS), in which the retort front moves perpendicular to the shale bedding planes, is being utilized for thicker deposits of shale at greater depths. While chemical effects in the two processes should be similar, physical phenomena (such as fluid product flow and heat transfer) can be substantially different due to gravity and anisotropic shale breakage associated with the shale bedding planes.

To illustrate both differences between the processes and some striking similarities, we present tracer data, thermal data (detailing movement of the steam and retorting fronts), and offgas and oil analysis data (allowing material and energy balance closures) from two recent field experiments, Sandia/Geokinetics Retort 23 (HIS) and Occidental Retorts 7&8 (VMIS). These data show, for example, a broader combustion front in the horizontal process, caused to some extent by oil dripping into, rather than away from, the combustion zone. As a result, more energy is wasted as sensible heat in the shale at the conclusion of the retort. On the other hand, overall oxygen utilization (.20-.25 kg shale retorted per mole of oxygen injected) and local oil yield (50-60% of Fischer Assay, with roughly two-thirds of the loss to oil combustion and one-third to oil coking and cracking reactions) were similar in the two experiments.

SANDIA/GEOKINETICS RETORT 23: A HORIZONTAL IN SITU RETORTING EXPERIMENT, SAND82-0139, C. E. Tyner, R. L. Parrish, B. H. Major, Sandia National Laboratories, 15th Oil Shale Symposium Proceedings, Colorado School of Mines, April 28-30, 1982, Golden, Colorado.

Sandia National Laboratories and Geokinetics, Inc., have recently completed processing of a 6000 tonne horizontal in situ oil shale retort near Vernal, Utah. The heavily-instrumented, explosively-fractured oil shale bed, containing 12% void, was combustion retorted using a number of distinct operating conditions, including air at high and low flow rates and air plus 30% combusted recycle gas. A number of techniques were used to evaluate the effectiveness of these various processing modes. The extensive suite of thermal instrumentation, for example, allowed continuous monitoring of the steam and retorting fronts and estimation of oil coking losses (from heating rate data) and total shale retorted. Actual sweep efficiency, based upon these data, was 79%; sweep efficiency estimates from steam front data were nearly identical, both in total shale contacted and spatial distribution of the swept zone. The thermal data also provided a direct means of assessing the validity of a number of retort diagnostic techniques based on fluid product (offgas and oil) analyses. Offgas material balance calculation estimates of sweep efficiency, for example, were 77% while retorting efficiency was 58% of Fischer Assay, with a 27% oil loss to combustion and a 15% loss to coking. Oil loss estimates based on oil analyses were similar. The experiment demonstrated that true in situ retorting of thin-seam rubbled shale beds with low void volume is practical using horizontal burn techniques, and that existing retort diagnostics are capable of providing a detailed analysis of the process.

MODEL CAPABILITIES FOR IN SITU OIL SHALE RECOVERY, SAND80-1873, P. J. Hommert and C. E. Tyner, Sandia National Laboratories, Century 2 -- Emerging Technology Conference, American Society of Mechanical Engineers, August 13-15, 1980, San Francisco, California.

The extensive oil shale reserves of the United States are now under development as an energy source. One of the approaches for extracting oil from shale is the so-called modified in-situ retort. The operation of such retorts for maximum yield requires an understanding of oil loss mechanisms so that operating strategies that minimize these losses can be developed. The present modeling capabilities for describing the behavior and yield from a modified in-situ retort are discussed. Two models that have been subject to comparison with laboratory retorts are described. The first is a one-dimensional model that treats the retort as a packed bed reactor; the second is a quasi-two-dimensional examination of block retorting. Both models are capable of predicting retorting rates, off-gas composition and oil yield losses to coking and combustion. The major need for modeling now is expansion to multi-dimensional simulation.

MATERIAL BALANCE CALCULATIONS FOR TRUE IN SITU OIL SHALE RETORTING, SAND79-0041, P. J. Hommert, Sandia National Laboratories, 12th Oil Shale Symposium, Colorado School of Mines, April 18-20, 1979, Golden, Colorado.

In an effort to further understand the characteristics of true in situ oil shale retorting, a comprehensive material balance procedure has been developed for this application. In addition to the normal elemental balances, laboratory data for the stoichiometry of oil coking and kerogen decomposition are used. This additional information allows estimates to be made as to the extent of the product loss mechanisms of oil coking and oil combustion. Assumptions are necessary in order to close the balance; thus sensitivity of the results to these assumptions is examined. The procedure has been applied to both the Site 9 and, on a preliminary basis, Site 12 oil shale retorts conducted by the Laramie Energy Technology Center. Results indicate that oil combustion and oil coking are significant loss mechanisms, i.e., on the order of 40-60% of oil retorted.

