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1 OF 1

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FOURTH QUARTER REPORT

For Period October 1, 1992 to December 31, 1992

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Project Title

HIGH EFFICIENCY SHALE OIL RECOVERY

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The U. S. Dept. of Energy

Office of Energy Related Inventions

By

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Introduction

Project Objective: The overall project objective is to demonstrate the high efficiency of the Adams Counter-Current shale oil recovery process. The efficiency will first be demonstrated on a small scale, in the current phase, after which the demonstration will be extended to the operation of a small pilot plant. Thus the immediate project objective is to obtain data on oil shale retorting operations in a small **batch** rotary kiln that will be representative of operations in the proposed **continuous** process pilot plant. Although an oil shale batch sample is sealed in the batch kiln from the start until the end of the run, the process conditions for the batch are the same as the conditions that an element of oil shale would encounter in a continuous process kiln. Similar chemical and physical (heating, mixing) conditions exist in both systems.

The two most important data objectives in this phase of the project are to demonstrate (1) that the heat recovery projected for this project is reasonable and (2) that an oil shale kiln will run well and not plug up due to sticking and agglomeration.

4th Quarter Summary: the following was completed and is reported on this quarter: (1) A software routine was written to eliminate intermittently inaccurate temperature readings. (2) We completed the quartz sand calibration runs, resolving calibration questions from the 3rd quarter. (3) We also made low temperature retorting runs to identify the need for certain kiln modifications and kiln modifications were completed. (4) Heat Conductance data on two Pyrolysis runs were completed on two samples of Occidental oil shale.

Accomplishments During Fourth Quarter

Software Routine to Cure Hardware Incompatibility: The time-proportioning temperature control system has a frequent on/off power transition which caused an intermittent hardware incompatibility problem. If the power to one of the heaters switched on simultaneously with a thermocouple reading, an error was induced in the reading which resulted in a "Wild" temperature reading. Wild temperature readings occurred in only about 2% of the readings. However, since 10 points are averaged together to obtain one averaged point, about 20% of the averaged points are affected. Although affected to a lesser extreme than individual readings, the averaged error is still very large. Wild readings ranged randomly between -1600F to +1600F. Efforts to shield the thermocouple lines from the induction errors were unsuccessful.

The problem was finally resolved by writing an elaborate routine, as a part of the "Kilntrol" software program. The routine analyzes each reading and sorts out and eliminates values that are more than a specified number of degrees deviation from the anticipated reading and from neighboring readings. If a number is very far from the expected value (a "Wild" point), it is easily identified. Some creativity was required to distinguish between a number that is only slightly erroneous (a "Wide" point) and a good reading of temperature that has actually changed from previous readings. This routine now keeps errors due to such averaged deviations limited to approximately 1 degree F. A schematic with explanations is included as Appendix A and explains the detail for trapping out "Wild" and "Wide" temperature readings.

Sand Calibration Runs:

Fig. 4 of last quarter's report did not include data for the high velocity range of kiln operation. Heat conductance was evaluated in greater detail during this quarter and a good Heat Conductance curve from 0 to 220 ft/min was established as shown in Fig. 1. The following generalizations can now be made from this data. Heat conductance between the kiln wall and the sand is

improved by an increase in sand mixing in the kiln. From 0 to about 60 ft/min, Heat Conductance increases almost proportionally to kiln velocity. Above about 60 ft/min the increase slows and above 150 ft/sec Heat Conductance decreases rapidly with increased kiln velocity. Appendix B provides the details for the determination of Heat Conductance in Fig. 1.

The reason for the decrease in Heat Conductance at high kiln velocity is due to at least two effects, both relating to centrifugation and diminished sand mixing. First, internal kiln surface irregularities, e.g. leading edges of auger blades, may tend to cause centrifugation at lower RPM than would occur without the irregularities. This point is significant to this project because the auger blades are a smoother design than previously used (in 1987), consequently the heat conductance peak is shifted to a somewhat higher RPM.

Secondly, centrifugation occurs at an RPM that is a function of the kiln diameter, or position that a particle is held from the kiln center. Fig. 2 is a graph of the function of $RPM_{CRITICAL} = [5873/Diam(ft)]^{1/2}$ and $V_{CRITICAL} = 241(Diam)^{1/2}$ ft/min. Here it is observed that although centrifugation may begin at the kiln surface, (e.g. at 115 RPM near the maximum kiln diameter of 5.4") particles may still flow and mix at various positions in the kiln closer to the kiln center not yet at critical RPM.

The maximum sand Heat Conductance is limited to just over 100 Btu/hr/ft²/°F for the 5.4" kiln. Fig. 2 also illustrates

that the critical velocity increases with increasing kiln diameter. So for larger kilns, Heat Conductance may increase by perhaps 10 or 20% by avoiding centrifugation at higher surface velocities than are allowed in the current small kiln. Larger kilns will also approximate flat plates better than small kilns and this fact is expected to improve heat conductance also (see data in Appendix B).

