**Modeling of Hydrologic Conditions and Solute Movement
in Processed Oil Shale Waste Embankments Under Simulated
Climatic Conditions**

**Quarterly Report
Second Quarter FY 1992
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1.0 Introduction

This report presents research objectives, discusses activities, and presents technical progress for the period January 1, 1991 through March 31, 1991 on Contract No. DE-FC-21-86LC11084 with the Department of Energy, Laramie Project Office. This research is titled "Modeling of Hydrologic Conditions and Solute Movement in Processed Oil Shale Waste Embankments Under Simulated Climatic Conditions" and is the continuation of previous research initiated in 1986.

The scope of the research program and the continuation is to study interacting hydrologic, geotechnical, and chemical factors affecting the behavior and disposal of combusted processed oil shale. The research combines bench-scale testing with large scale research sufficient to describe commercial scale embankment behavior. The large scale approach was accomplished by establishing five lysimeters, each 7.3 x 3.0 x 3.0 m deep, filled with processed oil shale that has been retorted and combusted by the Lurgi-Ruhrgas (Lurgi) process. Approximately 400 tons of Lurgi processed oil shale waste was provided by Rio Blanco Oil Shale Co., Inc. (RBOSC) through a separate cooperative agreement with the University of Wyoming (UW) to carry out this study.

Three of the lysimeters were established at the RBOSC Tract C-a in the Piceance Basin of Colorado. Two lysimeters were established in the Environmental Simulation Laboratory (ESL) at UW. The ESL was specifically designed and constructed so that a large range of climatic conditions could be physically applied to the processed oil shale which was filled in the lysimeter cells.

2.0 Milestone Schedule/Progress Summary

A continuation application and proposal which outlined and described the research to be conducted was submitted to the LPO in January 1991. The proposed research program would be conducted over a two year period. Budgets were developed for the first and second years for this research and submitted as part of the proposal. The proposal was accepted by LPO and the Morgantown Energy Technology Center (METC) in April 1990. Work was initiated on the proposed research May 1, 1991 upon notification that the first year budget had been finalized by METC and UW. A detailed contract summary and budget update is presented in section 2.1.

The objectives of the continuation research are:

- Determine and assess effects on the hydrologic and geotechnical properties of the disposed processed oil shale waste material caused by extreme precipitation input sufficient to achieve steady state drainage of water through the oil shale waste material.
- Determine and assess effects on the hydrologic and geotechnical properties of the disposed processed oil shale caused by multiple freeze-thaw cycles and extreme storm events.

Five milestones were outlined and discussed in the continuation research plan and the previous quarterly reports for this project. A time/activity schedule and a brief discussion of progress is presented below for these milestones:

1. **Prepare an interim report presenting data and discussing conclusions accomplished for Cooperative Agreement DE-FC21-86LC11084 from October 1986 to May 1991.**
Discussion: A draft of this report was completed for both internal review and review by the COTR in December 1991. This draft is currently being revised and finalized. The final draft for this report will be available in February 1992.
Status: Completed 4/92.
2. **Design (model) a series of simulated climatic conditions and rainfall events which will provide extreme hydrologic and geotechnical conditions to the processed oil shale in the Environmental Simulation Laboratory (ESL).**
Discussion: Two climatic models need to be developed to accomplish the research objectives. The first climatic model and sampling program (described below) is designed to accommodate objectives for infiltration behavior, and to develop and analyze saturated conditions in the processed oil shale. The second climatic model will be run after saturated conditions have been developed within the profile. This model will be designed to produce a series of freeze thaw conditions and analyze the effects on the processed oil shale. A detailed discussion of the climatic models designed are presented in Sections 3.1 - 3.2.

Schedule: 7/3/91 - 12/31/92.

Status: Completed.

3. Apply the designed climatic conditions in the ESL and collect hydrologic and geo-technical data.

Discussion: The environmental simulation laboratory has the capability of monitoring runoff and determining a runoff hydrograph via an automated weighing water collection system. Infiltration curves for each applied storm can be basically developed by subtracting the measured runoff hydrograph data from the applied rainfall hyetograph. Infiltration curves produced from different storm events will be evaluated as a function of the antecedent moisture content at several depths, and from the hydraulic gradients within the profile. Water contents will be measured before, during, and after all applied storm events. Hydraulic gradients will be calculated from water characteristic curves that were previously developed in this research program. Multiple regression techniques will aid in analyzing effects of existing hydraulic gradients and antecedent moisture contents by different depths vs infiltration rate.

Schedule: 2/10/92 - 5-31/91 (estimated).

Status: Climatic simulations were initiated in February 1992. Analyses are proceeding on schedule.

