I. COAL GASIFICATION

Introduction

Sandia's coal gasification research has emphasized in situ processes with research continuing in cavity growth modeling, linking technologies and process monitoring. The surface gasification studies included limited research on catalysis, hazards analyses and diagnostics; the surface gasification research was terminated in October, 1982. Research in support of the DOE program in in situ coal gasification can be divided in three basic areas. The development of instrumentation techniques to map the gasification process. Techniques being utilized include the use of CSAMT electromagnetic surveys and also specialized downhole transmission systems for thermometry. Laboratory and modeling studies are being conducted to better understand the dominant mechanisms of cavity growth. This work has identified thermomechanical effects as playing an important role in UCG cavity growth. The final area of activity involves the development of a cornering water jet drill system as a linking tool for research tests.

The primary objectives of the program in surface gasification have been to determine the catalytic role of mineral matter in the conversion of coal to methane, and to understand the detonation/deflagration potential of high-pressure, oxygen-blown entrained bed gasifiers. In addition, we have provided support for the development of sensors and instrumentation for determining char and coal mass flow rates.

A. Chemistry

THE CATALYTIC EFFECT OF IRON IN HYDROGASIFICATION OF COAL, SAND81-0715C, T. D. Padrick, D. D. Dees, T. M. Massis, Sandia National Laboratories, 11th Annual North American Thermal Analysis Society Conference, October 18-22, 1981, New Orleans, Louisiana.

Hydrogasification of coal is a technique to produce synthetic natural gas (SNG) which offers the advantage of methane production in a single process step. A fundamental limitation of hydrogasification is the low reactivity of hydrogen, compared to steam or oxygen, towards coal chars. Utilization of a low-cost catalyst, which would greatly enhance the reactivity of hydrogen towards coal char, would significantly impact the SNG program.

It has been known for some time that various inorganic species have a catalytic effect on gasification rates of carbons and graphites. The reactivity of lignite chars, doped with various metals by means of cation exchange was studied at 790°C by TGA techniques. It was found that iron and sodium were good catalysts for hydrogasification, but that potassium and calcium actually inhibited the hydrogasification of the lignite chars.

B. Processes

THERMOMECHANICAL CAVITY GROWTH MODELING, SAND82-0956A, R. E. Glass, Sandia National Laboratories, 8th Annual Underground Coal Conversion Symposium Proceedings, Keystone, Colorado, August 15-19, 1982.

The results of recent field and laboratory studies in UCG have indicated that the thermal and mechanical properties of coal may be the controlling parameters in determining initial cavity shape. In examining this possibility, laboratory efforts have been directed at determining temperature and bedding plane dependent properties of coal. These properties have been used in a cavity growth model composed of thermal and structural finite element codes. The results of the model have indicated that the cavity shapes seen at both the Hanna and Hoe Creek test sites may result from the temperature dependent properties of the coal such as the coefficients of thermal expansion and the elastic moduli which determine stress levels and a simple bedding plane dependent tensile failure mechanism.

THE ROLE OF SITE CHARACTERISTICS IN THE CONTROL OF UNDERGROUND COAL GASIFICATION, SAND80-2664, R. E. Glass, B. E. Bader, Sandia National Laboratories, Proceedings of AIChE 1981 Spring National Meeting, American Institute of Chemical Engineers, April 5-9, 1981, Houston, Texas and 5th Annual 1981 Symposium on Instrumentation and Control for Fossil Energy Processes, Argonne National Laboratory, June 8-10, 1981, San Francisco, California and Energy Progress-TM, American Institute of Chemical Engineers.

Underground Coal Gasification (UCG) offers many potential economic and environmental advantages. Offsetting these advantages is the substantial lack of ability to control the UCG process. For example, only three elements of external process control have been utilized. These are: 1) injected gas composition, 2) injected gas flow rate, and 3) product gas pressure. Variation of these independent variables in UCG tests has resulted in mixed indications of their effectiveness.

