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Canada Centre for Mineral and Energy Technology
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REPORT ON VISIT TO HEAVY OIL ENHANCED RECOVERY PROJECTS SPONSORED BY ERDA IN THE USA

D.S. MONTGOMERY
ENERGY ADVISOR - CANMET

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<u>ENERGY RESEARCH PROGRAM</u>

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REPORT ERP/ERL 77-92 (FT)

REPORT ON VISIT TO HEAVY OIL ENHANCED RECOVERY PROJECTS SPONSORED BY ERDA IN THE USA

by Dr. D.S. Montgomery

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CONTENTS

SYNOPSIS

Dates: Sept. 11-16, 1977

Accompanied by: M. Edwards, EMR
George Stosur, ERDA
Field Engineers, Alan Leighton
Harold Lichtenberg
Lee Marchand

Visit Sponsored by: ERDA

Locations: Bellevue Oil Field, Louisiana
Bakersfield, California
Laramie Energy Research Center's Project at Asphalt Ridge, Vernal, Utah
Sohio Quarry and Separation Plant, Vernal, Utah
Bonanza Mine, Vernal, Utah
Uinta County Asphalt Quarry, Vernal, Utah
Laramie Energy Research Center, Laramie, Wyoming

Organizations Visited:
Cities Services (Bellevue)
Chanslor Western Development Co. (Bakersfield)
Sohio Lease (Vernal, Utah)
Laramie Energy Research Centre (ERDA)

BACKGROUND GENERAL

Several discussions have taken place during the past year between Dr. C.H. Smith, Senior Assistant Deputy Minister, EMR, and Mr. Jack Vanderyn, Head of the International Division of ERDA, concerning the exchange of information related to the enhancement of heavy oil production and the development of tar sand deposits as sources of synthetic crude oil. Mr. Abe Kotb was assigned the responsibility to develop an itinerary that would be of interest to Canadian officials concerned with this problem. It was agreed that the Canadian team would consist of:

Dr. Maurice Carrigy, AOSTRA

Mr. Douglas Gillard, Saskatchewan Dept. of Mineral Resources

Mr. M. Edwards, EMR Energy Policy Section

Dr. D.S. Montgomery, EMR, CANMET

Dr. Gillard was not able to attend at the last minute; the other members made the tour.

It is understood that in exchange for this visit the Canadians would organize a similar tour for American experts of Canadian facilities.

DETAILED FIELD NOTE

Institution:	Cities Services
Location:	Bellevue Field, near Shraveport, Louisiana, U.S.A.
Date of Visit:	Sept. 12, 1977
Name of Project:	Bodcan Insitu Combustion Project
ERDA Field Engineer:	Alan Leighton
Previous Reports:	Bodcan In Situ Ignition Report, ERDA E(04-03) - 1189 ERDA BERC-77/1 No. 9, Enhancement of Recovery of Oil and Gas
Technology of Interest:	Improved oil recovery in insitu recovery by (1) Fire flood, and (2) Water injection at top of formation.

GEOLOGICAL SETTING

Oil sands are Upper Cretaceous in age and are 98 ft. in thickness, located under 300 ft. of overburden. There is a limestone parting 25 ft. from the top of the oil sand. The thickness of this parting is variable and it is permeable to combustion gases and water. It is not very thick, possibly 6 ft. or so. The sand and silt is unconsolidated. Net pay is 56 ft. in the project area.