4. Destructively sample and dispose of the processed waste material in the lysimeter beds of the ESL.

Discussion: Destructive sampling will be conducted to extract undisturbed specimens and cores of the processed oil shale at several different depths. These specimens will be used to evaluate hydrologic properties, soil mechanical properties, and leachate chemical properties. These data obtained and the properties measured from the "weathered" processed oil shale will be compared to the results from the testing program which was previously conducted.

Schedule: 8/92 - 9/92. (estimated).

Status: Program would be initiated after completion of all climatic simulations.

5. Analyze and evaluate all data sets and prepare final report.

Discussion: This report will be a comprehensive report, detailing all data and results, for this Cooperative Agreement.

Schedule: 9/92 - 4/93.

*Page 4 & 5 removed.
Budget info*

3.0 Technical Progress/Results

3.1 Simulated Climatic Models

Two climatic models were developed to accomplish the research objectives. The first climatic model was designed to accommodate objectives for infiltration behavior, and to develop and analyze saturated conditions or conditions of steady state drainage within the processed oil shale. Hydrologic analysis from the RBOSC, Tract C-a field lysimeters taken from 1988 - 1992, indicated that the greatest flux of water infiltration was during this period. These data have been discussed in previous quarterly reports, the FY 1990 annual report, and the Comprehensive Interim Technical Progress Report for 1986 - 1991. Ambient temperature and relative humidity conditions were modeled (designed) based on the Normal mean-monthly temperature and relative humidity measured for Rifle, Colorado, near the Piceance Basin. The Normals for May were used because it was assumed that the primary input of water to an embankment or a disposal facility would occur during the April/May period. The climatic model was designed to provide a constant ambient temperature of 17.1° C and 48% relative humidity. A constant solar flux of 30 W/m² was designed for input by the light source for 12.5 hours per day. The constant climatic conditions were designed to help insure constant evaporation from the processed oil shale. Rainfall rates and storms produced in the ESL with this climatic model will be discussed in the next section (3.2), in association with the infiltration measurements.

The second climatic model was designed to run after saturated conditions had developed within the profile to produce a series of freeze thaw events. Based on earlier freeze tests, it was determined that the freezing front within the processed oil shale would progress at an adequate rate at temperatures between less than -12° C. The climatic model, therefore, was designed to produce temperatures between -18° and -12° C. Relative humidity was designed to be between 30% and 90% in psychrometric ranges common for the desired ambient temperatures requested. Solar flux of 95 W/m² was designed for input by the light source for 8.5 hours per day. The application of this second climatic design had not been initiated at the time of this report. Two objectives of this series of climatic experiments are to document potential changes in infiltration rate and infiltration behavior caused by the freeze-thaw cycles, and to determine potential mechanical/ geotechnical changes in the processed oil shale caused by the freeze-thaw cycles. Infiltration tests will again be conducted after freeze-thaw conditions and compared to those previously measured.

3.2 Lysimeter Infiltration Measurements

The ESL has the capability of monitoring runoff and determining a runoff hydrograph from the plots via an automated weighing water collection system. In order to measure infiltration using this system rainfall must exceed the infiltration rate of the material and runoff must be generated. Based on previous experience, and the in situ infiltration measurements reported in the previous quarter, it was determined that a rainfall rate of 97 mm/hr would liberally, exceed the infiltration rate of processed oil shale waste in the lysimeters. Runoff would be generated and passed over a weir system where it would be collected and measured by a pressure transducer system. The processed oil shale was placed into the lysimeter cells at

a 1% slope to the weir. Placement of the material into the ESL lysimeter cells was previously described in the FY 1989 Annual Report.

Storm events were designed to be input by the rainfall simulation system of the ESL at a rate of 97 mm/hr. Storm events were applied for approximately 1.5 hours three times per week. Infiltration curves for each applied storm were developed by subtracting the measured runoff hydrograph data from the applied rainfall hyetograph. Accumulated runoff was automatically measured every thirty seconds by the pressure transducer/data logging system. Infiltration curves were developed by smoothing the runoff measurements to eliminate noise, and subtracting them from the applied rainfall amounts for each storm. Soil moisture measurements were taken using TDR and Neutron Moderation before and after storm events. Future data analysis will consist of comparing and correlating infiltration measurements with in situ water contents and existing hydraulic conditions. Hydraulic gradients will be calculated from water characteristic curves that were previously developed in this research program. The development of water-characteristic curves were discussed in the Comprehensive Interim Technical Progress Report. Multiple regression techniques will aid in analyzing effects of existing hydraulic gradients and antecedent moisture contents by different depths.