This study indicates other possible elements of control based on the results of recent field tests and modeling efforts. These elements are associated with the selection of the specific site where the process is conducted and with the design of the test itself. The results of previous UCG field tests have indicated that the conditions that exist in the coal seam and overburden before the start of the combustion process may dominate all other factors. These conditions are the geotechnical characteristics, such as faulting and groundwater hydrology, as well as the details of the test layout, well completions, and linking method.

Evidence exists to support the thesis that these preignition conditions can be dominant factors in process control of in situ operations. The data from recent UCG tests have been analyzed with respect to the effect of the site geotechnical characteristics and the test design. The results of this analysis indicate that geologic faulting, coal seam permeability distributions, well completions, and coal strength are important elements of control in the process behavior. Attempts to influence Hanna IVB by varying external process parameters could not overcome these effects. Similar results have been observed in other UCG tests.

THE EFFECT OF THERMAL AND MECHANICAL PROPERTIES ON INITIAL CAVITY GROWTH, SAND81-1063, R. E. Glass, Sandia National Laboratories, Proceedings of 7th Annual Underground Coal Conversion Symposium, September 7-11, 1981, Fallen Leaf Lake, California.

Recent field and laboratory studies in UCG have indicated that the thermal and mechanical properties of coals may be the controlling parameters in determining initial cavity growth. To examine this possibility, laboratory tests are being conducted on the Hanna coal to measure these properties. These properties will be incorporated in a finite element thermomechanical model to determine the stress field and subsequent cavity growth directions. The properties will be varied over a range of possible values to determine the role they play in determining the stress field. Sensitivity studies to date indicate that the orthotropic nature of the coal and the depth of burial are important parameters in UCG.

POST-BURN DRILLING RESULTS FOR THE HANNA II, PHASES 2 AND 3 UNDERGROUND COAL GASIFICATION EXPERIMENT, SAND81-1070, R. E. Glass, A. D. Youngberg, D. Sinks, Sandia National Laboratories.

During the Fall of 1980 LETC completed an exploratory drilling program at the Hanna II, Phases 2 and 3 experimental site. Twenty-two drill holes with geophysical logging were completed. Results from thermal data and material balance calculations were combined with the drill hole and geophysical logging information to further define the boundaries of the gasification zone. Four vertical cross sections were constructed to show the size and shape of the burn cavity. Eight 3-D plots showing different views of the cavity were completed using a DISSPLA plotting package. Performance of the equipment used during the drilling operation is also discussed.

THE EFFECT OF THERMOMECHANICAL PROPERTIES ON INITIAL CAVITY GROWTH, SAND81-1941, R. E. Glass, Sandia National Laboratories, Proceedings of the 7th Annual Underground Coal Gasification Symposium, September 7-11, 1981, Fallen Leaf Lake, California.

Recent field and laboratory studies in UCG have indicated that the thermomechanical properties of coals may be the controlling parameters in determining initial cavity growth. To examine this possibility laboratory and modeling efforts are being directed at determining these properties and incorporating them in a cavity growth model. The results of the work emphasize the critical role that anisotropic strengths play in determining the shape of the cavity.

RESULTS OF THE FOURTH HANNA FIELD TEST, SAND80-0847, L. F. Wojdac, J. R. Covell, F. A. Barbour, G. W. Gardner, Laramie Energy Technology Center; P. J. Hommert, R. E. Glass, Sandia National Laboratories, Proceedings, Sixth Annual Underground Coal Conversion Symposium, July 13-17, 1980, Afton, Oklahoma.

The Hanna IV experiment was completed in September 1979. The experiment was conducted in two phases due to operational difficulties. The first phase, Hanna IVA, resulted in an override. Characterization of the remaining coal indicated that air communication could be established between process wells positioned 112.5 feet apart in the same well line. Reverse combustion linking was attempted over a 75-foot and a 37.5-foot portion of the 112.5-foot well spacing. Thermal activity was generally noted in the top 10 feet of the coal seam. Gasification over the 112.5-foot distance resulted in the propagation of the burn front at the coal-overburden interface. Gasification over the final 75-foot distance also resulted in a high burn zone, probably influenced by the first burn. Post-burn evaluation points to fractures as major influencing factors.

