D. Program Summaries/Project Reviews

CHARACTERIZATION AND SUPPORTING RESEARCH FOR IN SITU COAL GASIFICATION RESEARCH AND DEVELOPMENT PROJECT PLAN, SAND82-0494, S. L. Love, Sandia National Laboratories.

Underground Coal Gasification (UCG) is an emerging technology with the potential for greatly increasing the usable coal supply in the USA. Of the remaining problems with this technology, perhaps the most significant is the inability to reliably forecast test results. Experience now indicates that to anticipate test results, one must be able to forecast the evolving shape of the underground reaction zone. Further, the most important factors governing this cavity growth may be the initial site and process conditions. This document describes a research plan which is designed to provide the needed UCG characterization in terms of cavity growth as determined by the nature of the UCG site. Laboratory and small-scale field investigations are proposed which should 1) define the characteristics of sites that are suitable for UCG, 2) identify and quantify the key process factors, and 3) develop mathematical models which can be used to forecast site-specific test results. Included in this document are task descriptions and objectives, time scales, and budget estimates. Also, some of the activities described are underway, and pertinent results to date are discussed.

INSTRUMENTATION AND PROCESS CONTROL DEVELOPMENT FOR IN SITU COAL GASIFICATION, SAND80-1921, Robert E. Glass, Editor, Sandia National Laboratories.

This report discusses the result of modeling efforts by Sandia National Laboratories in in situ coal gasification. The main areas addressed are 1) flow characteristics, and 2) initial cavity growth. The flow characteristics problem has been addressed using both a single phase finite element model and a two-phase finite difference model. The initial cavity growth problem has been addressed using a finite element structural model. These models are useful for providing insight into the processes and for determining the characteristics needed to insure successful in situ coal gasification.

Also to be discussed is the development of the controlled source audio magnetotelluric (CSAMT) electromagnetic geophysical prospecting technique. This technique is being evaluated for use in mapping in situ processes. The application discussed is the LETC tar sands project near Vernal, Utah.

CATALYTIC EFFECTS IN COAL GASIFICATION, SAND82-0791, Thomas D. Padrick, Daniel E. Trudell, Sandia National Laboratories.

This quarterly report, for the period April-June, 1981, summarizes the activities of Sandia National Laboratories' program on mineral matter effects in coal gasification. The objective of this program is to develop a fundamental understanding of the mechanism of the catalytic effects of mineral matter in coal gasification, and to use this knowledge for future process improvements. Experiments using various catalyst dispersion techniques indicate that for a given iron compound, improved dispersion results in improved catalytic activity. We observed that the addition of inert or catalytically active minerals eliminated agglomeration in the Bruceton coal. We also determined that addition of the iron catalysts increases the surface area and shifts the pore volume distribution to smaller pore sizes, but the magnitude of the effect varies greatly from one compound to another.

II. OIL SHALE

Introduction

Sandia National Laboratories has as its overall goal for research in Oil Shale the development of a predictive capability for the in situ technologies. The research encompasses both the bed preparation (fracturing) and retorting stages of a given in situ recovery technology. During the period of time covered by this report one of the primary activities performed by Sandia has involved field measurement of large scale in situ recovery processes. This work allows an assessment of the current technologies and identifies areas for possible process improvement. These field measurements have shown that the retorting process as it occurs on a large scale in situ is not well understood and furthermore that the predominant mechanism of control of the in situ reactor is the initial bed preparation step. As a result of these findings, laboratory and modeling studies are being conducted to better understand the dominant loss mechanism in low void in situ retorting. In addition, an experimental and modeling effort is underway to predict void distribution and particle size as a function of blast design.

A. Bed Preparation

A STRAIN-RATE SENSITIVE ROCK FRAGMENTATION MODEL, SAND82-0889, E. P. Chen, M. E. Kipp, D. E. Grady, Sandia National Laboratories, Chapter in Mechanics of Oil Shale.

The dependence of rock fracture and fragmentation on strain-rate is examined in this chapter. This dependence is first derived within the context of dynamic fracture mechanics. This feature is then incorporated explicitly into a dynamic rock fragmentation model in which the fracture process is modeled as a continuous accrual of damage in the rock mass, leading to a state of fragmentation. The damage is defined to be the volume fraction of material that has been stress relieved by multiple crack growth. The model is calibrated on data over several decades of strain rate. Application of the model to oil shale has been made by using a two-dimensional finite-difference wave propagation code. Correlation of calculation results with available experimental data from both laboratory and field scale tests is made.