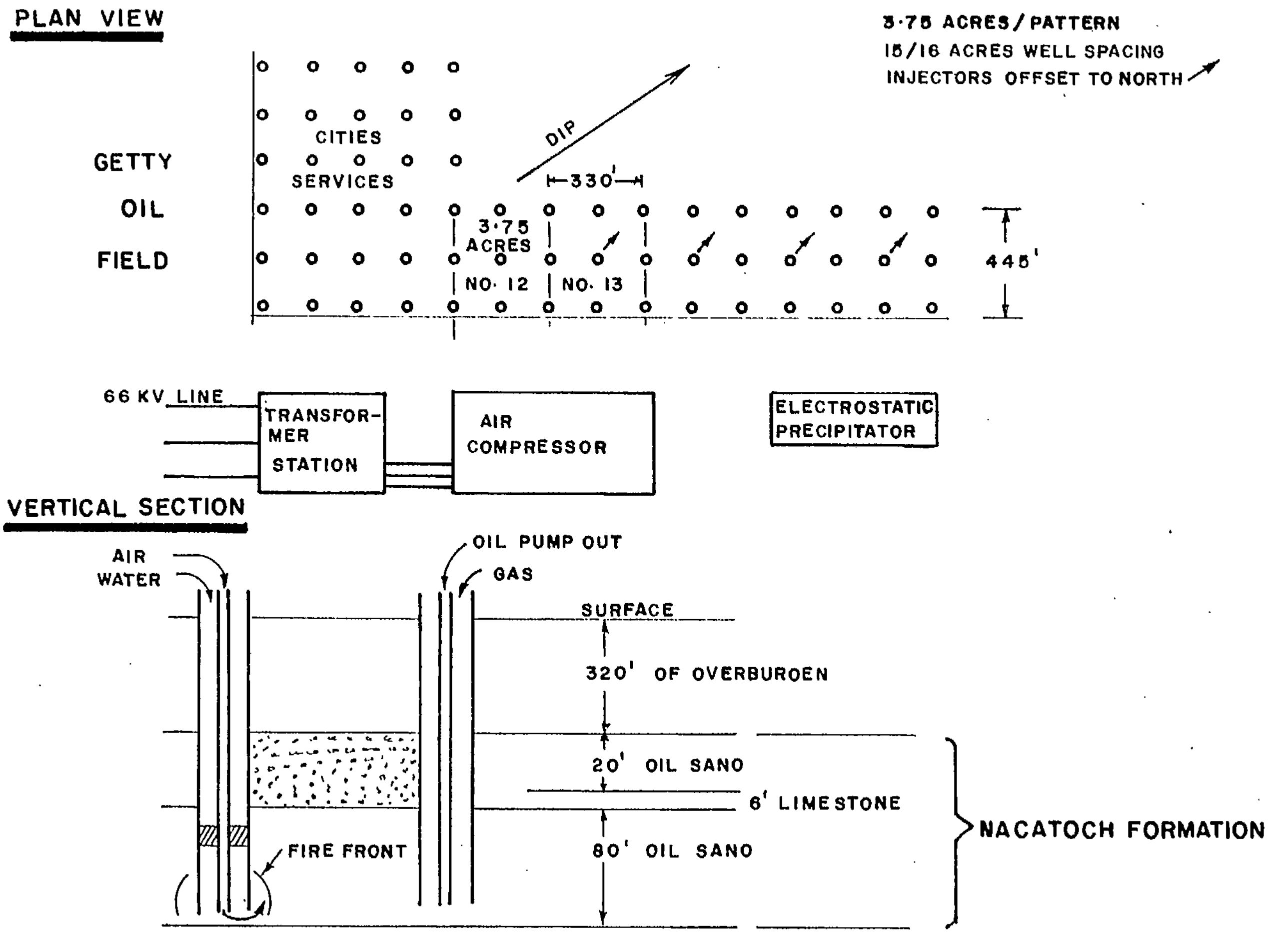
PAST HISTORY OF FIELD

The field was discovered in 1921 and a major producer is the Getty Oil Co. The portion of the field operated by Cities Services consists of 29 producers, formerly 1-2.5 barrels per day (B/D) of oil were produced per production well with a field production of 150 B/D of water. Before ignition the field production was stated to be 69 B/D. One month after ignition, 100 B/D oil were produced; two months after ignition, 200 B/D oil at a water to oil ratio of 1.3 were produced; current production is 400 B/D oil (4.5 B water per B oil). Injected water 1 B water per B oil.

FIELD LAYOUT

Plan Section

The wells are arranged according to the following plan:


PLAN VIEW
3·75 ACRES / PATTERN
15/16 ACRES WELL SPACING
INJECTORS OFFSET TO NORTH
GETTY
OIL
FIELD
CITIES
SERVICES
DIP
330'
3·75
ACRES
NO. 12
NO. 13
445'
66 KV LINE
TRANSFOR-
MER
STATION
AIR
COMPRESSOR
ELECTROSTATIC
PRECIPITATOR
VERTICAL SECTION
AIR
WATER
OIL PUMP OUT
GAS
SURFACE
320' OF OVERBURDEN
20' OIL SAND
6' LIMESTONE
80' OIL SAND
FIRE FRONT
NACATOCH FORMATION

CHARACTERISTICS OF OIL SAND

Oil content	1900 B/acre foot
Oil in place	1,984,000 in Cities Services Field
Estimated oil recovery	35% or 700,000 B
API gravity	18
Porosity	33.9%
Water saturation	27.4
Permeability	700 millidarcies (variable)
Viscosity	700 cp at reservoir temperature $\sim$50 cp at 150^{o}F

Since the oil sand is unconsolidated, rubber sleeves are required to secure cores of the oil sand.

FIELD OPERATION

Cities Services have been operating fire flood wells in this field since 1971. President Carter has called for the production of an additional 500,000 B/D from heavy oil sources. ERDA was approached by Cities Services for funds to assist in underwriting an experiment which involves the injection of water at the top of the Nocatoch formation to keep the fire from running up the side of the injection well and across the formation at the limestone parting to the production well and burning the well out at the top of the formation. ERDA accepted the project on the basis that it would help achieve the President's goal and there was an element of novelty albeit a small one.

The ignition of the well was achieved by lowering a 30 KW electrical heater to heat the air to 600^{o}F. The air pressure was raised to 250 psi until a break-through to the production wells was achieved. The pressure was then lowered to 130 psi. The quantity of air injected was approximately 2 million cu ft per pattern 9 wells (6 injectors, 3 producers) per day. The air was compressed in a three-stage electrically driven compressor. The installed capacity was 4200 hp (Ingersol Rand) plus an additional

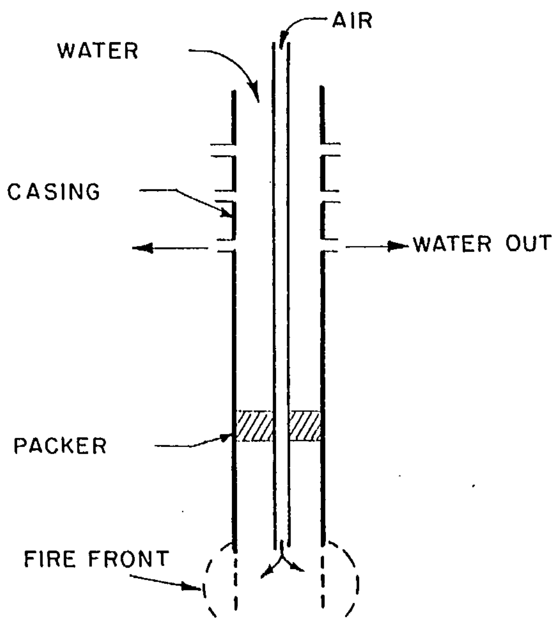
1000 hp compressor to deliver 20 million cu ft per day to the field, that is, 2 million scf per pattern per day. There are a total of 10 patterns, 5 Cities Services and 5 ERDA. The initial water injected per pattern was 150 B/D. The total field requirement was now stated to be closer to 500 B/D of water.

Ignition of the centre wells in the 9-hole pattern was followed by forward combustion to the producing wells. The tendency was for the combustion to rise up to the top of the formation near the injection well and follow the limestone parting to the production well. This was counteracted by the injection of water into the top of the formation to hold the fire down.

When the fire burned through to the producing wells as evidenced by high localized temperatures at the top of the wells, production was halted and cement was injected to seal off the flow of combustion gas at the top of the well. Additional squeezes were applied successively down the wells as burn-through occurred.

The distance between wells was approximately 300 ft; the tendency was to lengthen the distance in the direction of greater permeability.

Once producing well temperatures reached 200°F water was injected down the annuli to cool the bottom hole equipment.



