APPENDIX B: SITE VISIT REPORTS

Assessment of Research Needs for Oil Recovery from Heavy-Oil Sources and Tar Sands (FERWG-III A)

March 1982

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APPENDIX B: SITE VISIT REPORTS

ASSESSMENT OF RESEARCH NEEDS FOR OIL RECOVERY
FROM HEAVY-OIL SOURCES AND TAR SANDS

FOSSIL ENERGY RESEARCH WORKING GROUP - IIIA
(FERWG-IIIA)

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March 1982

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AB-1

SITE VISIT AND DISCUSSIONS AT
THE UNIVERSITY OF UTAH, SALT LAKE CITY
(Friday, March 20, 1981)

Participants

FERWG Member Alex G. Oblad served as host; the following FERWG Members participated: F. W. Camp, J. Clardy, A. E. Kelley, F. X. Mayer, S. S. Penner, R. P. Sieg, and D. D. Whitehurst for P. B. Weisz; R. Anderson represented DOE. Formal presentations were made according to the attached scheduled (Table 1).

Viewgraphs describing the DOE program appear in AB-1, Appendix I. Research on oil recovery from tar sands has been in progress at the University of Utah since 1972. The Utah tar sands resources are summarized in AB-1, Appendix II. Three articles by J. D. Miller and his associates (AB-1, Appendix III) contain descriptions of ambient water and hot-water digestion-floatation techniques for the separation of bitumen from tar sands. Viewgraphs (by F. V. Hanson) and a paper summarizing studies on fluid bed thermal recovery techniques for bitumen from Utah tar sands are reproduced in AB-1, Appendix IV. J. D. Seader discussed fluid bed recovery using a heat-pipe reactor; both J. W. Bunger and F. V. Hanson reviewed upgrading procedures for bitumens.

Of particular interest to FERWG members were the presentations by K. Hatfield dealing with near-term implementation of a 50 BPD pilot plant by Enecor on Sohio property near Vernal, Utah, which is expected to become operational by mid-summer 1981. The design of this pilot plant incorporates research results obtained at the University of Utah, especially studies showing that the bitumen may be separated from Utah sands, to which it adheres directly and without an intermediary water layer (as on the tar

Table 1. Schedule of Presentations

9:00	Department of Energy Program for Oil Sands	R. Anderson Office of Fossil Energy Department of Energy
9:30	Introduction to University of Utah Program on Tar Sands	Alex G. Oblad Distinguished Professor of Metallurgical and Fuels Eng. University of Utah
9:40	The Resource	Howard Ritzma Assistant Director and Chief Petroleum Section Utah Geological and Mineral Survey
10:20	Water Extraction	Jan D. Miller Professor of Metallurgy University of Utah
11:00	Fluid Bed Thermal Recovery	Francis V. Hanson Associate Professor of Fuels Engineering University of Utah
11:30	Fluid Bed Recovery - Heat Pipe Reactor	J. D. Seader Professor of Chemical Engineering University of Utah
12:00	Combined Water Extraction - Fluid Bed Thermal Process	F. V. Hanson
12:30	Heat Recovery in Thermal Processing	J. D. Seader
1:00	Box lunch - Discussion of Oil Sand Program of FERWG	S. S. Penner Director of Energy Center University of California, San Diego
2:00	Characterization of Utah's Tar Sand Bitumen	James W. Bunger Research Assistant Professor University of Utah State Science Advisor
2:25	Upgrading of Bitumens	J. W. Bunger
2:55	Upgrading of Bitumens	F. V. Hanson
3:05	Pilot Plant Program	Kent Hatfield Vice President and Director Ford, Bacon and Davis Inc.
3:30	Economics of Bitumen Recovery	K. Hatfield

sands of Alberta), by the judicious application of shear flows. Equally important is subsequent separation by air floatation rather than by gravity settling. Flocculent addition to improve bitumen separation and extensive water recycling are other important processing characteristics.

A 2000 BPD plant has been estimated to require capital costs of about $\$26 \times 10^6$ (i.e., \$16,000/BPD) in 1981 dollars. With upgrading, product costs will probably fall around \$40/B at a reasonable rate of return. Water requirements correspond to about 3B per B of bitumen.

AB-1

Appendix I

U.S. DEPARTMENT OF ENERGY

FOSSIL ENERGY PROGRAM REVIEW

TAR SAND

NEED FOR A DEFINITION

- 1. TAR SANDS ARE EXEMPT FROM WINDFALL PROFITS TAX**
- 2. TAR SANDS ARE INCLUDED IN SFC PROJECTS**
- 3. TAR SANDS ARE CURRENTLY CLASSIFIED "OTHER MINERAL" BY IRS. AS SUCH, THEY ARE STILL ENTITLED TO A 15 PERCENT DEPLETION ALLOWANCE, WHILE DEPLETION ALLOWANCES FOR CONVENTIONAL OIL HAVE BEEN ELIMINATED.**

PROPOSED DOE DEFINITION OF TAR SAND

- 1. VISCOSITY GREATER THAN 10,000 CP AT RESERVOIR
TEMPERATURE**
- 2. DEPOSIT MUST BE MINED TO BE PRODUCED**

COMPARISON OF U.S.-CANADA-VENEZUELA RESOURCES

	U.S.	CANADA	VENEZUELA
TAR SAND RESOURCE (BOIP)	25 TO 36 BILLION	900 BILLION TO 2 TRILLION	(ORINOCO) 700 BILLION TO 2 TRILLION
HEAVY OIL RESOURCE (BOIP)	100 BILLION		
TAR SAND OIL VISCOSITY (CP)	15,000 TO 2 MILLION	20,000 TO 2 MILLION	1,500 TO 20,000
TAR SAND OIL GRAVITY (°API)	-2 TO 14	6 TO 14	4 TO 18
TAR SAND WETTABILITY	NOT WATER WET	WATER WET	PROBABLY WATER WET

TAR SAND OCCURRENCES IN THE U.S.