Data for two oil shale runs are included in the Heat Conductance figures and is understandably lower than quartz sand, at about 70 Btu/hr/ft²/°F. This is primarily because quartz has a high thermal conductivity, and oil shale mineral has typically only 15% quartz, while the remaining 85% (mostly dolomite, calcite, illite and feldspar) has a lower conductivity. Heat conductance in the range of 70 is at least 4 times that achieved in typical (slow) rotary kilns and will provide sufficient heat recovery for the success of the heat recovery kiln. More detail on pyrolysis runs will be included in the next quarterly report.

Kiln Modification Oil Shale Runs: We made low temperature retorting runs to identify the need for additional kiln modifications (specified in Task 4 of the Contract Project Description, Attachment A). Two modifications were observed to be necessary. These are (1) an expanded volume filter system to condense the atomized shale oil mist and (2) alterations in the filter heater and exit tube.

When oil shale is retorted and the shale oil vapor temperature is reduced below the dew point and begins to slowly coalesce, the vapor is referred to as "atomized mist." The condensation of the mist is a significant problem in oil shale systems due to the difficulty in coalescing or precipitating the mist. A compact filter container was developed during this quarter which is an improvement of that previously used and works satisfactorily to precipitate the atomized mist. Two of these filters are used in a series, as shown in the flow diagram in Fig. 4. The first precipitates the bulk of the mist while the second acts as a backup and measures the efficiency of the first.

Other modifications include alterations in the filter heater (in the exit end of the kiln) and modification to the exit tube so the filter heater can be removed through the exit tube. This alteration improves the ease of assembly and disassembly of the filter, filter heater and thermocouple in the vapor exit tube.

APPENDIX A

ROUTINE TO TRAP & EXCLUDE "WIDE" & "WILD" POINTS ©

Wild & Wide points are defined by the IF statement on the right. Wild points are discarded without changing the LMT_i limit. Wide points are possible good points so the LMT_i is increased to account for that possibility. The LMT_i is 1st increased by 30% then 70% on successive increments of CNT_i. When a widened limit satisfied the $NLM_i < 1$ IF statement, then CNT_i is set back to 0 and LMT_i gradually narrows to the minimum, 7, 9, or 13. By excluding Wild & Wide points & averaging 10 successive readings, accuracy is closer than 1 degree.

APPENDIX B

THERMAL CONDUCTANCE FOR THE ROTARY KILN

An Unsteady State Heat Analysis of the rotary kiln allows us to obtain **Thermal Conductance** of the system: During the time moment, dt , the sand heats dT_s . Some of the heat transfers from the sand to the inner kiln (auger blade assembly) and the inner assembly heats dT_i . The internal kiln temperature increment, dT_i , will be proportional to dT_s , or $dT_i = k dT_s$, where k will be a function of the sand mass in the kiln. The increase in sand energy in time moment, dt , is given by:

Change in Sand Energy = Heat Flow to Sand - Heat Flow to Inner Auger

Thus $m_s c_s dT_s = U A F_c \Delta T dt - m_i c_i k dT_s$

Where T = Temp. ($^{\circ}\text{F}$) (differential values dT & dt are defined above.)

ΔT = Wall Temp. - Sand Temp.

U = Thermal Conductance into the kiln ($\text{Btu/hr/ft}^2/^{\circ}\text{F}$)

t = Time (hr or min)

A = Total area of kiln wall

F_c = Fraction of the kiln wall covered by the sand

m_s = Mass (lb) of sand

m_i = Mass (lb) of interior kiln metal (auger blade assembly)

c = Specific Heat of quartz sand or steel

k = term relating the heating rate of the interior metal to the heating rate of the sand.

The equation can be rearranged as follows:

$$(dT/dt)/\Delta T = UAF_c/(m_s c_s + m_i c_i k)$$

By plotting the heating rate vs ΔT , we obtain the slope of the curve corresponding to the left side of the above equation. On the right side of the equation, values for A , F_c , m and c are available. The term $m_i c_i k$ has to be inversely proportional to the rate of heat transfer to the inner assembly, so k is an inverse function of m_s (because m_s is directly proportional to the heat transfer).

Figs. A1 through A4 (next page) illustrate how the inverse proportionality term is determined empirically by adjusting the value of k so that the data for large loads are in the same range as the data for small loads. Fig. A3 provides the best fit of large-load data with the small-load data. Consequently a value of $k = 3/m_s$ is used for the calculations in Fig. 1, of the Fourth Quarter Report. Each of the data points in the figures was determined from a separate run at the indicated kiln velocity (as illustrated in the last report). Data points agree within about $\pm 5\%$ which indicates a good heat transfer data system.

The low RPM data in the figures appear to be slightly lower than the literature data of Sullivan & Sabersky (*Int. J. Heat, Mass Transfer*, 18, pp 97-107, 1975) for sand particles sliding on a flat plate. We anticipate that as the kiln diameter is increased (in larger kilns) the heat transfer will more closely simulate that of a flat plate.

APPENDIX B

Figure A1: $k = 2/m_s$

Figure A2: $k = 2.5/m_s$

Figure A3: $k = 3/m_s$

Figure A4: $k = 3.5/m_s$

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