COST OF OIL

A breakdown of the costs of production of the oil were supplied to give an idea of the distribution of costs:

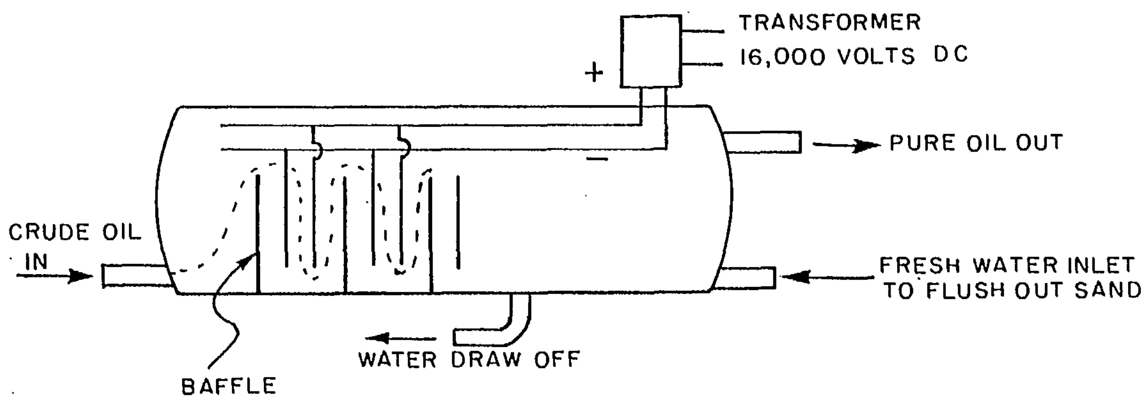
Distribution of Costs	$	$ Current
Lease Operation	.76	.84
Lease Maintenance	1.28	1.49
Water & Air Compression	2.04	2.42
Cities Service Overload	1.73	2.05
Louisiana Severence Tax	1.40	1.55
Depletion	1.79	2.37
	$9.00/B	$10.74/B

Current costs were stated to be $10.74/B

Since this is regarded as new oil, Cities Services receives $13.30/B. Net revenue is positive, therefore payout is taking place. Whether or not the project will be economical in the sense of generating an adequate return on investment only time will tell.

OIL CLEAN UP

The crude oil and water from the production wells was sent to a primary horizontal settling tank. The sand and water was withdrawn from the bottom. The water was then further separated from the sand and re-injected into the formation. The oil layer was sent to a vertical tank heated with an automatic gas heater. The separated oil was then sent to a stock tank for transfer to the electrostatic separator. The electrostatic separator was made by Combustion Engineering and called an Avalion Electrostatic Oil Treater. The internals were described as follows:



As the oil is produced from a module, the quality of the oil continues to decrease, that is to say, the oil contains more and more emulsified water and associated mineral matter at the oil water interface. In order to break this emulsion surfactants are used. It has been found by experience that two surfactants are required, one specifically designed to wet the silica surfaces with water, another designed to promote the reduction of water in the oil phase by assisting water droplets to coalesce. Although numerous requests have been made to the vendors of surfactants for assistance that resulted in the study of samples of emulsions withdrawn from various points in the oil gathering system, the results have shown that the conclusions found in the laboratory have not been borne out in the field.

A variety of surfactants have been tried, costs have ranged up to 90¢ per barrel. Currently this has been reduced to 22¢ per barrel.

SCIENTIFIC BACKUP

There appeared to be a minimum of measurements taken to monitor what was taking place underground. No mathematical models or physical models were used to relate field performance to variations in the operating variables. The entire operation was focussed upon securing the maximum amount of oil with a minimum of investment. The principal independent variables measured were the volume of water and air injected into the patterns, measurements were also made of the water and oil produced which were the dependent variables. The temperatures of the production wells were monitored for hot spots. These were observation wells. There appeared to be a minimum of scientific back-up to assist the field engineers with the emulsion breaking problems or the interpretation of the response of the field to changes in the independent variables.

CONCLUSIONS

(1) There is great similarity in the behaviour of this field and Lloydminster. Both produce considerable quantities of sand

and silt with the oil. Any attempt to restrain the sand from being produced by the use of gravel packs tends to shorten well life.

(2) The production wells in the Bellevue Field are very sensitive to back pressure on the combustion gas. Even the few inches of water back pressure required to scrub the combustion gases to remove SO_2 could not be tolerated by the wells.

(3) Very little scientific information can be expected to come out of the ERDA supported program at Bellevue, but it will put in the public domain information on field performance.

Institution:	Chanslor Western Development Co.
Location:	Taft, Calif., U.S.A., Midway Sunset Field (near Bakersfield, Calif.)
Date of Visit:	Sept. 13, 1977
Name of ERDA Project:	"200" Sand Steam Flood
ERDA Field Engineer:	Mr. Harold Lichtenberg
ERDA Reports:	BERC-77/1, No. 9 ERDA Enhancement of Recovery of Oil and Gas
Chanslor Staff:	Mr. Osborne, Senior Engineer W. Alfred, Project Engineer R. Bosworth, Reservoir Engineer
Technology of Interest:	Steam Flood

GEOLOGICAL SETTING

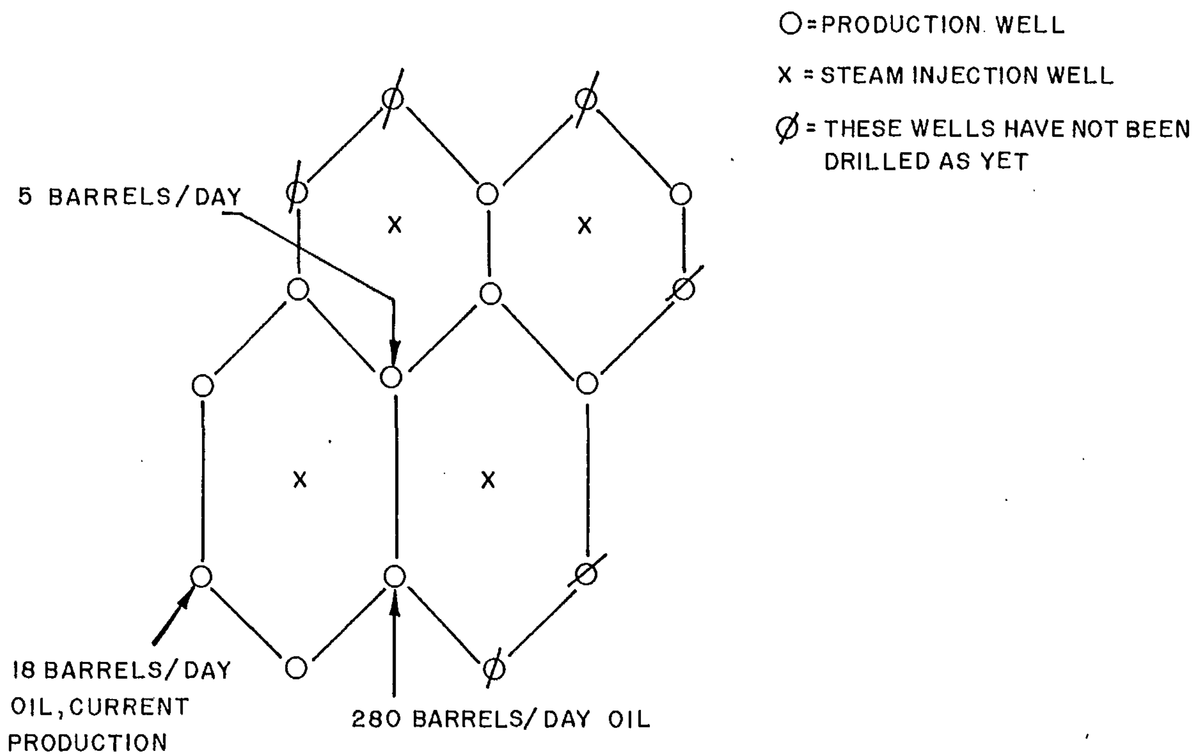
The oil is deposited in a shallow anticline of unconsolidated sand of Upper Miocene age, consisting of clean silt and very little clay. The reservoir is essentially dead, that is to-day, there is no associated gas. The oil saturated sand is ~200 ft thick, net pay 150 ft and covered with 400 to 600 ft of over-burden. The producing horizon is the Spellacy formation.