TABLE 1
DEPOSITS OF BITUMEN-BEARING ROCKS IN THE UNITED STATES
WITH RESOURCES OVER 1,000,000 BARRELS

STATE AND NAME OF DEPOSIT	ESTIMATED RESOURCES (MILLIONS OF BARRELS)	
	LOW	HIGH
CALIFORNIA:		
OXNARD	565.0	-
SANTA MARIA	500.0-	2,000.0
EDNA	141.4-	175.0
SOUTH CASMALIA	46.4	
NORTH CASMALIA	40.0	
RICHFIELD	40.0	
PARIS VALLEY	30.0-	100.0
SISQUOC	29.0-	106.0
SANTA CRUZ	10.0	
McKITTRICK	4.8-	9.0
POINT ARENA	1.2	
CALIFORNIA TOTAL	1,407.8	3,092.6
KENTUCKY:		
KYROCK AREA	18.4	
DAVIS-DISMAL AREA	7.5-	11.3
BEE SPRING AREA	7.6	
KENTUCKY TOTAL	33.5-	37.3
NEW MEXICO: SANTA ROSA	57.2-	600.0
TEXAS: UVALDE	124.1-	3,000.0
UTAH:		
TAR SAND TRIANGLE	12,504.0-	16,004.0
P.R. SPRING	4,000.0-	4,500.0
SUNNYSIDE	3,500.0-	4,000.0
CIRCLE CLIFFS	1,000.0-	1,507.0
ASPHALT RIDGE	1,000.0-	1,200.0
HILL CREEK	300.0-	1,160.0
SAN RAFAEL SWELL AREA	385.0-	470.0
ASPHALT RIDGE, NORTHWEST	100.0-	125.0
RAVEN RIDGE	75.0-	100.0
WHITEROCKS	65.0-	125.0
WICKIUP	60.0-	75.0
ARGYLE CANYON	50.0-	75.0
RIM ROCK	25.0-	30.0
COTTONWOOD-JACKS CANYON	20.0-	25.0
PARIETTE	12.0-	15.0
WHITE CANYON	12.0-	15.0
MINNIE MAUD CREEK	10.0-	15.0
WILLOW CREEK	10.0-	15.0
LITTLEWATER HILLS	10.0-	12.0
LAKE FORK	6.5-	10.0
NINE MILE CANYON	5.0-	10.0
CHAPITA WELLS	7.5-	8.0
TEN MILE WASH	1.5-	6.0
TABIONA	1.3-	4.6
THISTLE	2.2-	2.5
SPRING BRANCH	1.5-	2.0
COW WASH	1.0-	1.2
UTAH TOTAL	23,164.5-	29,512.3
UNITED STATES TOTAL	24,787.1-	36,242.2

UTAH TAR SAND DEPOSITS

TECHNOLOGIES FOR RECOVERY OF U.S. TAR SANDS

1. SURFACE MINING AND EXTRACTION

2. IN SITU RECOVERY

A. IN SITU COMBUSTION

B. STEAM DRIVE

C. NOVEL CONCEPTS (RF HEATING, ETC.)

3. COMBINATION OF MINING AND IN SITU METHODS

SURFACE MINING AND RECOVERY TECHNOLOGY

I. SURFACE MINING

- A. TECHNOLOGY GENERALLY AVAILABLE THROUGH EXPERIENCE IN MINING OTHER RESOURCES (E.G. COAL) AND CANADIAN EXPERIENCE IN ATHABASCA**
- B. CURRENT ESTIMATES SHOW APPROXIMATELY 20% OF THE DOMESTIC TAR-SAND RESOURCE MAY HAVE POTENTIAL TO BE SURFACE MINED**

II. SURFACE EXTRACTION OF BITUMEN FROM TAR SANDS

THE FOLLOWING PROCESSES ARE BEING DEVELOPED ON A LABORATORY SCALE TO EXTRACT BITUMEN FROM TAR SANDS:

- A. HOT-WATER PROCESS – THE MINED TAR SAND IS MIXED WITH STEAM, WATER, AND A CAUSTIC WETTING AGENT. THE RESULTING HYDRATION FORCES DISPLACE THE BITUMEN INTO THE AQUEOUS PHASE, FROM WHICH THE OIL IS SEPARATED.**
- B. SOLVENT EXTRACTION – THE MINED TAR SAND IS MIXED WITH AN ORGANIC SOLVENT WHICH REMOVES THE BITUMEN FROM THE ROCK. THE SAND IS REMOVED BY SETTLING, THE BITUMEN AND THE SOLVENT ARE THEN SEPARATED, AND THE SOLVENT IS RECYCLED.**
- C. PYROLYSIS METHODS – HEAT IS USED TO DISTILL THE BITUMEN FROM THE TAR SAND**

COMBINED MINING AND IN SITU RECOVERY TECHNIQUES

I. TECHNOLOGIES

VARIOUS CONCEPTS HAVE BEEN PROPOSED EMPLOYING THESE COMBINED TECHNIQUES. SOME OF THE MORE PROMISING ARE:

A. MODIFIED IN SITU -- THE DEPOSIT IS RUBBLEIZED IN DESCREE SECTIONS AND THEN AN IN SITU PROCESS IS APPLIED TO THE RESULTANT HIGHLY PERMEABLE SECTION.

B. GRAVITY DRAINAGE WITH STEAM -- TUNNELS ARE DRILLED UNDER THE FORMATION, A LARGE NUMBER OF SHORT WELLS ARE DRILLED UPWARD, AND HEAT IS INJECTED TO REDUCE THE OIL VISCOSITY AND ALLOW IT TO DRAIN DOWN INTO THE TUNNELS. A VARIATION IS TO MINE OUT CAVERNS AND DRILL HORIZONTAL, RADIAL WELLS INTO THE FORMATION.

FIGURE 18
GRAVITY DRAINAGE METHOD

PROMINENT CURRENT U.S. TAR SAND ACTIVITY

LOCATION	OPERATOR	PROCESS	REMARKS
TEXAS			
UVALDE DEPOSIT	CONOCO	IN SITU STEAM DRIVE (PILOT)	TECHNICAL SUCCESS, 53% RECOVERY FROM 5-ACRE FIVE SPOT
UVALDE DEPOSIT	WHITE MINES	QUARRY PRODUCING PAVING MATERIAL	CARBONATE ROCK
CALIFORNIA			
CAT CANYON FIELD	GETTY OIL CO.	IN SITU STEAM DRIVE (PILOT)	APARENTLY TECHNICAL SUCCESS, DOE SUPPORT
MARPORT FIELD	OGLE PET. CO.	IN SITU STEAM DRIVE (PILOT)	SOME DOE SUPPORT
McKITTRICK	GETTY OIL CO.	STRIP MINING & DRAVO AND LURGI PROCESSES (PILOTS)	DIATOMACEOUS EARTH DEPOSIT
PARIS VALLEY FIELD	HUSKY OIL CO.	IN SITU WET COMBUSTION (PILOT)	TECHNICAL FAILURE, DOE SUPPORT
UTAH			
ASPHALT RIDGE DEPOSIT	UINTAH COUNTY ROAD DEPT.	QUARRY PRODUCING PAVING MATERIAL	RIMROCK SANDSTONE, SOHIO OWNED
NORTHWEST ASPHALT RIDGE	DOE-LETC	IN SITU THERMAL PROCESSES	RIMROCK SANDSTONE, SOHIO OWNED