FINAL REPORT--SITE SELECTION AND CHARACTERIZATION FOR AN UNDERGROUND COAL GASIFICATION TEST IN WASHINGTON STATE, VOLUME 1--PROJECT SUMMARY; VOLUME 2--PROJECT DETAILS, L. C. Bartel, S. L. Love, Sandia National Laboratories, SAND81-2151/1-2.

This project was conducted in the State of Washington to select and characterize a site (or sites) suitable for an Underground Coal Gasification (UCG) experiment.

A set of general criteria, based on previous UCG experience, was used to screen potential sites. Based on these criteria, the Tono Basin in the Centralia-Chehalis coal district, was selected for detailed characterization. The basin is near the Centralia Steam Electric Generating Plant, and it contains a

47-foot thick seam of sub-bituminous coal at a depth of about 600 feet. Geotechnical characterization of Tono was accomplished by using a combination of surface seismic surveys, surface electromagnetic surveys, borehole logging, coring, and hydrological testing. An environmental survey of the Tono Basin was also conducted.

The results of the project have not disclosed any characteristics which would preclude conducting a gasification experiment in the Tono Basin. However, several factors need further evaluation before committing to a test: 1) the effect of the coal's high ash content, 2) the effect of possible fracturing near the top of the coal seam, 3) the seam's directional permeability, 4) the hydrogeologic characteristics of overburden sandstone, and 5) the local hydrology of the test site. A preliminary test plan was developed which, if implemented, should lead to a quantitative assessment of the correlation between pre-test characteristics and the functional UCG process, the product gas quality and potential use, and the environmental effects.

C. Instrumentation

PRELIMINARY EVALUATION OF A RADIATION GAUGE FOR COAL/CHAR DENSITY MEASUREMENTS FOR COAL GASIFICATION APPLICATIONS, SAND81-1819, J. G. Castle, G. C. Stoker, D. G. Sample, M. G. Thomas, J. K. Linn, Sandia National Laboratories.

The development of entrained-bed coal gasifiers is being hindered by the lack of suitable two-phase gas/solids flow measurement instrumentation in critical coal and char feed lines. One possible flow measurement technique is the combination of an x-ray density measurement with a two-location time-correlation velocity determination. This report describes experiments and analyses that have been conducted to evaluate the feasibility and accuracy of x-ray density measurements of coal/char in high pressure feed lines. Transmission of 70 keV x-rays through steel pipe and various coal samples have been measured for various beam diameters (.254 and 1.0 cm) and coal thicknesses. Experimental results of signal filtering on noise reduction are reported for filtering time constants of .01 to .30 seconds. Analyses are reported that extend the range of x-ray energies up to 200 keV that could minimize the detectable char/coal density differences. From the data and analyses reported, it is concluded that x-ray transmission density measurements are feasible in gas/solids feed lines. Area coal density changes of about .01 gm/cm^2 and .05 ggm/cm^2 are detectable with signal filtering time constants of .30 and .01 seconds, respectively. These minimum detectable changes translate to absolute measurement uncertainties of .3 and 1.6 percent solids (by volume), respectively, in a 3.16 cm Schedule 160 feed line. These compare to the nominal 10-15 percent solids filling under normal flow.

TESTING OF A CORNERING WATER JET DRILLING SYSTEM FOR DRILLING HORIZONTAL HOLES IN COAL, SAND81-1720C, S. L. Love, K. M. Timmerman, Sandia National Laboratories, Proceedings of the 7th Annual Underground Coal Conversion Symposium, September 7-11, 1981, Fallen Leaf Lake, California.

Sandia National Laboratories is developing a drilling system which uses high pressure water jets to drill horizontal holes in a coal seam which is accessed through a vertical borehole. These horizontal holes can be drilled for the purpose of draining methane before mining begins or for creating linkage paths between vertical boreholes in a linked vertical well underground coal gasification process.

In two years of work, the elements of the water jet drill which have been developed and tested are the drilling head, an articulated drill string, and an instrumentation system for directional control and hole mapping. In the most recent field tests, six to eight inch diameter holes of up to 102 feet long

were drilled into a coal seam accessed at the face of a surface mine pit.