HEAT AND MASS TRANSFER IN POROUS MEDIA, SAND80-2825, Proceedings of 14th Oil Shale Symposium, Colorado School of Mines, April 22-23, 1981, Golden, Colorado, T. L. Cook, J. J. Travis, F. H. Harlow, Los Alamos National Laboratory, and T. J. Bartel and C. E. Tyner, Sandia National Laboratories.

Field test data on the OOSI MR 3 experiments are used as a basis for exhibiting the computational capabilities of the WAFE computer code, which is a generalized tool for the analysis of heat and mass transfer in multi-dimensional domains of porous geothermal materials.

IN SITU BOREHOLE RETORTING OF OIL SHALE, SAND79-2161, Proceedings of 3rd Annual Oil Shale Conversion Symposium, January 15-17, 1980, Denver, Colorado, C. E. Tyner, Sandia National Laboratories.

One major difficulty in the preparation of an in situ oil shale retort involves the creation, by a rubblization process, of uniform permeability throughout the retort bed. A retort design involving no rubblization, but rather utilizing uniformly-spaced drilled holes as flow paths, can virtually guarantee the required uniformity of flow through the entire bed. Such a design would necessarily be low in void, thus requiring a minimum of material removal and allowing maximum resource utilization.

Mathematical modeling and laboratory studies of this type of retort are in progress as part of a program to determine the minimum bed conditions for in situ retorting. Preliminary modeling studies have shown, for example, that a borehole retort with 15 cm holes drilled on one meter centers in a hexagonal pattern could have an oil yield in excess of 65%. Details of this modeling work, as well as some preliminary laboratory results and cost studies, will be presented.

AN OVERVIEW OF IN SITU OIL SHALE TECHNOLOGY AND RECENT DEVELOPMENTS IN TRUE IN SITU RETORT MODELING, SAND78-2367, 14th Intersociety Energy Conversion Engineering Conference, American Chemical Society, August 5-10, 1979, Boston, Massachusetts, C. E. Tyner, Sandia National Laboratories.

In view of current liquid fuel shortages, development of the oil shale resources of Colorado, Utah, and Wyoming, estimated to contain more than one trillion barrels of oil equivalent, must be considered. The in situ processing of this resource offers a potentially attractive alternative, both economically and environmentally, to surface processing. Current research areas, including laboratory studies, modeling, and field experiments, in both true and modified in situ oil shale processing are briefly outlined.

LABORATORY SIMULATION OF TRUE IN SITU RETORTING, SAND78-2348, 12th Oil Shale Symposium, Colorado School of Mines, April 18-20, 1979, Golden, Colorado, C. E. Tyner, Sandia National Laboratories.

A laboratory apparatus for combustion retorting of low surface-area competent shale samples has been developed to study the true in situ retorting process. The apparatus consists of a 2.5 cm diameter by 15 cm long cylinder of oil shale sealed in a stainless steel retort tube and combustion retorted adiabatically from a 0.3 cm axial hole. Typical results, including temperature profiles, extents of retorting and char combustion, and oil yields, are presented and compared to results of a true in situ retorting model developed to simulate both laboratory and field retorting.

IN SITU OIL SHALE RETORTING, SAND78-2175, Penrose Conference on Heat Transport Processes in the Earth, Geological Society of America, November 13-17, 1978, Vail, Colorado, C. E. Tyner, Sandia National Laboratories.

The major scientific problems and recent accomplishments in in situ oil shale retorting, both true and modified, are outlined to provide the basis for contributions of information from other disciplines during subsequent discussion periods.

TRUE IN SITU RETORT MODELING - APPLICATIONS TO ROCK SPRINGS SITE 12, SAND78-2161, 2nd Annual Oil Shale Symposium, December 6-8, 1978, Grand Junction, Colorado, C. E. Tyner, Sandia National Laboratories.

A numerical model developed to simulate true in situ oil shale retorting has been used to study the Rock Springs Site 12 retorts. Using site-specific bed conditions, model calculations were made to examine the expected effects of input gas flow rates, steam dilution, and ignition conditions on oil yield, retorting rates, and peak retort temperatures. The use of this information in determining optimal retort operating conditions and in the design of future retorts is discussed.