GETTY SURFACE MINING PROJECT

- 1. MCKITTRICK FIELD, CALIFORNIA**
- 2. DIATOMACEOUS EARTH DEPOSIT, ABOUT 13.6 API,
0-1200 FT. DEPTH, 38 GAL/TON (16 WT. %)**
- 3. GOAL IS 20,000 B/D FOR 48 YEARS, STARTING IN LATE
1980'S**
- 4. EVALUATED 15 EXTRACTION PROCESSES, HAVE
NARROWED DOWN TO LURGI RETORT AND A DRAVO
SOLVENT**
- 5. PLAN TO BEGIN 150 B/D PILOT TESTS OF EACH IN
LATE 1980**

CONOCO STEAMFLOOD PROJECT

- (a) UVALDE, TEXAS, DEPOSIT**
- (b) -2 API, VISCOSITY GREATER THAN 1,000,000 CP**
- (c) ONE 5 SPOT PATTERN, STEAM DRIVE**
- (d) ESTIMATED RECOVERY 53 PERCENT, AT A RATE OF 300-350 B/D OVER 2-3 YEARS**
- (e) ABOUT 60 PERCENT OF PRODUCED OIL BURNED AS GENERATOR FUEL**
- (f) PLAN SECOND PILOT FOR 1981, SEVERAL MILES AWAY, USING FBC OF COAL**
- (g) ULTIMATE COMMERCIALIZATION PLANS CALL FOR COAL AS FUEL, USING EITHER FBC OR LOW BTU GASIFICATION**
 - GOAL IS 20,000-25,000 B/D BY 1990**

SOHIO SURFACE MINING PROJECT

- 1. HAS DIVULGED PLANS TO BEGIN PILOT PLANT WORK LEADING TO 20,000 B/D OPERATION IN 1989, USING SOLVENT EXTRACTION**
- 2. ASPHALT RIDGE DEPOSIT NEAR VERNAL, UTAH**
- 3. 6.4 — 29 GAL/TON**
- 4. 24 BBL/DAY PILOT PLANT SCHEDULED FOR 1982**
- 5. FEASIBILITY STUDY TO BE COMPLETE IN 1984 TO DECIDE WHETHER THE NEXT PHASE SHOULD BE 5,000 OR 20,000 B/D PLANT**

TAR SANDS PROGRAM BUDGET

PROGRAM BUDGET (M\$)

<u>FY 1978</u>	<u>FY 1979</u>	<u>FY 1980</u>	<u>FY 1981</u>	<u>FY 82 REQUEST</u>
938	2,424	5,166	5,500	6,000

DOE TAR SAND PROGRAM FY 1981 BUDGET BREAKDOWN

<u>ACTIVITY</u>	<u>(M\$)</u>
------------------------	---------------------

RESOURCE ASSESSMENT	750
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IN SITU RECOVERY FIELD EXPERIMENT	3,500
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ENVIRONMENT	800
--------------------	------------

SEPARATION AND UPGRADING	<u>450</u>
---------------------------------	-------------------

	5,500
--	--------------

FIGURE 4.1-1

RESOURCE PETROLEUM
ACTIVITY ENHANCED OIL RECOVERY
SUBACTIVITY TAR SANDS

DOE IN-HOUSE TEST

IN SITU COMBUSTION TEST (FY 78)

(a) NORTHWEST ASPHALT RIDGE DEPOSIT NEAR VERNAL, UTAH

- TEST CONDUCTED BY DOE-LARAMIE E.T.C.**

(b) 40 x 120 FOOT, 9 WELL, LINE DRIVE PATTERN

(c) 13 FOOT THICK SEAM, 350 FOOT DEPTH

(d) REVERSE COMBUSTION PREPARATORY PHASE THROUGH HIGH PERMEABILITY STREAK AT BOTTOM OF FORMATION

(e) FOLLOWED BY FORWARD COMBUSTION PRODUCTION PHASE

(f) APPROXIMATELY 25 PERCENT OF THE OIL IN PLACE, 580 BBLs., WAS PRODUCED OVER 183 DAYS

(g) ESTIMATED COST OF \$30 PER BARREL (1979) FOR 15 PERCENT ROR

DOE IN-HOUSE TEST

2. STEAM DRIVE TEST (4/80 - 10/80)

- **FIVE SPOT PATTERN, 400 B/D STEAM RATE FOR 160 DAYS**
- **PRODUCTION WAS 1,150 BBLS OIL AND 6,250 BBLS WATER**
- **TEST HAS SHOWN:**
 - **STEAM CAN BE INJECTED AT ACCEPTABLE RATES**
 - **SATISFACTORY THERMALLY EFFICIENT WELL COMPLETIONS ARE POSSIBLE**
 - **PRODUCED WATER CAN BE CLEANED AND RECYCLED THROUGH STEAM GENERATOR**
 - **PRODUCED BITUMEN IS AN ACCEPTABLE STEAM GENERATOR FUEL**
 - **FUTURE TESTS MUST INCORPORATE STEAM STIMULATION OF PRODUCTION WELLS**

DOE-ALTERNATE FUELS SOLICITATIONS FEASIBILITY STUDY AWARD

1. AMOCO

(a) NO COST TO DOE

(b) SUNNYSIDE DEPOSIT, UTAH

(c) ESTIMATED 80 MM BARRELS RECOVERABLE

(d) 10,000 B/D FOR 23 YEARS FROM AMOCO LEASES

(e) IF FIELD UNITIZED — 50,000 B/D

**(f) FEASIBILITY STUDY FOR DESIGN AND
ENVIRONMENTAL WORK ON DRAVO SOLVENT PILOT
PLANT**

DOE-ALTERNATE FUELS SOLICITATIONS FEASIBILITY STUDY AWARD

2. NATOMAS

(a) \$367,000 DOE SHARE (100%)