PAST HISTORY OF FIELD

The Midway Sunset Field is very large, consisting of thousands of wells with a spacing of approximately 300 ft, amounting on the average to 1.25 acres per well. Cyclic steam injection will not work in this particular part of the field; the reason for this was not too clear; possibly because associated gas content is very small. The character of the oil varies considerably within the field, at the margins where the ERDA pilot is in operation the API gravity is low and the viscosity is high. This oil when hot can be blended with other oils within the field for pipeline transmission to the refineries on the coast.

FIELD LAYOUT

The field layout of wells was as follows for the ERDA pilot experiments:



FIELD OPERATION

Steam was injected at the rate of 200 to 255 B/D. It was the intention to inject a total of 10,000 B before undertaking serious measurements of the response of the production wells. A total of 8000 B of steam has been injected to date in one of the pilot modules. It is expected that 1,000,000 B of steam will have to be injected before there is a significant response from the 4 modules.

Short bursts of steam were put into the production wells to raise the local temperature.

Two steam generators are used for the pilot experiment with a capacity of 1700 B/D of steam. The output from these was steam at 420°F, of 80% steam and 20% water. At the well head the steam pressure is 150 psi, 72% steam and 28% water at 350°F. The temperature objective is 200°F for the reservoir.

Currently 120 B/D oil are consumed to produce steam to recover 40 B/D of oil, so that the operation is far from economic. The prices of oil are:

Old oil	\$3.98
New oil	\$9.20
Stripper oil	\$11.40

Currently, 120 B of old oil are used to recover 40 B of new oil.

Gravel packs can be used to retain the sand and, in fact, sand can be re-injected into the producing wells without injuring their performance. The character of this oil field is very different from Lloydminster or Athabasca in that there is virtually no clay and there is very little mineral matter produced with the oil. The emulsification problems are also much less.

The waste water produced with the oil is settled, skimmed and passed through a D.E. filter before re-injection into the reservoir.

The water produced with this oil is not monitored for pH, dissolved salts or silica.

There are no temperature observation wells. It was stated that such a well would cost \$65,000 and was difficult to justify on the basis of the oil production.

The produced oil went to heated settling tanks (240^{o}F to 260^{o}F) with the addition of Treatolite. The remaining water was removed by flash evaporation at 400^{o}F.

CHARACTERISTICS OF THE OIL SAND

Oil Content	1370 B/acre foot
Gravity	11 API
Viscosity	6500 CP @ 90^{o}F
	60 CP @ 212^{o}F
Porosity	30%
% Saturation oil	59%
Permeability	1000 Millidarcies (oil free)
	3 Millidarcies oil saturated

Institution:	SOHIO Property
Location:	Asphalt Ridge, near Vernal
Date of visit:	Sept. 14, 1977
Name of Project:	Hot Water Separation Pilot
SOHIO Field Engineer:	Mr. Reese Madsen (Civil Engineer)
ERDA Field Engineer:	Mr. Lee C. Marchant
Previous Reports:	Nil
Technology of Interest:	Hot Water Separation Following Addition of Kerosene

GEOLOGICAL SETTING

The asphalt seam outcrops south-west of Vernal, Utah, and at the location of the pilot plant approximately 60 ft of the seam was exposed. The unconsolidated tar sand belongs to the formation. The reserves held by SOHIO amount to 100 million B with an average bitumen concentration of 8% or 22 US gal/ton.