LABORATORY AND MODELING STUDIES OF THE COMBUSTION RETORTING OF LARGE BLOCKS OF OIL SHALE, SAND78-1564, AIChE Meeting, April 1-5, 1979, Houston, Texas, J. J. Duval, Laramie Energy Technology Center; C. E. Tyner, Sandia National Laboratories.

Laboratory experiments are being conducted to study the combustion retorting process in large blocks of competent oil shale. Two 0.3 m x 0.6 m x 1 m blocks are spaced 0.01 to 0.02 m apart (creating an "open fracture"), and then sealed and insulated. This geometry simulates the low-porosity fractured beds characteristics of true in situ retorts. The blocks are ignited with hot gas injected into the fracture and subsequently retorted with a mixture of air and carbon dioxide or steam. The extent of retorting, oil yield, temperature distribution, and exit gas composition are studied as a function of injection gas flow rate and composition.

NUMERICAL MODELING OF A TRUE IN SITU OIL SHALE RETORT, SAND78-1306, 86th AIChE National Meeting, April 1-5, 1979, Houston, Texas, C. E. Tyner, P. J. Hommert, Sandia National Laboratories.

A numerical model has been developed to simulate the true in situ retorting process. The retort is assumed to be a low-porosity fractured bed composed of large seams of competent shale separated at intervals by open fractures. Kerogen and carbonate decomposition and char, oil, and gas combustion, as well as other reactions, are considered.

In contrast to the results of rubblized-bed models, the retorting of seams thicker than one meter is characterized by incomplete retorting and significant oil combustion (10-40% of that retorted). The amount of shale retorted can, however, be maximized by proper control of air and steam injection creates, with the injected gas being optimally 40-50% steam. The oil available for recovery from a two meter seam can then be, for example, as high as 50% of Fischer Assay.

SANDIA/GEOKINETICS RETORT 23: A HORIZONTAL IN SITU RETORTING EXPERIMENT, Craig E. Tyner, R. Leon Parrish, Bruce H. Major, Sandia National Laboratories, James M. Lekas, Geokinetics, Incorporated, SAND81-2087A, AIChE Spring 1982 National Meeting, American Institute of Chemical Engineers, June 7-10, 1982, Anaheim, California.

As part of a joint experiment, Sandia National Laboratories and Geokinetics, Inc., have recently completed processing of a 6000 tonne horizontal in situ oil shale retort near Vernal, Utah. The heavily-instrumented, fractured shale bed, containing 12% void, was combustion retorted with air or air plus recycle at several flow rates. A number of techniques were used to evaluate the effectiveness of these various processing modes. Material balance calculations using offgas and flow data, for example estimated a sweep efficiency of 77% and an average local retorting yield of 58% of Fisher Assay (resulting from a 15% loss to oil coking and a 27% loss to oil combustion). These results are compared, as a function of operating conditions, to estimates from other offgas correlations, thermal data, oil analyses, and actual oil production rates.

RESISTIVE HEATING FOR OIL SHALE RETORTING, SAND81-2122, J. T. Schamaun, R. J. McAniff, L. K. Warne, Sandia National Laboratories.

Since 1941, researchers have explored the use of electrical energy to convert oil shale into usable liquid fuels. The attractiveness of these electrical methods stems from the fact that they allow for true in situ processing. One specific method that appears to hold promise is electrical resistive heating. In this method, heat is induced from an electrical power input at two spatially separated electrodes. As retorting begins, the electrical resistivities of the shale formation are expected to increase dramatically. This in turn allows the power input to be focused primarily at the retort zone. To explore the feasibility of this method, the thermal response of the shale to electrical inputs is calculated analytically and also numerically through a finite element formulation. Results and limitations of the research, as well as a set of recommendations are included in this report.

LOW VOID RETORTING STUDIES, SAND81-0232, 4th Annual Oil Shale Conversion Symposium, March 24-26, 1981, Denver, Colorado, C. E. Tyner, Sandia National Laboratories.

As part of a program to determine the minimum conditions required for in situ oil shale processing, a series of laboratory retorting experiments has recently been completed. The oil shale samples, composed of both shale blocks and rubble, ranged in void from 7-16% -- considerably lower than previous laboratory or pilot retorts (25-50% void) or previous modified in situ field tests (15-40% void). The instrumented samples were ignited with electric heaters and combustion retorted with air in an insulated retort vessel. Comparisons of experimental data with retort model calculations were good. For example, on one 16% void experiment, observed yield was 95% of Fischer Assay, calculated yield, 92.8%; experimental retorting rates varied from 8.9-9.5 cm/hr, calculated rates from 10.0-10.3 cm/hr; and observed peak temperatures ranged from 815-825°C, calculated from 820-825°C. For all experiments, both oil yield

(75-95%) and overall bed permeability were adequate to demonstrate the feasibility of low void retorting. Commercial processing in this void range would offer the potential for considerable reduction in costs and environmental impact associated with the mining, material handling, and disposal requirements of current in situ processes.