(b) NO SITE

**(c) AIMED AT 2,000 B/D MODULE BY 1984, 20,000 B/D
BY 1989**

**(d) TOLUENE EXTRACTION PROCESS CURRENTLY IN
0.3 B/D OPERATION AT SRI**

**(e) DESIGN AND ENVIRONMENTAL STUDY FOR 60-100
B/D PILOT**

DOE-ALTERNATE FUELS SOLICIATIONS FEASIBILITY STUDY AWARD

3. GREAT NATIONAL CORPORATION

- 1. \$3.4 MM DOE COST (100%)**
- 2. SUNNYSIDE DEPOSIT, UTAH**
- 3. ENGINEERING DESIGN AND ECONOMIC EVALUATION
AIMED AT 25,000 B/D OPERATION FOR 20 YEARS**
- 4. INCORPORATES MODIFIED HOT WATER PROCESS
FOLLOWED BY PYROLYSIS RECOVERY**

DOE-ALTERNATE FUELS SOLICITATIONS FEASIBILITY STUDY AWARD

4. ENPEX

- 1. UVALDE DEPOSIT, TEXAS**
- 2. \$2.3 MM DOE COST (100%)**
- 3. DESIGN AND COST ESTIMATE OF OPTIMUM FACILITY
FOR 15,000 B/D OPERATION**
- 4. IN SITU STEAM FLOOD USING COAL AS FUEL, EITHER
FBC OR GASIFICATION**
- 5. PROPOSER PLANS TO CONDUCT 300 B/D PILOT TEST
AT HIS COST USING 50 MM BTU F.B.C. STEAM
GENERATOR**

ILLINOIS INSTITUTE OF TECHNOLOGY RADIO-FREQUENCY HEATING DOE FUNDED TEST

- **PROCESS**
 - APPLY RF ENERGY THROUGH A SPECIAL PATTERN OF CONDUCTORS IN BOREHOLES TO UNIFORMLY HEAT FORMATION TO 100°C
 - CONVERT BOREHOLES TO INJECTION AND PRODUCTION WELLS AND CONDUCT A HOT CAUSTIC FLOOD
- **LAB TESTS HAVE BEEN COMPLETED SHOWING EFFICIENT HEATING AND RECOVERY OF BITUMEN**
- **PLANNED FIELD EXPERIMENT**
 - **PHASE I** — SELECT SUITABLE SITES
 - **PHASE II** — IDENTIFY SITE SPECIFIC CHARACTERISTICS AND OPTIMIZE PROCESS CONDITIONS. CONDUCT 5 BBL/DAY PILOT
 - **PHASE III** — SCALE UP, ENGINEERING DESIGN, AND FINAL SITE SELECTION FOR 25-35 BBL/DAY PILOT
 - **PHASE IV** — CONDUCT 25-35 BBL/DAY PILOT

UNIVERSITY OF UTAH RESEARCH ON ADVANCED PROCESSES (DOE FUNDED)

1. HOT WATER PROCESS

- (a) MODIFICATION OF CANADIAN PROCESS USING HIGH SHEAR FORCES IN THE REACTOR AND THE ADDITION OF A CAUSTIC WETTING AGENT TO OVERCOME THE OIL WET FORCES**
- (b) LAB SCALE TEST WORKING EFFECTIVELY, READY FOR PILOT TESTING**

2. FLUIDIZED BED RETORT

- (a) TWO ZONE REACTOR**
- (b) UPPER ZONE -- BITUMEN RETORTING**
- (c) LOWER ZONE -- RESIDUAL COKE COMBUSTION FOR HEAT INPUT**
- (d) TWO ZONES CONNECTED BY HEAT CONDUCTION PIPES AND AIR FLOW**
- (e) LAB TESTS TO OPTIMIZE PROCESS CONTINUING**

3. EVALUATION OF TAR SAND UPGRADING PROCESSES

- (a) VISBREAKING, COKING, CAT CRACKING, AND HYDROPYROLYSIS COMPARED**
- (b) HYDROPYROLYSIS APPEARS MOST EFFECTIVE**
- (c) TWO STEP VISBREAKING THEN CAT CRACKING ALSO APPEARS GOOD**

TAR SAND LEASING

- a. HISTORY — DOI HAS NOT ISSUED A TAR SAND LEASE SINCE 1965
- b. AREA — 701,000 ACRES OF FEDERAL LAND IN MAJOR TAR SANDS AREAS, ONLY 133,000 NOT UNDER OIL AND GAS LEASES
- c. IF HR 7242 PASSES — EACH OIL AND GAS LESSEE CAN CONVERT TO COMBINED HYDROCARBON LEASE WITHOUT BONUS UPON SUBMISSION OF AN ACCEPTABLE PLAN OF ACTION
- d. IF HR 7242 DOES NOT PASS — SELECTED OIL AND GAS LESSEES WILL BE ISSUED NONCOMPETITIVE TAR SAND LEASES IF (1) THEY ARE LOCATED IN AN IDENTIFIED TARGET AREA WITH AN EIA; (2) UPON SUBMISSION OF AN ACCEPTABLE PLAN OF ACTION
- e. PLANNED DOI PROCEDURE
1. USGS WILL DESIGNATE MAJOR TAR SANDS AREAS. PROBABLY START WITH FIVE — CIRCLE CLIFFS, P.R. SPRING, SUNNYSIDE, ASPHALT RIDGE, TAR SAND TRIANGLE
 2. DEVELOP PROGRAMMATIC EIS
 3. ISSUE CALL FOR NOMINATIONS TO DETERMINE INDUSTRY INTEREST
 4. CHOOSE TWO AREAS TO ALLOW LEASING, THEN OPEN UP OTHER AREAS WHEN ACCEPTABLE DEVELOPMENT PROVEN ON FIRST TWO. TWO OF THE EASIER DEPOSITS, PROBABLY SUNNYSIDE AND ASPHALT RIDGE, WILL PROBABLY BE CHOSEN FIRST. THE TOUGHER ENVIRONMENTAL BATTLES OF CIRCLE CLIFFS AND TAR SAND TRIANGLE, WHICH BORDER OR OVERLAP NATIONAL PARKS, WILL PROBABLY BE SAVED FOR LATER, EVEN THOUGH TAR SAND TRIANGLE IS BY FAR THE LARGEST DEPOSIT.
 5. DEVELOP SITE SPECIFIC EIS'S
 6. ANTICIPATE EARLIEST POSSIBLE LEASING BY 1982