DYNAMIC FRACTURE AND FRAGMENTATION OF OIL SHALE: APPLICATION OF A NUMERICAL MODEL TO A BLAST DESIGN, SAND80-2686C, R. R. Boade, M. E. Kipp, D. E. Grady, Sandia National Laboratories, Proceedings of 14th Oil Shale Symposium, Colorado School of Mines, April 22-24, 1981, Golden, Colorado.

A portion of Sandia's rock mechanics program has been directed at the study of the fracture and fragmentation properties of oil shale, with a goal of developing computational procedures for use in designing and/or evaluating blasting concepts for preparing in situ retort beds. A variety of experiments have revealed that the failure phenomenon in oil shale is highly strain-rate dependent. Data from the experiments have provided a base for a computational model for dynamic fracture and fragmentation. This model has been incorporated into a two-dimensional wavecode called TOODY and is now ready for rudimentary assessments of practical blasting schemes. Such an application has recently been undertaken for a modified in situ blasting concept which uses an array of vertically oriented explosive charges configured and sequentially detonated in decks. The charges are in boreholes drilled from a horizontal surface (floor or back) of a mined cavity. Within each deck the charges are in a square pattern. From deck-to-deck, the positions of the square patterns alternate so charges in one deck are centered with respect to charges in an adjacent deck. The computational procedures have been used to evaluate the fracturing and fragmentation that occur in the rock surrounding each charge and to determine some of the key parameters of the blast design (spacing between charges, burden thicknesses, explosive quantity requirements, etc.).

ON THE EFFECT OF PULSE LOADS ON DYNAMIC ROCK FRACTURE, SAND81-1942, E. P. Chen, Sandia National Laboratories. Proceedings of the Joint Conference of Society of Experimental Stress Analysis and Japan Society of Mechanical Engineers, May 23-30, 1982, Honolulu, Hawaii.

The objective of this research was to develop an analytical model which is capable of predicting the fracture pattern in the rock surrounding a wellbore upon which a dynamic loading pulse is applied. The development of the model followed the principle of elastodynamic fracture mechanics. Specifically, inherent cracks are assumed to exist around the edge of the wellbore. Depending on the pulse shape, these cracks are activated to form various fracture patterns. The criterion for initiation of crack growth is determined by the magnitude of the dynamic stress intensity factor associated with the crack. The finite element code HONDO was used to calculate the dynamic stress intensity factors. Analytical predictions were correlated with field experimental data and good agreements were found.

RUBBLIZATION OF NEAR-SURFACE TRUE IN SITU OIL SHALE RETORTS, SAND81-1978, J. T. Schamaun, Sandia National Laboratories.

Most in situ extraction techniques to obtain oil from oil shale beds are dependent upon explosive fracturing and rubbling of rock to increase the retort permeability in a controlled and predictable manner. Besides the rubbling requirement, it is also important that the surrounding rock remain competent to minimize fluid leakage during processing. In areas where the proposed retort zone is fairly close to the ground surface, explosive can be used to raise the overburden material and to create a retort. This bed preparation concept, near surface in situ retorts, is the subject of this report. The report includes some basic theory and concepts pertinent to standard blasting in addition to the discussion of confined or near-surface blasting. The importance of delay timing and interaction with the overburden in determining the effective rubblization is presented. Design and analysis techniques are presented to provide the basis for two typical blast designs. The technical problem areas that may require further analytical or experimental study are discussed.

DYNAMIC FRACTURE AND FRAGMENTATION STUDIES ON OIL SHALE, SAND80-2686, Oil Shale Symposium, Green Center Colorado School of Mines, April 22-24, 1981, Golden, Colorado, M. E. Kipp, D. E. Grady, and R. R. Boade, Sandia National Laboratories.