IN SITU BOREHOLE RETORTING OF OIL SHALE: LABORATORY STUDIES, SAND80-2770, Proceedings 14th Oil Shale Symposium, April 22-24, 1981, Golden, Colorado, C. E. Tyner, Sandia National Laboratories.

In situ borehole retorting of oil shale involves drilling a pattern of uniformly-spaced holes through an oil shale zone (between mined, underground rooms) and processing that shale ahead of a flame front propagate down the holes. Important features of the process are that material removal is kept to a minimum (4-8%), no rubblization is involved, and the drilling operation allows creation of a uniformly-permeable retort cross-section. Laboratory experiments demonstrating the technical feasibility of retorting in this configuration have been conducted. The experiments have also served to validate (at least at the laboratory scale) a detailed two-dimensional mathematical model developed to describe the process. For example, an insulated 7.6 cm diameter by 28 cm long core of shale with seven 1 cm axial holes (filled with coal rubble) was combustion retorted with air at a flux of 1.1 m^3/m-min. The observed retorting rate was 9.7 cm/hr, while the model-calculated retorting rate was 9.0 cm/hr. Other comparisons included local heating rate in the retorting zone (11.5°C/min observed, 9.5°C/780-820°C calculated), and yield (69% of Fischer Assay observed, 780-820°C calculated), and yield (69% of Fischer Assay observed, 78% FA calculated). Observed peak temperatures and yield were probably lower than predicted values because of experimental heat losses. The results of additional experiments investigating the effects on retort performance of hole size and spaving, retorting rate, and use of shale or coal rubble in the boreholes will also be presented.

AN OVERVIEW OF IN SITU OIL SHALE TECHNOLOGY AND RECENT ADVANCES IN TRUE IN SITU RETORT MODELING, SAND78-2367, Proceedings, 14th Intersociety Energy Conversion Engineering Conference, IECE, August 5-10, 1979, Boston, Massachusetts, C. E. Tyner, Sandia National Laboratories.

In view of current liquid fuel shortages, development of the oil shale resources of Colorado, Utah, and Wyoming, estimated to contain more than one trillion barrels of oil equivalent, must be considered. The in situ processing of this resource offers a potentially attractive alternative, both economically and environmentally, to surface processing. True and modified in situ retorting technologies are described and current research in these areas briefly outlined.

True in situ and related low-void in situ processes would minimize the mining and materials handling problems associated with other technologies. A comprehensive mathematical model has been developed to describe the retorting process in these beds. Use of the model to investigate the effect of various retort geometries and bed conditions on the oil yield from true in situ and low-void in situ retorts is discussed.

HEAT AND MASS TRANSFER IN POROUS MEDIA, SAND80-2825, T. L. Cook, F. H. Harlow, B. J. Travis, Los Alamos National Laboratory, T. J. Bartel, C. E. Tyner, Sandia National Laboratories, Proceedings of 14th Oil Shale Symposium, Colorado School of Mines, April 22-23, 1981, Golden, Colorado.

Field test data on the OOSI MR3 experiments are used as a basis for exhibiting the computational capabilities of the WAFE computer code, which is a generalized tool for the analysis of heat and mass transfer in multi-dimensional domains of porous geothermal materials.

D. Program Summaries/Project Reviews

OIL SHALE PROGRAM TWENTY-SIXTH QUARTERLY REPORT APRIL-JUNE 1982, SAND82-2699, P. J. Hommert, Editor, Sandia National Laboratories.

This report describes the principal activities of the Sandia National Laboratories, Albuquerque (SNLA) in the DOE Oil Shale Program during the period April 1 to June 30, 1982. During six years of involvement in the DOE program, Sandia has been pursuing a goal of developing the technology to improve the overall efficiency of shale oil recovery processes. In particular, the Sandia activities have focused on in situ shale oil recovery processes. The objective of these activities has been to acquire the ability to prescribe an efficient process for in situ recovery of a given oil shale resource. The overall efficiency of shale oil recovery processes is determined primarily by a combination of sweep efficiency, retorting efficiency and volumetric efficiency. These efficiency components are related to the way in which the retort bed is prepared, the retorting technique employed and the structural characteristics of the mine and in situ retorts. Therefore, the Sandia program addresses these three main areas: Bed Preparation and Characterization, Retorting Process, and Structural Stability.