A quarter scale laboratory model of the cornering device has been built and tested to evaluate the design, and hardware is being built for the full-scale version. Tests of the complete round-the-corner system will be performed later this year.

THE ROLE OF INSTRUMENTATION IN UCG PROCESS DEVELOPMENT, SAND81-2484A, P. J. Hommert, Sandia National Laboratories, 1982 Spring National Meeting, Invited Paper, American Institute of Chemical Engineers, June 7-10, 1982, Anaheim, California.

Underground coal gasification field test results obtained since 1976 are reviewed, illustrating the important role that the UCG process feature of a varying reactor geometry has on resource recovery and gas quality. The different instrumentation used on these tests is then reviewed, particularly as to its effectiveness or lack of in defining process geometry. Instrumentation such as thermocouples, HFEM, acoustic and surface resistivity are discussed with respect to concept, cost, resolution, data acquisition and data analysis. Results indicate that when instrumentation is appropriately deployed it can provide significant insight into the dynamics of reactor growth.

INSTRUMENTATION FOR THE CORNERING WATER JET DRILL, SAND82-0971, B. P. Engler, Sandia National Laboratories, Proceedings of the Eighth Annual Underground Coal Conversion Symposium, August 15-19, 1982, Keystone, Colorado.

Sandia National Laboratories is developing a cornering drilling system which utilizes rotating high pressure water jets to drill horizontal holes from a vertical borehole. Above-ground tests of the full-scale system are underway. A key feature of the system is the ability to monitor the performance of the drilling equipment and the location of the drill string underground at all times. To do this, the drill utilizes on-board directional transducers, a computerized data acquisition and processing subsystem, and a driller's control station. The instrumentation system has worked satisfactorily in the two holes drilled at the Sandia National Laboratories testing facility. This report summarizes the design and evaluation of that instrumentation system to date.

DEVELOPMENT TESTING OF A CORNERING WATER JET DRILL, SAND82-0970, D. L. Shirey, S. L. Love, Sandia National Laboratories, Proceedings of Eighth Annual Underground Coal Conversion Symposium, August 15-19, 1982, Keystone, Colorado.

Sandia National Laboratories is developing a drilling system which uses high pressure water jets to drill horizontal holes in a coal seam accessed through a vertical borehole. For underground coal gasification, these horizontal holes are used to create linking paths between vertical process wells. Currently, the full-scale cornering drill system is undergoing above-ground evaluation tests in Albuquerque. An elevated test platform is being used to permit observation of the cornering and drilling mechanisms during operation. A simulated coal block serves as a convenient drilling target during these tests. Recorded hole location data have been compared with independently determined measurements. Test results, to date, indicate satisfactory performance of the major drill components.

INSTRUMENTING AND EVALUATING LARGE SCALE IN SITU EXPERIMENTS, SAND81-0968C, G. S. Davidson, P. J. Hommert, Sandia National Laboratories, AIChE Spring 1981 National Meeting and 11th Petro-chemical and Refining Exposition, American Institute of Chemical Engineers, April 5-9, 1981, Houston, Texas.

Research experiments in in situ combustion require extensive instrumentation coverage if they are to be adequately diagnosed. The instrumentation includes both process related and in situ reactor sensors. Specialized sensors that overcome some of the survivability problems associated with standard thermometry are described. In order to maximize the information from any such large scale instrumentation effort requires a computer based data acquisition system. The data acquisition developed at Sandia National Laboratories for use on in situ combustion experiments is discussed. The system contains features that allow it to be flexible in its ability to accommodate changes in experiment definition and that facilitate real-time validation and analysis of the data. Examples of the systems analysis capability include thermocouple diagnostics and extensive plotting routines.

EVALUATION OF THE CSAMT TECHNIQUE FOR MAPPING ENHANCED OIL RECOVERY PROCESSES, SAND81-1055A, L. C. Bartel, Sandia National Laboratories, 51st Annual Meeting of the Society of Exploration Geophysicists, October 11-15, 1981, Los Angeles, California.