Infiltration curves were plotted for individual storms along with cumulative infiltration, precipitation and runoff. Results from a particular storm will be used as an example to show how the data was plotted and used to determine rainfall-infiltration relationships. Storm six was run on March 2, 1992 with a requested rainfall rate of three inches per hour with an actual duration of 1.183 hours (approximately 71 minutes). Figure 3.2.1 shows the plots of rainfall requested by the computer, rainfall measured by the tipping bucket rain gage in the ESL, and infiltration rate. The rainfall data points measured by the tipping bucket rain gage are used to verify the rainfall input by the rainfall simulators.

Figure 3.2.2 is a plot of cumulative precipitation against cumulative infiltration for the same storm event. This graph demonstrates the total precipitation the plot received against the total amount of water infiltrated into the substrate. Infiltration data like those presented in Figure 3.2.1 and Figure 3.2.2 were being conjugated and summarized at the time of this report.

3.3 Lysimeter Leaching Measurements

As was discussed in section 3.1, the first climatic model was designed to accommodate measurements for infiltration, and to develop and analyze saturated conditions or conditions of steady state drainage within the processed oil shale. The processed waste was placed in the ESL lysimeters above a 15 cm coarse gravel layer to allow drainage of leachate through perforated well pipe to the outside. The analysis of the conditions leading to steady state drainage through the processed oil shale and the subsequent generation of leachate was being analyzed at the time of this report.

Preliminary data is presented in Figures 3.3.1-3.3.6. Each graph shows the original in situ water content profile before application of the first climatic model and rainstorm events and profiles before and after specific rainstorm events. Data are presented for each cell at dates in the beginning, middle, and near the end of the application of heavy rainfall events. As was

Figure 3.2.1 Infiltration and rainfall rate measured for cell 1. Storm was produced on March 22, 1992 in the ESL.

Figure 3.2.2 Cumulative infiltration and cumulative rainfall for cell 1. Storm was produced on March 22, 1992 in the ESL.

previously indicated, these data will be analyzed in detail to determine flux, changes in hydraulic gradients, and changes in unsaturated hydraulic conductivity during drainage conditions.

It is apparent from these data, however, that saturated conditions and steady state drainage of leachate developed in cell 2 before cell 1. Two conditions may have contributed to this difference. The processed oil shale in cell 2 of the ESL was placed with 40% w/w, 15 cm nominal, overburden. The oil shale in this cell may have a slightly higher hydraulic conductivity than the material in cell 1 because of the overburden mixture. A factor which may be more important, however, is that the overburden material caused the surface roughness of cell 2 to be much higher than that of cell 1. This factor was easily noticeable when observing rainfall events within the ESL. The coarse material lying on the surface of cell 2 significantly slowed surface runoff toward the weir system. This causes increased water retention time, and therefore, the amount of water which infiltrated into the plot. These conditions would increase gravitational heads within cell 2 also promoting faster drainage.

Leachate water has been sampled for cell 1 and cell 2 on a daily basis from the time leachate first appeared from each cell. This sampling was continuing at the time of this report. Water samples will be analyzed for the following chemical constituents: Sodium (Na), Calcium (Ca), Magnesium (Mg), Copper (Cu), Boron (B), Molybdenum (Mo), Iron (Fe), Lead (Pb), Selenium (Se), Arsenic (As), Sulfate (SO_4), Chloride (Cl), Fluorine (F), total organic carbon (TOC), total alkalinity, and pH. Results for these leachate data will be presented in the next quarterly report.

Figure 3.3.1 Water content profiles for cell 1 showing the initial baseline condition, before a rainstorm produced in the ESL on February 20 1992, and 24 hours after conclusion of the storm.

Figure 3.3.2 Water content profiles for cell 2 showing the initial baseline condition, before a rainstorm produced in the ESL on February 20 1992, and 24 hours after conclusion of the storm.

Figure 3.3.3 Water content profiles for cell 1 showing the initial baseline condition, before a rainstorm produced in the ESL on March 9, 1992, and 24 hours after conclusion of the storm.

Figure 3.3.4 Water content profiles for cell 2 showing the initial baseline condition, before a rainstorm produced in the ESL on March 9, 1992, and 24 hours after conclusion of the storm.

Figure 3.3.5 Water content profiles for cell 1 showing the initial baseline condition, before a rainstorm produced in the ESL on April 15, 1992, and 24 hours after conclusion of the storm.

Figure 3.3.6 Water content profiles for cell 2 showing the initial baseline condition, before a rainstorm produced in the ESL on April 15, 1992, and 24 hours after conclusion of the storm.

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