INTERNATIONAL AGREEMENTS FOR JOINT COOPERATION IN THE DEVELOPMENT OF HEAVY OILS AND TAR SANDS

I. U.S. — CANADA

A. MEMO OF UNDERSTANDING SIGNED

B. SIX AREAS OF COOPERATION IDENTIFIED:

- 1. RESOURCE CHARACTERIZATION**
- 2. COMPARISON OF ECONOMICS AND SWEEP EFFICIENCIES OF
STEAMFLOODING AND IN SITU COMBUSTION**
- 3. PERMEABILITY-ENHANCEMENT METHODS**
- 4. TREATMENT OF PRODUCED WATER**
- 5. STEAMFLOODING WITH ADDITIVES**
- 6. LABORATORY AND FIELD PROJECT REVIEWS**

C. METHODS OF COOPERATION:

- 1. EXCHANGE OF PERSONNEL AND INFORMATION**
- 2. JOINT FUNDING OF R,D&D PROJECTS**
- 3. SEMINARS AND SITE VISITS**

LOW PRESSURE DOWNHOLE GENERATOR

ADVANTAGES

- HIGH THERMAL EFFICIENCY (92%)
- LOW CAPITAL COST
- NO PARTICULATE INJECTED INTO RESERVOIR

DISADVANTAGES

- AIR QUALITY
- SIZE AND NUMBER OF STRINGS
- PARTICULATE IN RETURN GASES

HEAT BALANCE INFORMATION

INJECTION PRESSURE 1500 PSIA, DEPTH 2500 FT
BASED ON LOWER HEATING VALUE = 18,293 BTU/LB

HEAT INPUT		HEAT OUTPUT	
SOURCE	%		%
COMBUSTION FUEL (750.02 LB/HR)	81.9	COMBUSTION EXHAUST LOSS	4.1
DIESEL FUEL (165.71 LB/HR)	18.1	DIESEL ENGINE EXHAUST LOSS	2.2
TOTAL (915.73 LB/HR)	100	DIESEL COOLANT LOSS	0
		OTHER: DIESEL STRAY & PUMP WORK	1.0
		ABOVE GROUND TOTAL	7.3
		WELL BORE LOSS	0.50
		INJECTED GAS (EXCLUSIVE OF STEAM)	0
		USEFUL HEAT (85% QUALITY STEAM)	92.2
		BELOW GROUND TOTAL	92.7
		TOTAL	100.0

HIGH PRESSURE DOWNHOLE GENERATOR

ADVANTAGES

- ADDRESSES AIR QUALITY
- COMBINES THERMAL WITH CARBON DIOXIDE RECOVERY
- COMPACT DESIGN

DISADVANTAGES

- PARTICULATE INJECTION TO RESERVOIR
- HIGH PRESSURE COMBUSTION
- HIGH PRESSURE AIR SUPPLY

HEAT BALANCE INFORMATION

INJECTION PRESSURE 1500 PSIA, DEPTH 2500 FT
 BASED ON HEATING VALUE = 18,293 BTU/LB

HEAT INPUT

SOURCE	%
COMBUSTION FUEL (676.8 LB/HR)	65.3
COMPRESSOR FUEL (360 LB/HR)	34.7
TOTAL (1036.85 LB/HR)	100

HEAT OUTPUT

COMBUSTION EXHAUST LOSS	0
DIESEL ENGINE EXHAUST LOSS	4.9
DIESEL COOLANT LOSS	7.1
OTHER: DIESEL STRAY & PUMP WORK	0.8
ABOVE GROUND TOTAL	12.8
WELL BORE LOSS	0.2
INJECTED GAS (EXCLUSIVE OF STEAM)	5.6
USEFUL HEAT (85% QUALITY STEAM)	81.4
BELOW GROUND TOTAL	87.2
TOTAL	100

IN SITU COMBUSTION PROCESS

STEAM FLOODING PROCESS

PROJECT DEEP STEAM FIELD TEST/BAKERSFIELD, CA.

HIGH PRESSURE DOWNHOLE GENERATOR

ADDITIONAL APPLICATIONS

<u>DEEP LIGHT OIL</u>	<u>SHALLOW HEAVY OIL</u>	<u>SUPER CRITICAL RESERVOIRS</u>	<u>OFF-SHORE</u>	<u>TAR SANDS</u>	<u>OIL SHALE</u>
<ul style="list-style-type: none"> • 95% THEORETICAL SWEEP • LESS CO₂ REQUIRED THEN FOR CO₂ DRIVE • GASES ARE PRODUCED AT RESERVOIR 	<ul style="list-style-type: none"> • PERMEABILITY MODIFICATIONS • AID IN SWEEP CONTROL 	<ul style="list-style-type: none"> • IMPROVED SWEEP EFFICIENCY ABOVE CRITICAL PRESSURE • REDUCED COST OF AIR SUPPLY 	<ul style="list-style-type: none"> • SIZE • COMBUSTION PROCESSES REMOVED FROM PLATFORM 	<ul style="list-style-type: none"> • SWELLING OF BITUMEN • INCREASED LATENT HEAT 	<ul style="list-style-type: none"> • SUPER HEATED STEAM • NO DELIVERY HEAT LOSS

AB-1

Appendix II

OIL-IMPREGNATED SANDSTONE DEPOSITS

UTAH

UINTA BASIN

1. TABIONA
2. WHITEROCKS
3. ASPHALT RIDGE
4. RAVEN RIDGE
5. P. R. SPRING
6. HILL CREEK
7. SUNNYSIDE

CENTRAL SOUTHEAST

8. SAN RAFAEL SWELL
 9. TEASDALE
 10. CIRCLE CLIFFS
 11. TAR SAND TRIANGLE
- ### OTHER AREAS
12. MEXICAN HAT
 13. ROZEL

AGE OF ROCKS IN WHICH DEPOSITS OCCUR UINTA BASIN, NORTHEASTERN UTAH

AGE	NUMBER, SIZE OF DEPOSITS
TERTIARY
CRETACEOUS	
JURASSIC
TRIASSIC	
PERMIAN

GIANT +500 MILL. BBLS.

BLOCKS =
 BILLIONS OF BBLS.

LARGE, 10-100 MILL. BBLS.

MED. - SMALL, 0.5 - 10 MILL. BBLS.

VERY LARGE,
 100 - 500 MILL. BBLS.

MINOR, LESS THAN 0.5 MILL. BBLS.