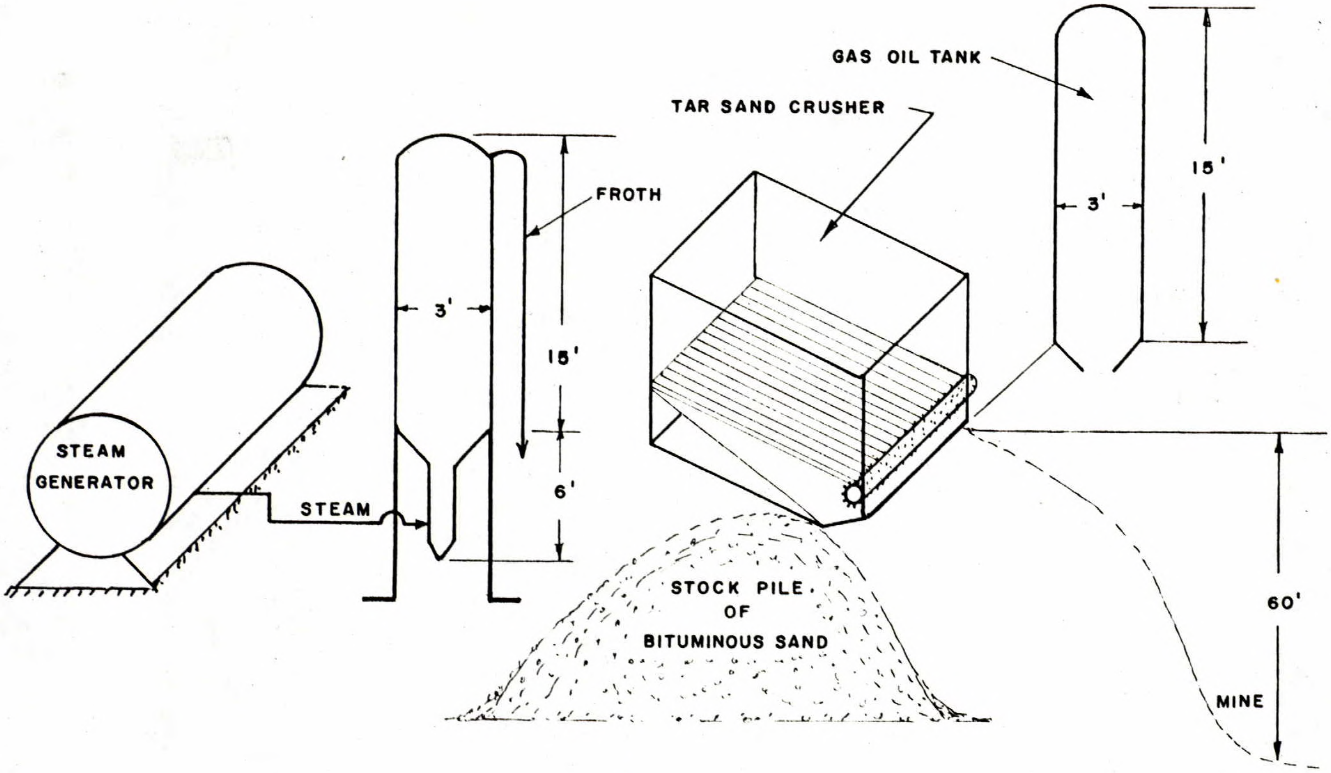
PILOT PLANT DESCRIPTION

The pilot plant was designed for summer operation only on the scale of 100 B/D. The operation was undertaken by The American Independent Oil Company (Aminol), a subsidiary of R.J. Reynolds, Burma Oil, and Signal Oil and Gas Co.

The process flow sheet was difficult to decipher since many of the connecting pipes had been removed. Mr. Madsen indicated the following steps:

1. Crushing
2. Dilution with gas oil in a vertical tank
3. Transfer to a tall slender separation cell with steam and hot water injection at the bottom
4. Froth removal at the top without skimming to allow gas and water to settle out.

Mr. Madsen stated that the pilot plant was halted because the emulsification of water in the oil was very bad and it appeared to be stabilized by the mineral matter. It is understood that the oil companies concerned are doing more laboratory work before undertaking further pilot plant experiments.



CONCLUSIONS

1. The designers of the pilot plant did not understand the fundamental principles of tar sand separation; this was illustrated by:
   a. Prewetting the tar sand with gas oil which makes water wetting more difficult
   b. Failure to introduce water at the crushing stage to maximize wetting of the silica with water, without incorporating much water in the oil phase.
   c. No froth skimming section
   d. Introduction of steam low down in the separation vessel which carries the fine mineral matter up to the top
   e. This pilot plant does not give a valid indication as to whether the hot water process will work or not on the Asphalt Ridge bituminous sand.

Institution: Laramie Energy Research Center

Location: North-west Asphalt Ridge, near Vernal

Date of Visit: Sept. 15, 1977

Name of Project: In Situ Recovery of Oil from Tar Sands

ERDA Field Engineer: Lee C. Marchant

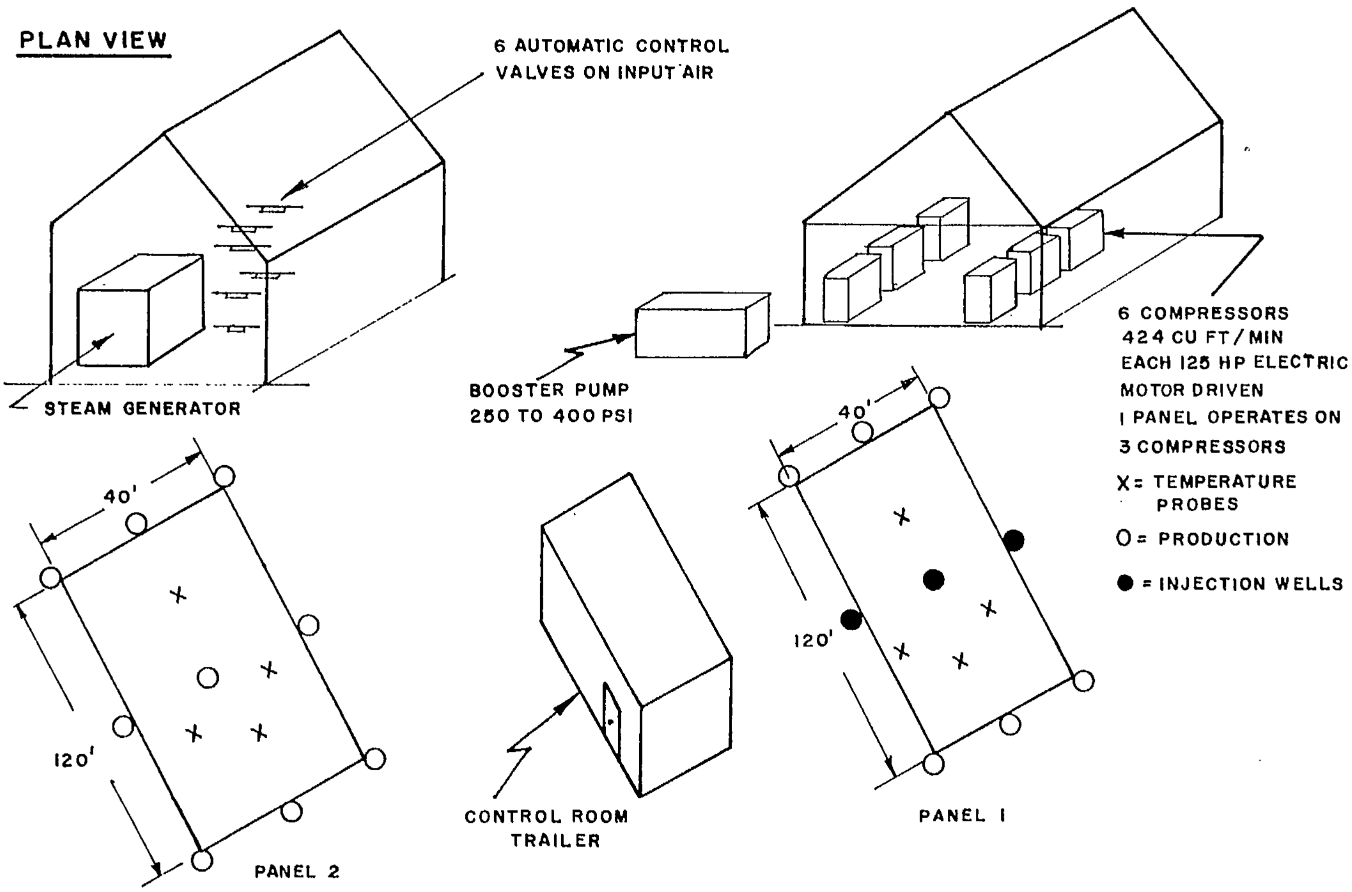
Previous Reports: (4, 5, 6, 8, 10, 12) See attached list, also RI7791