The mapping of enhanced oil recovery (EOR) processes is important to predict process behavior and to exhibit some control of the process for maximizing the stimulation of oil reservoirs. Sandia National Laboratories is evaluating various surface

exploration geophysical techniques that may be applicable for mapping EOR processes. At the present time, field trials have been conducted using the controlled source audio-frequency magnetotelluric (CSAMT) electromagnetic (EM) geophysical prospecting technique. Use of electrical and/or EM survey techniques to map EOR processes depends upon electrical resistivity changes of the affected region during the process. The resistivity of the oil pay-zone depends upon the resistivity of the groundwater, permeability, formation porosity, and the degree of water saturation and may be higher or lower than the surrounding strata. However, during an EOR process (steamflood and/or fireflood and possibly certain types of chemical floods) the resistivity of the affected region will change. Both the steamflood and fireflood processes lead to a lower value of resistivity in the affected region.

Field trials of the CSAMT technique have been conducted at steamflood, tar sand oil recovery experiment conducted by the Laramie Energy Technology Center (depth 500 ft) and at a fireflood heavy oil recovery experiment conducted by the Bartlesville Energy Technology Center (depth 360 ft). Illustrative constant apparent resistivity controus for a steamflood and a fireflood are shown in the figures where the area of low apparent resistivity outline the affected region. In both experiments, controus of constant apparent resistivity for measurements taken several months apart show the movement and asymmetry of both processes and the affected areas agree with production records. Data were taken in both the near and far field regimes. Although from the interpretation of near field data it is difficult to obtain depths and absolute resistivity values, the near field regime tends to magnify resistivity contrasts and the near field data are valuable for determining areal extent of the process. The results of the field measurements and mathematical modeling in progress will be discussed. The CSAMT technique appears to be a viable technique for mapping certain types of EOR processes.

RESULTS OF USING THE CSAMT GEOPHYSICAL TECHNIQUE TO MAP AN UNDERGROUND COAL MINE FIRE, SAND81-1067A, L. C. Bartel, S. L. Love, Sandia National Laboratories, Proceedings of 7th Underground Coal Conversion Symposium, September 8-11, 1981, Fallen Leaf Lake, California.

Throughout the United States there are many abandoned underground coal mines which are on fire. A great deal of effort has been invested by many agencies to locate and extinguish these fires. For the DOE UCG program, such fire control projects present an opportunity to investigate certain aspects of in situ coal gasification. Studying of the mine fires under natural conditions provides valuable information on the UCG process and, for example, allows an evaluation of monitoring techniques, subsidence effects, and multimodule effects.

Activities have been initiated to: 1) develop techniques to map existing underground coal mine fires to determine areal extent and provide information to predict the growth of the combustion zone; and 2) develop methods to predict the growth of the combustion zone. Subsequent studies may include investigative methods to utilize the combustion gas, and if feasible, perform a small-scale field test to extract the gas.

The controlled source audio-frequency magnetotelluric (CSAMT) electromagnetic (EM) exploration technique is being evaluated for use in mapping the UCG process. This geophysical prospecting technique has been used to map a mine fire near Marshall, Colorado. The coal seam in this area varies in depth from essentially outcrop to a depth of 27 m with a thickness of 3m. Large apparent resistivity variations have been observed across the old mine workings. The mines in this area were mined by room and pillar methods near the turn of the century and significant subsidence has taken place. The resistivity variations have been interpreted as due to areas of active fire and/or areas containing char, water saturated rooms where the roof has subsided, pillars, and empty rooms. Results of the CSAMT mapping will be discussed, as well as the applicability of this technique to map the UCG process.

INSTRUMENTATION AND ANALYSIS TECHNIQUES FOR FUTURE UCG APPLICATIONS, SAND79-1021, P. J. Hommert, G. S. Davidson, Sandia National Laboratories, Proceedings, Fifth Annual UCC Symposium, June 18-20, 1979, Alexandria, Virginia.