AGE OF ROCKS IN WHICH DEPOSITS OCCUR CENTRAL SOUTHEAST UTAH

AGE	NUMBER, SIZE OF DEPOSITS
JURASSIC	●xx
TRIASSIC
PERMIAN	xxx
PENNSYLVANIAN	●x

GIANT + 500 MILL. BBLS.

BLOCKS =
BILLIONS OF BBLS.

● LARGE, 10-100 MILL. BBLS.

● MED. - SMALL, 0.5-10 MILL. BBLS.

x MINOR, LESS THAN 0.5 MILL. BBLS.

VERY LARGE,
100-500 MILL. BBLS.

UIN TA BASIN DEPOSITS

% SULFUR IN OIL EXTRACTED FROM UTAH
 OIL-IMPREGNATED SANDSTONE DEPOSITS

CENTRAL SOUTHEAST DEPOSITS

GEOLOGIC
AGE

1.0 2.0 3.0 4.0

Jurassic

-TAR SAND TRIANGLE-

*Permian**Permian*

-CIRCLE CLIFFS-

Triassic
(*Moenkopi*)*Triassic*
(*Shinarump*)

% SULFUR IN OIL EXTRACTED FROM UTAH
OIL-IMPREGNATED SANDSTONE DEPOSITS

AB-1

Appendix III

CONCENTRATION OF UTAH TAR SANDS
BY AN AMBIENT TEMPERATURE FLOTATION PROCESS

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ABSTRACT

Physical separation of bitumen from low-grade Utah tar sand deposits containing a relatively high viscosity bitumen phase (Sunnyside and Tar Sand Triangle deposits) has been accomplished by traditional size reduction and froth flotation techniques. At appropriate experimental conditions more than 90 percent of the bitumen can be recovered in a concentrate, containing more than 20 weight percent bitumen, which should be a suitable feed material for subsequent hot water or thermal processing. The efficiency of bitumen recovery depends on the extent of size reduction, promoter and dispersant addition. Rejection of greater than 60 percent of the sand at ambient temperature and ease of water removal from the concentrate make such a process strategy both energy and cost effective. The energy required to achieve effective separation by the ambient temperature process is significantly less than the energy required for the recently developed hot water process.

The flotation behavior of the tar sand has been analyzed with respect to flotation pH, contact angle measurements and the apparent isoelectric point of the bitumen. The best flotation response at pH 7.8 to 9.0 can be correlated with the maximum contact angle developed between the air bubble and bitumen surface and with the apparent isoelectric point of the bitumen ($\sim$ pH 8.0).

INTRODUCTION

Recent interest in energy sources other than petroleum has directed considerable research effort to develop physical separation techniques for the processing of fossil fuels minerals such as coal, oil shale and tar sands. More than thirteen million tons of coal per year are processed by froth flotation (Aplan, 1976) and concentration techniques for the processing of oil shale by froth flotation has been developed in Sweden and Russia (Fahlstrom, 1979; Kiminskii, 1978). With regard to the development of physical separation processes for tar sands, the hot water process is a commercial reality in Canada (McConville, 1975; Oliver, 1976, Porteous, 1978) and has been modified for the processing of Utah tar sands (Sepulveda and Miller, 1978; Misra and Miller, 1980). However, only a modest amount of research effort (Farnard, et. al., 1961; Bichard, et. al., 1974) has been reported on the development of conventional ambient temperature separation technology for the well known tar sand deposits of Athabasca in Canada, and no research on conventional concentration technology has yet been reported for other tar sand deposits of the world.

Numerous methods for the recovery of bitumen from Athabasca tar sands have been developed. Processes such as the hot water process (Clark, 1923; Clark and Pasternack, 1932; Clark, 1944; McConville, 1975), solvent extraction process (Cottrel, 1974) and thermal process (Gishler, 1944; Peterson and Gishler, 1950) are worth mentioning. Out of all these processes, the hot water process is the only process which has been commercialized both by Suncore Inc. (formerly GCOS), which since 1967 has produced 60,000 barrels of synthetic crude per day, and by Syncrude, designed to

produce 125,000 barrels of synthetic crude per day (McConville, 1975). Unfortunately, the same hot water process cannot be applied directly to the Utah tar sands due to the inherent difference in physical and chemical properties of these deposits (Sepulveda and Miller, 1978; Misra and Miller, 1980). Unlike Athabasca tar sand, Utah tar sands contain no detectable indigenous water. Therefore, in the absence of a connate film of water, the bitumen in Utah tar sands is bonded directly to the sand particles. Another important feature of the Utah tar sands is its substantially greater bitumen viscosity in comparison to the bitumen viscosity of Athabasca tar sands as shown in Figure 1 (Miller and Misra, 1981). For example, the viscosity of bitumen from the Sunnyside deposit is about two orders of magnitude greater than the viscosity of Athabasca bitumen. Furthermore, it is estimated that the viscosity of the bitumen from the Tar Sand Triangle outcrop sample is well over four orders of magnitude greater than the viscosity of the same Athabasca bitumen (Misra and Miller, 1980).

With this understanding and making necessary provisions, Miller and Sepulveda (1978) developed a modified hot water process for the separation of bitumen from the tar sands containing moderate viscosity bitumen (Asphalt Ridge and P. R. Spring deposits). Later Misra and Miller (1980) found that in the case of tar sand containing high viscosity bitumen, such as the Sunnyside deposit, the addition of a diluent is necessary to achieve effective phase disengagement during digestion. However, for the low-grade and highly viscous bitumen from the Sunnyside deposit, the quality of separation was still inferior to that of the high grade and moderately viscous bitumen from the Asphalt Ridge and P.R. Spring deposits.

As can be seen from Table 1, it is estimated that more than 75% of the total tar sand deposits in Utah contain less than 10 weight percent bitumen,

of a highly viscous nature. Besides the technological limitations, a low feed grade also limits the hot water processing for economic reasons. Nevertheless, these low grade deposits are certainly a significant domestic energy resource. The depletion of conventional petroleum reserves and the quest for energy may eventually require the exploitation of low-grade deposits containing highly viscous bitumen which currently is considered to be economically marginal. In this regard, research was initiated to develop an appropriate low temperature separation strategy for these deposits and to recover a satisfactory product for further processing by hot water digestion, solvent extraction, or thermal recovery techniques.