OIL SHALE PROGRAM 23RD & 24TH QUARTERLY REPORTS JULY 1981 THROUGH DECEMBER 1981, SAND82-0606, B. E. Bader, Editor, Sandia National Laboratories.

This report describes the principal activities of the Sandia National Laboratories, Albuquerque (SNLA) in the DOE Oil Shale Program during the period July 1 to December 31, 1981. During six years of involvement in the DOE program, Sandia has been pursuing a goal of developing the technology to improve the overall efficiency of shale oil recovery processes. In particular, the Sandia activities have focused on in situ shale oil recovery processes. The objective of these activities has been to acquire the ability to prescribe an efficient process for in situ recovery of a given oil shale resource. The overall efficiency of shale oil recovery processes is determined primarily by a combination of sweep efficiency, retorting efficiency and volumetric efficiency. These efficiency components are related to the way in which the retort bed is prepared, the retorting technique employed and the structural characteristics of the mine and in situ retorts. Therefore, the Sandia program addresses these three main areas: Bed Preparation and Characterization, Retorting Process, and Structural Stability.

OIL SHALE PROGRAM NINETEENTH QUARTERLY REPORT JULY 1980 THROUGH SEPTEMBER 1980, SAND81-0204, A. L. Stevens, Editor, Sandia National Laboratories.

This nineteenth quarterly report describes the principal activities of the Sandia National Laboratories (SNL) in the DOE Oil Shale Program during the period July 1 to September 30, 1980. Currently, Sandia's activities are focused upon: The development, deployment, and field use of instrumentation, data acquisition, and process monitoring systems to characterize and evaluate in situ shale oil recovery projects that show promise for commercial development, and the development and use of analytical and experimental modeling techniques to describe and predict the retort properties and retorting process parameters that are material to the preparation, operation, and stability of in situ retorts. In contrast to the organization of previous reports, SNL in-house activities and field activities (at the Geokinetics Oil Shale Project and the Occidental Oil Shale Project) are described under the headings, Bed Preparation, Bed Characterization and Evaluation, Report Characterization and Evaluation, and Mine Stability, that serve to identify major areas for study in the development of the technology leading to viable commercial extraction operations. The intent of this organizing structure is to provide a clear indication of where each of the various SNL activities contributes to the total oil shale program through these principal areas of investigation.

OIL SHALE PROGRAM TWENTIETH QUARTERLY REPORT OCTOBER 1980 THROUGH DECEMBER 1980, SAND81-1038, B. E. Bader, Editor, Sandia National Laboratories.

This twentieth quarterly report describes the principal activities of the Sandia National Laboratories, Albuquerque (SNLA) in the DOE Oil Shale Program during the period October 1 to December 31, 1980. Currently, Sandia's activities are focused upon: The development and use of analytical and experimental modeling techniques to describe and predict the retort properties and retorting process parameters that are important to the preparation, operation, and stability of in situ retorts, and The development, deployment, and field use of instrumentation, data acquisition, and process monitoring systems to characterize and evaluate in situ shale oil recovery operations.

OIL SHALE PROGRAM TWENTY-FIFTH QUARTERLY REPORT, JANUARY 1982 THROUGH MARCH 1982, SAND82-2063, P. J. Hommert, Editor, Sandia National Laboratories.

This report describes the principal activities of the Sandia National Laboratories, Albuquerque (SNLA) in the DOE Oil Shale Program during the period January 1 to March 31, 1981. During six years of involvement in the DOE program, Sandia has been pursuing a goal of developing the technology to improve the overall efficiency of shale oil recovery processes. In particular, the Sandia activities have focused on in situ shale oil recovery processes. The objective of these activities has been to acquire the ability to prescribe an efficient process for in situ recovery of a given oil shale resource.

MINIMUM BED PARAMETERS FOR IN SITU PROCESSING OF OIL SHALE - 2ND QUARTERLY REPORT, SAND80-1455, C. E. Tyner, Sandia National Laboratories.

This is the second in a series of quarterly reports on the Minimum Bed Parameters for In Situ Processing of Oil Shale Program. It describes activities during the period January 1-March 31, 1980, including modification of the laboratory retorting system to eliminate problems with the ignition and product collection systems and the successful retorting of a 16% void sample.