Over the past five years Sandia Laboratories has been engaged in instrumentation development for the In Situ Coal Gasification Program. This paper summarizes the present state of this work with particular emphasis on future instrumentation systems. While continued improvements in hardware are being pursued, considerable work over the past year has been in the development of standardized analysis software. Procedures developed to produce a real-time display of the affected coal region are discussed. Two key elements of the software are generally application independent of test site or well pattern, and implementation on a field mini-computer. The requirements for the use of this software in terms of instrumentation hardware and data acquisition are outlined. The accuracy of results is examined through the use of generated data. Results indicate that on future tests, with increased confidence in model predictions and greater reliance on remote monitoring techniques, the same information can be obtained with significantly fewer instrumentation wells.

PARAMETER ESTIMATION APPLIED TO THERMAL DATA FROM IN SITU COAL GASIFICATION EXPERIMENTS, SAND78-0591, P. J. Hommert, Sandia National Laboratories, 53rd Annual Technical Conference and Exhibition, Society of Petroleum Engineers of AIME, October 1-4, 1978, Houston, Texas.

Parameter estimation techniques that allow quantitative treatment of thermal data from an in situ coal gasification experiment are presented. After a discussion of the important aspects of using parameter estimation, the specific models used for the Hanna II and Hanna IV test data are outlined. In particular, conduction models have been useful for describing the reverse combustion process and a formal mapping procedure has provided quantitative detail of cavity growth during forward gasification.

TRACER AND AIR ACCEPTANCE CHARACTERIZATION OF A SAN JUAN BASIN COAL, F. L. Williams, H. E. Nuttall, University of New Mexico, C. E. Tyner, R. D. Jacobson, Sandia National Laboratories, Proceedings of 6th Underground Coal Conversion Symposium, July 13-17, 1980, Afton, Oklahoma.

As part of the ongoing effort to develop and assess the feasibility of underground coal gasification in New Mexico, a field study was performed to determine the natural flow characteristics of an undisturbed coal seam. Dewatering, air injection, and tracer experiments were conducted on a two-hole test pattern, spaced 30 ft apart, in a 15-ft-thick seam located about 500 ft below the surface. This was the first field experiment in coal to utilize a newly developed downhole measuring system designed and operated by Sandia National Laboratories. From the tracer flow logs and air acceptance tests we found that the formation allows gas flow (100 SCFM at 250 psi) with low water production (50 gpd). While some vertical variation in air flow and tracer residence time through the coal seam was found, all of the coal sustained flow through a relatively low volume of active voids. Only 10 percent of the injected air was recovered and the recovery rate paralleled trends in the injection rate.

A TRACER FLOW SYSTEM FOR IN SITU BED CHARACTERIZATION, 4th Symposium of Rocky Mountain Fuel Society, Brigham Young University, February 9-10, 1979, Salt Lake City, Utah, C. E. Tyner, Sandia National Laboratories.

A downhole tracer system has been developed to allow interrogation of wellbore-to-wellbore flow paths in geologic formations. The system consists of a downhole tracer injector located in an injection well and a string of four downhole detectors located in a recovery well. In addition, a second

injector, located at the bottom of the detector string, allows determination of flow rates in the recovery well. The system was tested in a simulation facility with controlled bed and flow conditions to evaluate system performance and to provide a basis for assessing reliability and accuracy of results of future tests. The results of these controlled tests and of initial field tests are discussed.

MASS FLOW MEASUREMENT OF SOLIDS/GAS STREAM USING RADIOMETRIC TECHNIQUES, SAND82-0228A, J. K. Linn, D. G. Sample, Sandia National Laboratories, 1982 Symposium on Instrumentation and Control for Fossil Energy Processes, Department of Energy/Argonne/SCIEP, June 7-9, 1982, Houston, Texas.

A mass flowmeter utilizing radiometric techniques has been designed and built for measuring char/gas flow in coal gasification processes. The instrument combines a radiometric density measurement and a time cross-correlation velocity determination into a non-intrusive gas/solids mass flowmeter. The instrument is designed to measure coal/char flow of up to 10% by volume at velocities in the range of 1-5 meters per second. The flowmeter is designed for non-intrusive measurements of high pressure (750 psi) flows. Obtainable mass flow accuracy is dependent on natural flow perturbations and the spacing of multiple detectors.