Technology of Interest: Reverse Combustion

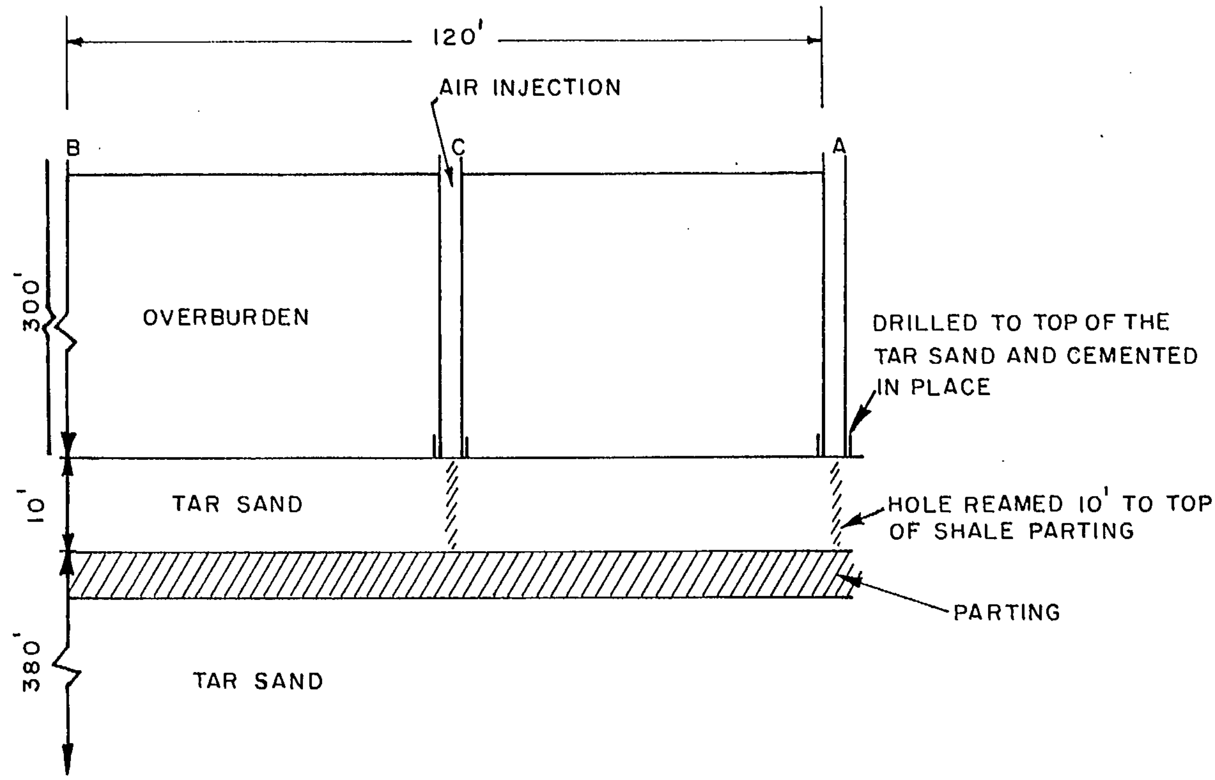
GEOLOGICAL SETTING

The tar sand deposit is overlain with 300 ft of overburden; there is a 10 ft seam of tar sand separated from the main body by a parting of shale. Under this parting is 380 ft of bituminous sand. The reverse combustion experiments to be described were conducted in the 10 ft seam above the parting.

FIELD LAYOUT



VERTICAL SECTION



OPERATION OF EXPERIMENT

In panel 1 the production and injection holes were drilled to 9-5/8" diameter and a 7" casing was inserted, cementing it to the top of the tar sand formation. The hole was reamed through the 10 feet of tar sand section. The observation wells were drilled to take a 1½" casing; the thermocouples were contained in ¼" copper tubing.

The formation was then fractured employing a pressure of 325 psi to obtain permeability. The pressure was allowed to fall to a value that would supply 35 cu ft of air per minute per sq ft of surface at the combustion zone. The permeability was measured using Krypton 95.

Briquettes soaked in igniter fluid were lowered into the tar sand and ignited with an electric heater. Air was injected at A and B, the production holes, and combustion was initiated in the forward direction. After the flame front was well established, the air was reversed, that is to say, it was injected at the three holes in the centre of the pattern C and production of the oil and gas commenced through A and B.

The oil in place in Panel No. 1 was 800 B, the actual recovery at the time of termination was 75 B. The termination occurred due to lack of insulation on the oil lines from the top of the production casing. The low outside temperature solidified the oil in the lines.

In Panel No. 2 the lines have been suitably insulated and the reverse burning was in progress. The maximum temperature in the burning zone was estimated to reach 650^{o}F, but the actual measured temperature was of the order of 275^{o}F.

The instrumentation and control of the experiment was excellent. All data from the observation wells were fed into a Hewlett-Packard 2100 which had a memory of 5 mega bytes. There were tape recording and printout facilities which could give a complete printout of the temperature distribution every six minutes. The temperature distribution indicated what level of air pressure should be maintained. This was set and the automatic air control valves maintained this level.