Experimental evidence gathered on oil shale indicates that this rock, like many others, exhibits strain-rate dependent strength and fragment size properties. A variety of techniques, including gas gun, torsional split-Hopkinson bar, small scale explosive, and tensile machine, provide a wide range of strain rates leading to fracture and fragmentation. A model has been developed to characterize this failure behavior, with the intent to apply it to oil shale retort blasting operations. In explosive fracture, the strain rate experienced by the rock depends upon its location relative to the explosive and nearby free surfaces. Use of the fracture model in a wave-propagation code permits evaluation of possible generic blasting techniques, thus reducing the extent of field experimentation needed to obtain a viable scheme.

DYNAMIC ROCK FRAGMENTATION: OIL SHALE APPLICATIONS, SAND80-0857, Proceedings of Society for Experimental Stress Analysis Meeting, October 12-17, 1980, Ft. Lauderdale, Florida, R. R. Boade, Sandia National Laboratories.

Explosive rock fragmentation techniques used in many resource recovery operations have in the past relied heavily upon traditions of field experience for their design. As these resources, notably energy resources, become less accessible, it becomes increasingly important that fragmentation techniques be optimized and that methods be developed to effectively evaluate new or modified explosive deployment schemes. Computational procedures have significant potential in these areas, but practical applications must be preceded by a thorough understanding of the rock fracture phenomenon and the development of physically sound computational models.

This paper presents some of the important features of a rock fragmentation model that was developed as part of a program directed at the preparation of subterranean beds for <u>in situ</u> processing of oil shale. The model, which has been implemented in a two-dimensional Lagrangian wavecode, employs a continuum damage concept to quantify the degree of fracturing and takes into account experimental observations that fracture strength and fragment dimensions depend on tensile strain rates. The basic premises of the model are considered in the paper as well as some comparisons between calculated results and observations from blasting experiments.

BED PREPARATION CONCEPTS FOR TRUE IN SITU OIL SHALE PROCESSING: AN EVALUATION OF CURRENT TECHNOLOGY, SAND79-0582, 54th Annual Technical Conference and Exhibition, Society of Petroleum Engineers of AIME, September 23-26, 1979, Las Vegas, Nevada, R. R. Boade, A. L. Stevens, Sandia National Laboratories.

Field experiments performed during recent years to develop explosive methods for preparing relatively deep oil shale beds for true in situ processing have in most cases employed the wellbore springing or the hydraulic/explosive fracturing concept. These efforts, in general, have not been successful in that the required permeability has not been satisfactorily introduced into the normally very tight shale beds. In the present paper, the physical phenomena which control the above named fracturing concepts are examined and on the bases of this examination, reasons are given for the negative results observed in the field experiments. The primary difficulties with the wellbore spring concept stem from the cylindrical symmetry, which leads to rapidly attenuating stress waves because of divergence and to a residually stressed region around the explosive cavity that restricts fluid flow and hinders void redistribution efforts. With the hydraulic/explosive fracturing concept, success has been thwarted because many of the essential underground operations cannot be controlled and because regions of enhanced permeability are formed only in the immediate vicinity of explosive filled hydraulic fractures. In evaluating the wellbore springing and hydraulic/explosive fracturing concepts, it was concluded that their inherent deleterious traits will prevent both concepts from ever becoming viable for practical applications. It was further concluded that bed preparation concepts for deep oil shale beds, where significant overburden lift cannot be achieved by explosive means, must include some form of material removal in addition to that associated with the drilling of wellbores, as well as an effective method to distribute the void through the shale bed.

TRUE IN SITU PROCESSING OF OIL SHALE -- AN EVALUATION OF CURRENT BED PREPARATION TECHNOLOGY, SAND78-2162, 2nd Annual Oil Shale Symposium, December 6-8, 1978, Grand Junction, Colorado, R. R. Boade, Sandia National Laboratories.

Information needed to realistically plan future activities with regard to true in situ processing of oil shale was recently obtained in a study to evaluate the current status of bed preparation technology. The study was based on results of field experiments performed by LETC and jointly by LETC and Sandia, as well as on theoretical and phenomenological assessments of rubblization techniques that have been examined. The study excluded cases where significant overburden lift is possible. Analyses of the available information indicated that the two rubblization techniques given the most attention in prior experimentation, namely, the wellbore springing and hydraulic/explosive fracturing concepts, both have inherent characteristics which will prevent them from ever becoming viable for practical applications. Principal difficulties are related to inadequate fluid-flow properties; specific problems for one or both concepts are insufficient permeability caused by insufficient initial void volume, non-uniform flow properties caused by inadequate redistribution of the available void, and excessive leakage into the surrounding formation caused by the propagation of fractures beyond the region intended for processing. It was concluded that successful implementation of true in situ processing is dependent upon the development of methods to introduce initial void volume into the shale bed and to uniformly redistribute that void; the methods developed must be controllable and predictable and must result in a rubblized region that is bounded. Salient details of the study will be discussed in the paper.