One low temperature process is the sand reduction process developed by Imperial Oil Enterprises, Ltd. (Bichard, et. al., 1974) which operates at ambient temperature (70°F). In this process tar sand is mixed in a screw conveyer and the pulp is discharged into a rotary drum screen submerged in water and the bitumen agglomerate is screened from the bulk sand. A spherical agglomeration technique developed by the National Research Council of Canada facilitates the recovery of bitumen, and rejection of a large amount of sand is achieved efficiently. These cold water processes have been tested only in small scale continuous plants and have yet to be commercialized. No work has yet been reported for the ambient temperature flotation of Utah tar sands.

EXPERIMENTAL PROCEDURE

Tar sands from three different Utah deposits, Sunnyside, Tar Sand Triangle, and Asphalt Ridge, were used in this investigation. The initial size reduction of the Sunnyside Tar Sand sample was accomplished by conventional crushing techniques; after freezing in liquid nitrogen, the product

was sized to -4 mesh and kept in airtight polyethylene bags for further processing by conventional ambient temperature flotation techniques. The Tar Sand Triangle sample containing less than 5 weight percent bitumen was crushed to -4 mesh with conventional crushing equipment without cryogenic treatment and stored similarly in airtight bags to avoid oxidation. In addition, some experiments were conducted with a high-grade Asphalt Ridge tar sand sample.

Ambient Temperature Separation Experiments

Mineral processing techniques can be applied to separate bitumen from certain Utah tar sands. Most attention was focused on the Sunnyside sample, and preliminary experiments were made to determine the feasibility of such a process strategy for Tar Sand Triangle and Asphalt Ridge samples. The -4 mesh crushed product was wet ground in a six-inch ball mill at 70 weight percent solids. Some experiments were also conducted in a twelve-inch ball mill, coupled with a torque meter to determine the energy required to achieve various levels of size reduction (Siddique, 1977). For bench scale flotation experiments, the grinding was conducted with 800 grams of tar sand and 366 cc of water in the six-inch ball mill. After grinding for a specified time, the slurry was filtered and divided into four parts. Unless otherwise specified, flotation experiments were done with a feed material, the sand size distribution of which corresponded to 25% passing 100 μm . Flotation experiments were conducted in a Galigher flotation machine. One part of the filtered material (200 grams) was conditioned in the flotation cell with 2000 ml of water and dispersant (if necessary) for 10 minutes. Next, appropriate amounts of promoter were added and conditioned for one more minute. Unless otherwise mentioned light fuel oil (Coleman gas) and

dispersant (sodium silicate) were used as promoter and dispersant, respectively. The bitumen was floated for five minutes with an air flow rate of 3000 cc/min at 900 rpm. The concentrate and tailing were collected, filtered, and dried. Representative amounts of concentrate and tailings were analyzed with respect to bitumen, sand, and water by a Dean-Stark analytical technique.

Hot Water Processing of Ambient Temperature Concentrate

The concentrate obtained from the ambient temperature process contains about 21 weight percent bitumen on a dry basis. In order to test the suitability of the concentrate as a feed material for the modified hot water process, experiments were conducted in a one gallon stirred tank reactor which was designed exclusively for the hot water processing of Utah tar sands. In this regard two batches (4000 grams each) of Sunnyside feed material were wet ground in the twelve inch ball mill at 70% solids. After 30 minutes grinding, the slurry was filtered using a pressure filter, and flotation was conducted in a 37 liter flotation cell at 900 rpm and an air flow rate of 20 liters/min with the addition of 5 lb/ton promoter (Coleman gas). The concentrate from the flotation cell was filtered to remove excess water associated with the concentrate. From the analysis it was established that the concentrate after filtration contains at least 20% water on a wet basis. The concentrate thus produced was fed to the standard digestion unit at 70 percent solids, 15 lb/ton Na_2CO_3 and a diluent to bitumen volume ratio of 4.5 gal/ton. The pulp was digested for 15 minutes at 95°C. After digestion it was discharged to the 37 liter flotation cell and floated for 10 minutes.

Compositional Analysis

Representative samples of feed, concentrate, and tailing obtained during experimentation were analyzed to establish their composition with respect to bitumen, sand, and water, using a set of Dean and Stark tube assemblies. The assemblies were set up in accordance with the procedure described by the U.S. Bureau of Mines report (Rall and Raliferro, 1946).

Titration

A reverse titration technique was developed to determine the apparent isoelectric point of the tar sand bitumen. Titration was conducted using an automatic titration unit attached with a strip chart recorder, manufactured by London Company. The change of pH as a function of time was recorded by putting 5 gm of bitumen concentrate obtained from the ambient temperature process into 20 ml of water at a preadjusted pH.

In other cases solvented extracted bitumen and feed material were digested at 90°C, at an appropriate pH value for extended times and equilibrium pH values were measured using a Sargent-Welch pH meter.

Contact Angle Measurement

Contact angle measurements were made using a goniometer and optical bench manufactured by Ramé-Hart Inc.. The bitumen sample to be examined was placed in a plastic bottle cap and a smooth surface resulted after some time. The cap was then floated upside down in a 20 mm x 20 mm x 40 mm glass cell in the presence of an aqueous solution of known composition. An air bubble was then released at the surface of the bitumen. After stable attachment, the contact angle was measured within one minute. For the Asphalt Ridge bitumen, contact angles were measured within 30 seconds in order to avoid wetting of the bubble by the bitumen.

A different procedure was used to measure the contact angle of the Sunnyside core samples. A fresh sample approximately 10 mm x 10 mm x 20 mm was prepared and placed in the glass cell. A solution of desired composition was added to the cell. The micro-syringe needle was then positioned above the tar sand surface. The air bubble was released and allowed to gently touch the bitumen surface. The syringe was slowly raised from the tar sand surface and the contact angle was measured.

Particle Size Analysis

From a processing standpoint, sand size distribution is an important property of the tar sand feed. The sand size distribution for Utah tar sand feed and product was determined by the conventional wet-dry sieving technique in the size range of 590 μm to 38 μm . In this regard the required amount of tar sand feed and product were completely extracted using the Dean Stark assemblies. The clean sand thus obtained was mixed with water and 2 lb/ton sodium silicate using an overhead stirrer. After mixing for 30 minutes the slurry was screened on a 400 mesh screen. The size analysis of the +400 mesh material was conducted by conventional dry sieving techniques.