COST OF THE EXPERIMENT

The capital cost of the project to date is of the order of $2 million, the current salary budget is $300,000 per year. The budget for FY 1978 is $1.5 million.

CONCLUSION

1. The project is well engineered and the instrumentation and control is excellent, which should lead to the acquisition of reliable data.
2. It is too early to evaluate the oil recoveries obtainable by this procedure.
3. This experiment will give a datum from which comparisons at a later date can be made with wet combustion.

Institution: Laramie Energy Research Centre (LERC)

Location: Laramie, Wyoming

Date of Visit: Sept. 16, 1977

Names of Projects Reviewed:

1. Conversion of Shale Oil to Fuel Products, P.L. Cottingham
2. Shale Oil Composition, S. Dorrence
3. Coal Gasification
4. Shale Gasification
5. Out Shale Retoting
6. Mathematical Modelling

CONVERSION OF SHALE OIL TO FUEL PRODUCTS

The group under P.L. Cottingham is currently studying the problems of hydrogenating shale oil. It has been found necessary to filter the oil to remove shale dust before sending it over a fixed bed catalyst to increase catalyst life. It has also been found essential to work at 2500 psi to obtain satisfactory catalyst life in order to hydrogenate the foreign atoms out of the heavy gas oils. The catalysts used were cobalt molybdate or alumina with the addition of nickel to remove the nitrogen compounds. ERL should take note of a publication entitled "Shale Oil Denitrification Reactions over CoMo and NiW catalysts", by Silver, Wang and Jensen, Library of Congress Card Cat. No. 75-10415, 15BN 0-250-40092-8 1976.

SHALE OIL COMPOSITION

There is very considerable interest in the work of EMR in the use of optical activity of the saturated hydrocarbons as a measure of thermal treatment. They state that they are currently studying the decline in the optical activity of the oils produced from the reverse fire flood operation at Asphalt Ridge by this technique, as well as the retorted shale oil. ERL is requested to send information on the decline and optical activity during hydrocracking.

In the asphaltic oil produced from Asphalt Ridge by insitu combustion, 70% is unaltered and 30% is converted to material boiling in the kerosene naphtha range. The olefins that are produced by thermal cracking are in the range of 5 to 10% of the cracked crude as determined by C_{13} NMR. This work will be published shortly in Advances in Chemistry. The produced water contains a relatively high concentration of organic acids, lactones, phenols and ketones.

The mass spectoscopy is under the direction of Frank Guffy. The recent work showing the presence of per hydro B carrotene in considerable amounts in Asphalt Ridge bitumen will be published in the CIM proceedings of the recent meeting held in Calgary.

The mass spectral laboratory consists of the following mass spectrometers: a Consolidated Electro-dynamics 110 high resolution double focussing instrument with readout on silver halide-treated glass plates; a Bendix time of flight instrument fitted with a μV monochromator to ionize the parent ions; a MS 12 high resolution instrument with an INCOS data acquisition system.

To determine the aromaticity of petroleum and shale oil fractions, a Varian CF20, C_{13} NMR instrument is used.

IN SITU SHALE OIL PRODUCTION

The in situ shale retorting is conducted at Rocksprings, Wyoming. Site No. 9 has been prepared, communication has been achieved and the burn started.

Site No. 10 is to be rubblized before burning and consideration is being given to the required size distribution.

At White Mountain, two shafts 1500 ft deep with two 500 ft parallel tunnels driven between them are being constructed. The object is to study block caving as a means of rubblizing.

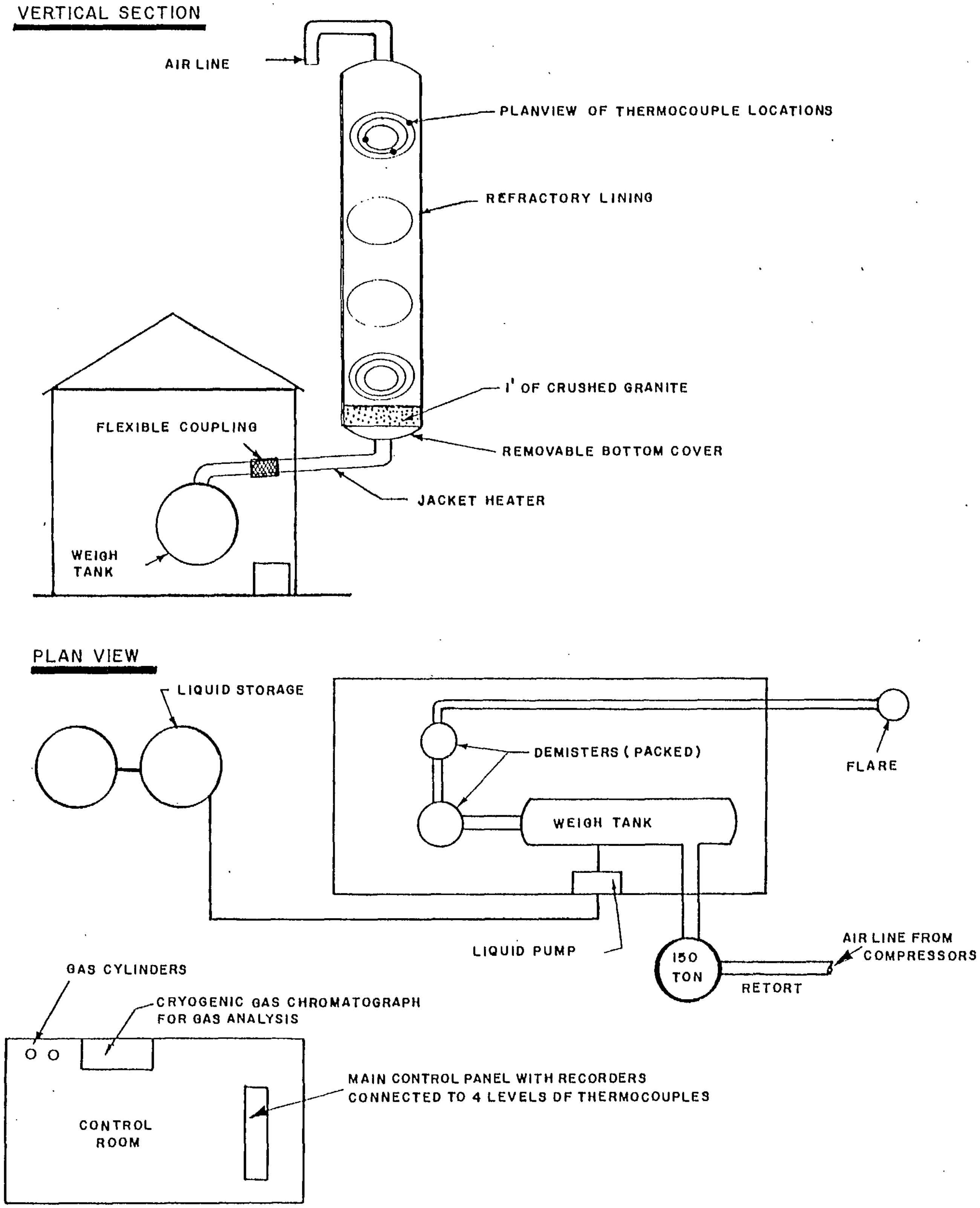
Occidental petroleum is experimenting with below ground retorting on the CB tract. The required void volume is created below the block by mining. This is followed by blasting the shale down into the void created.