B. Instrumentation

CHARACTERIZING A POROUS MEDIA WITH GASEOUS TRACERS, SAND82-0709A, T. J. Bartel, R. J. McAniff, K. L. Erickson, Sandia National Laboratories, 57th Annual Technical Conference and Exhibition, Society of Petroleum Engineers of AIME, New Orleans, Louisiana, September 26-29, 1982.

Gaseous tracers are commonly used to characterize the flow structure in porous media. Examination of data from recent tracer tests in explosively expanded rubble beds of oil shale indicates that simple 1-D analysis techniques are inadequate for reliably determining complex bed conditions. The present research focuses on extending the 1-D approach and developing a stochastic method to better interpret tracer data. This involves the use of a multi-dimensional computer code to generate a data base of tracer pulses for a variety of permeability structures. The dispersion model results are compared with data from large scale oil shale experiments. The stochastic approach specifies a given tracer response curve in terms of a probability density function (Gamma) using three parameters and a magnitude scale factor. Hypothesis testing is then performed on the data base to determine the most likely permeability structure. The question of uniqueness with respect to inverting tracer data is also quantitatively investigated via this approach.

MINE STABILITY INSTRUMENTATION SURVIVABILITY TEST: DATA REPORT, MINI-RETORT 3 FRAGMENTATION TEST, SAND80-1603, R. R. Neel, R. W. Donohoe, Sandia National Laboratories.

An experiment to assess the survivability of typical mine stability instrumentation during the explosive rubblization of the retort bed of Mini-Retort 3 was carried out by Sandia National Laboratories, Albuquerque (SNLA) in Occidental Oil Shale Inc.,'s (OOSI's) Logan Wash Research Mine. Mine stability instrumentation consisted of appropriately placed borehole stressmeters and extensometers. Environmental parameters were measured using accelerometers and temperature sensors. Prompt and long-term rubble pressures were measured in the lower room of the retort using special pressure cells. With the exception of one extensometer string and one stressmeter, all mine stability instrumentation functioned during the blast. The failure of the stressmeter was caused by internal electrical failure prior to the shot. Some accelerometers failed owing to malfunctions that developed as a result of adverse pre-shot environmental conditions.

MULTIPLE TRACER GAS ANALYZER, SAND82-0214A, J. E. Uhl, Sandia National Laboratories, 1981 Symposium on Instrumentation and Control for Fossil Energy Processes, June 7-9, 1982, Houston, Texas.

A multi-gas tracer system has been designed, built, and used on an explosively fractured oil shale rubble bed. This system is a field portable, self-contained unit, which utilizes a mass spectrometer for gas analysis. The unit has a 20 channel sample port capability and is controlled by a desk top computer. The system is configured to provide a dynamic sensitivity range of up to 6 orders of magnitude. A roots blower is manifolded to the unit to provide continuous flow in all sample lines. The continuous flow process allows representative samples as well as decreasing the time between each measurement. Typical multiplex cycle times to evaluate four unique gases is approximately 20 seconds.

GEOLOGIC FLOW CHARACTERIZATION USING TRACER TECHNIQUES, SAND80-0454, Robert D. Klett, Craig E. Tyner, Sandia National Laboratories, Eugene S. Hertel, Jr., The Dikewood Corporation.

A new tracer flow-test system has been developed for in situ characterization of geologic formations. This report describes two sets of test equipment: one portable and one for testing in deep formations. Equations are derived for in situ detector calibration, raw data reduction, and flow logging. Data analysis techniques are presented for computing porosity and permeability in unconfined isotropic media, and porosity, permeability and fracture characteristics in media with confined or unconfined two-dimensional flow. The effects of tracer pulse spreading due to divergence, dispersion, and porous formations are also included.