On CA tract a consortium of 17 oil companies including Ashland, Shell and the Paraho Oil Company are involved in a mining and retorting project to produce 100,000 B of shale oil for the Navy. This is supported by ERDA and involves the Paraho retort (above ground) at the Anvil Point Facility.

LERC OIL SHALE RETORTS

A visit was made to the two oil shale retorts which are on the outskirts of Laramie on Highway 40. There are two retorts of essentially identical design, one capable of handling charges of 150 tons of oil shale and the other 10 tons. This is a batch process in which the combustion air and flame front is established at the top of the retort and the flame front proceeds downward. The initial size distribution of the oil shale is specified in terms of 3 size factions. Future experiments will use large lumps 3' x 4' x 4', weighing several tons, to obtain a clearer indication of the influence of initial particle size distribution on the kinetics and oil yield that may be obtained in the in situ projects. The spent shale on the ground consisted of pieces 1" x 1" x 1" to 5" x 6" x 1" plates. The larger plates were black in the centre indicating slow diffusion of the oil out of the rock and pyrolysis of the kerogen in the interior. The objective of working with very large pieces is to determine to what extent these pieces will spall, when exposed to heat, and the influence this will have on the kinetics and oil yield.

LAYOUT OF LERC SHALE RETORTS



Problem Areas:

(1) The retort lining tends to spall away from the shell. New cements are going to be used that may have better resistance to thermal shock.

(2) The retorted shale oil tends to freeze in the 6" diameter outlet pipe to the weigh tank. This outlet line is therefore jacketed to permit the addition of additional heat before the flexible coupling to the weigh tank.

(3) The thermocouples have been burning out in the retort which has led to erronious readings.

COAL GASIFICATION

Mr. Larry Plemins gave a review of the progress of Hanna Experiment No. 3. This was finished on July 30 and it ran for 40 days. The mathematical model is currently being checked with the actual performance. Hanna Experiment 4 is being planned for a burn of 6 months duration. This will be a reverse link, forward burn experiment. LERC encountered ground water influx in Hanna Experiment No. 2, whereas in Experiment No. 3 the seam tended to dry out and water had to be added. As a result of these experiments and the interpretation afforded by the instrumentation, it is felt that underground combustion of sub-bituminous coal can be engineered. The problems of ground control and subsidence have yet to be addressed. In Hanna Experiment No. 3 the air pressure was maintained above the local hydrostatic pressure, thus the water from the overlying strata was kept out. All the hydrology associated with this project was done by LERC personnel.

MATHEMATICAL MODELLING

A review of mathematical modelling as applied to the following areas was presented by Dr. Leroy Dockter.

(1) Oil Shale Retorting and Scale-up from 10 to 150 tons

(2) Underground Coal Gasification

(3) Tar Sand Fire Flood

In 1968 it was desired to attempt to predict the oil and water yields as a function of time that would be produced on the scale of 150 ton batch retort from the results obtained on the 10 ton batch retort. Mathematical models were developed with the assistance of the University of Louisiana. It was noted that there were large voids in the data available at that time and steps were taken to correct this. Data were subsequently obtained on the reaction kinetics and diffusion rates of hydrocarbons out of the rock matrix. Jack George of the mathematics department of the University of Wyoming is the principal man in charge of the modelling in this area at the present time. Don Faucet has done most of the work on the kinetics of kerogen decomposition. The present state of the mathematical model for this process is that the oil yield can be predicted to within 6% on the basis of knowing the Fisher assay and the quantity of shale within each of three size fractions. The prediction of the maximum temperature is accurate but the rate of heating up to the flame front is poor and so is the yield of water. The model does indicate that there is an optimum length to diameter ratio to produce the maximum amount of liquid shale oil. The principal parameters in the model are: the assay, void fraction, flow rates, recycle combustion gas rate, thermal conductivity and diffusivity, and particle size.

The mathematical modelling associated with the underground coal gasification is a rather large effort; larger could be handled by the in-house resources, so that it was contracted out.

The tar sand fire flood operation is modelled by an in-house group headed by Dr. Almer. There are two models - a physical cold flow model and a mathematical model which predicts air flow based on the kinetics of combustion. In April 1976 it was discovered that only one-half of the air injected can be accounted for in the effluent gases.

CONCLUSION

(1) The mathematical modelling has been of very considerable assistance in guiding the work on shale retorting and it promises to be of great value in the engineering of in situ projects.

(2) The modelling in relation to underground coal gasification is in its infancy.

(3) The modelling of the tar sand fire flood operations are also in their initial stages but this work will be invaluable when the post mortem studies are made on Panel 2.

LARAMIE ENERGY RESEARCH CENTER

TAR SAND 'PUBLICATIONS'

August 1, 1977

Oil Recovery Processes

1. Cupps, C. Q. Energy Trends-Tar Sands. U. S. BuMines. Technology Trends and Developments in the Minerals Industry, 1972, 5 pp.

2. Land, C. S. and F. M. Carlson. Study of Spontaneous Ignition of (Utah) Tar Sands. Unpublished LERC report, 1973, 11 pp.

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