INSTRUMENTATION AND DATA ANALYSIS RESULTS FROM OCCIDENTAL RETORTS MR-3 AND MR-4, SAND80-2826, P. J. Hommert, Sandia National Laboratories, G. P. Gruber, Occidental Oil Shale, Inc., 14th Annual Oil Shale Symposium, Colorado School of Mines, Golden, Colorado, April 22-24, 1981.

Occidental Oil Shale, in conjunction with DOE and Sandia National Laboratories, is conducting two mini-retorts, MR-3 (November 1980) and MR-4 (January 1981). The retorts are primarily intended to test different burner configurations but are sufficiently instrumented to provide data on the retort process itself. The retorts are nominally 1600 sq ft in cross section and 50 ft deep. On both retorts there are approximately 120 thermal measurement points and 25 gas sample locations within the retort. There is also complete instrumentation on the inlet and outer gas flows including composition. The synthesis of these data through the use of a computer based data acquisition system has provided a picture of the modified in situ retort process with finer detail then has ever been seen before.

The initial results from MR-3, while limited because burner operating problems did not allow for a stable retort operation, show clearly the initial flow structure within the rubble bed. These data are compared with the pre-test tracer data which also examine the rubble bed flow distribution. Both sets of data indicate some non-uniformities in the flow structure. The more complete data from MR-4 addresses the question of whether non-uniformities observed at gas temperatures below retorting temperatures translate into a significant distortion of the retorting front distribution.

TRACER DETERMINATION OF IN SITU OIL SHALE RETORT FLOW CHARACTERISTICS, SAND81-0231, 4th Annual Oil Shale Conversion Symposium, March 24-26, 1981, Denver, Colorado, C. E. Tyner, R. L. Parrish, Sandia National Laboratories.

A downhole tracer system has been used to determine the flow characteristics of a number of horizontal in situ oil shale retorts at the Geokinetics, Inc. (GKI) field site near Vernal, Utah. The system consists of surface and downhole Kr^{85} tracer injectors and a string of four downhole detectors. The system is capable of providing both the vertical and horizontal distribution of permeability and active void throughout the retort, as well as flow logs of the recovery wells. Examples of the results of tracer tests on GKI retorts 19 through 24 will be presented. The use of this data in the planning and evaluation of the retorting phase of retort 23 (a joint Sandia/GKI experiment) will be emphasized.

IN SITU FORMATION EVALUATION USING TRACER AND FLOW TECHNIQUES: DOE SITE 12, ROCK SPRINGS, WYOMING, SAND78-2161, 2nd Annual Oil Shale Symposium, December 6-8, 1978, Grand Junction, Colorado, Fred Turner, Laramie Energy Technology Center, C. E. Tyner, Sandia National Laboratories.

Several techniques were used to evaluate the extent of natural and man-caused fracturing in oil shale on DOE's Site 12 in Rock Springs, Wyoming. Among these were gas tracer, flow logging, TV logging, and caliper logging. The flow logging and gas tracer techniques are described and show the progressive changes in the formation from a natural condition prior to any fracturing experiments through three hydrofracs and one successful explosive fracture. The final series of tracer and flow tests describe the formation just prior to in situ retorting of the site.

TECHNIQUES AND PROBLEMS RELATING TO IN SITU MEASUREMENT OF FREE-FIELD STRESS WAVES IN RUBBLIZATION EXPERIMENTS, SAND78-2268, 20th U. S. Symposium on Rock Mechanics, U. S. National Committee on Rock Mechanics, June 3-6, 1979, The University of Texas at Austin, R. P. Reed, R. R. Boade, Sandia National Laboratories.

A resurgence of interest in in situ processing of oil shale has made available some federal and private financing for field studies of in place retorting. As a result, several projects are being proposed or planned. The goal is the development of an economical and environmentally acceptable process for utilizing this extensive fossil fuel resource. The most critical obstacle to true or modified in situ retorting of oil from oil shale is the efficient creation of an adequate rubble bed. Subsurface fracturing and rubblization for retorts has already been attempted by a variety of explosive techniques with but limited success. Under controlled laboratory conditions, kerogen in the oil shale (organic marlstone) is readily converted to oil. Under controlled small-scale conditions, the parameters affecting efficiency of recovery are being studied. The rubble bed characteristics essential to adequate full-scale deep underground retorting are not yet established. Clearly, the size and gradation of particle size are important but the amount and distribution of porosity may be even more significant.