RESULTS AND DISCUSSION

The principles of this ambient temperature separation process are similar to any other conventional concentration process. First of all raw material is crushed and ground in a standard ball mill to achieve the liberation of the valuable component (bitumen) from the gangue (sand). Such an approach is contrasted with the hot water process in which phase disengagement (liberation) is achieved by high temperature digestion (Sepulveda and Miller, 1978; Misra and Miller, 1980). After grinding in the ambient

temperature process, the valuable component, (bitumen), is recovered by conventional flotation with the addition of necessary flotation reagents.

Criterion for Phase Disengagement by Grinding

Initial experience with the size reduction of various tar sand samples led to the conclusion that a viscosity for the bitumen phase of 50 poise or greater (as determined at 90°C) will probably be required in order to achieve liberation by traditional grinding techniques. Bitumen from two Utah deposits, Sunnyside and Tar Sand Triangle, meet this criterion. (See Figure 1). Tar sands with bitumen of lower viscosity, less than 10 poise at 90°C, undergo agglomeration during size reduction, and the bitumen under these circumstances is not liberated and thus separation cannot be effected. The high viscosity criterion (50 poise at 90°C) indicates that the bitumen phase is sufficiently viscous to be broken from the sand particles and dispersed as "particle droplets" in the aqueous phase. Such a condition and process strategy is fundamentally different from the spherical agglomeration process developed for Canadian tar sands by the National Research Council of Canada (Farnard, 1961).

Sand Size Distribution

The flotation recovery and the grade of the bitumen concentrate mostly depend on the extent of size reduction and the liberation of bitumen from the sand-bitumen network. The specific energy required to obtain products of different sand size distribution for the Sunnyside tar sand was determined for batch grinding in a standard ball mill equipped with a torque meter and recorder. Selected sand size distribution curves for ground products are shown in Figure 2 at various levels of energy input. As would

be expected higher energy levels produce a finer sand size distribution. For example at 6.36 kwh/ton, 50% of the sand is finer than 100 μm , whereas for 12.8 kwh/ton, about 80% of the sand is finer than 100 μm . Moreover, the grinding behavior of sand in the tar sand material is different than that of pure quartz, particularly at a finer size range (Misra, 1981). This is due to the inherent differences in the physical properties of the sand particle present in tar sand feed material. The interstices of the sand particles are inundated with bitumen which completely envelopes each sand particle. As a result the breakage of sand particles present in the bitumen-sand matrix is comparatively more energy intensive than that of pure quartz.

Flotation recovery of the bitumen as a function of weight percent of sand particles less than 100 μm is shown in Figure 3 for 5 lb/ton promoter and 5 lb/ton dispersant. It should be noted that as the percentage of sand particles smaller than 100 μm increases, the recovery of bitumen in the concentrate increases significantly, reaches a maximum and then decreases gradually. Examination of the ground product at higher levels of energy input indicated that a portion of the bitumen tends to agglomerate, which prevents recovery of this bitumen by froth flotation. Also, it seems that more extensive size reduction of the sand particles results in a concomitant reduction of the bitumen's intrinsic hydrophobicity.

It might be expected that the concentrate grade would also be diminished by the production of finer sand particles and this indeed was found to be so. Entrapment and transport of hydrophilic particles into the froth phase generally increases as particle size decreases and such a phenomenon appears not to be unexpected for the flotation of tar sands (See Figure 3).

Bitumen-Tar Sand Surface Chemistry

Generally, flotation occurs due to the attachment of an air bubble to the surface of hydrophobic particles and the thermodynamic considerations of bubble-particle attachment have been discussed by several authors (Laskowski, 1974; Fuerstenau and Raghavan, 1976; Finch and Smith, 1979). The attachment phenomenon is characterized by the contact angle which is a measure of the hydrophobic nature of the surface. In this regard contact angles for Sunnyside tar sand were measured in the presence and absence of various hydrocarbon homologs and light fuel oil as a function of pH. The results are presented in Table 2. Both in the absence and presence of hydrocarbon oil, Sunnyside tar sand exhibits a finite contact angle, characteristic of the native flotability of the bitumen phase. As can be noticed from Table 2, the addition of 250 mg/l of promoter or any of the hydrocarbon homologs does not significantly increase the contact angle between the tar sand surface and the air bubble.

The contact angles developed at the surface of solvent extracted bitumens from the Sunnyside and Asphalt Ridge deposits are shown in Figure 4 (Misra and Miller, 1981) and, as can be noticed, a maximum contact angle between the bitumen surface and the air bubble is possible under moderately alkaline conditions ~pH 8. These results demonstrate that tar sand feed material as well as solvent extracted bitumen exhibit moderate hydrophobicity, which accounts for the recovery of the bitumen during ambient temperature flotation. These findings should be contrasted to the results of hot water separation experiments in which case flotation is accomplished by bubble entrapment rather than by bubble attachment to the bitumen phase (Smith and Miller, 1981).

In another experiment an apparent iso-electric point of the tar sand was identified by measuring change of pH as a function of time for different initial pH values as shown in Figure 5. Interestingly, the apparent iso-electric point of the bitumen was found to be in the range of pH 7.8-8.3, which is in excellent agreement with the measured contact angle. The surface chemistry associated with these results are discussed elsewhere (Misra and Miller, 1981). At the iso-electric point, the charge (potential) of the surface is minimum. As a result the attachment of the air bubble at the surface is facilitated. Blake and Kitchner (1972) report that bubble attachment at a hydrophobic surface is not possible if the surface is highly charged. So the reduction in charge density at the bitumen surface at a moderately alkaline pH (pH ~ 8) enhances the attachment event resulting in a higher contact angle.

Bench Scale Flotation

Promoter Addition

Since bitumen is naturally hydrophobic, a small addition of ordinary fuel oil might be used as a promoter. In this regard, the coefficient of separation is shown as a function of promoter addition in Figure 6. Conditions for a typical experiment and corresponding results are given in Table 3. A small addition of promoter (5 lb/ton) increases the coefficient of separation from 0.48 to 0.50. However, excessive addition (10 lb/ton) results in an emulsion or dispersion of surface bitumen layers, and an increased loss of the dispersed bitumen in the flotation cell. As can be seen from Figure 6, the addition of a small amount of sodium carbonate (10 lb/ton) during the grinding stage increased the coefficient of separation

significantly. It was also observed that higher additions of sodium carbonate (>15 lb/ton) destroy the intrinsic hydrophobicity of the bitumen particulates so much that bitumen cannot be separated by froth flotation. A similar effect was observed in hot water separation experiments (Misra, 1980).

Coefficient of separation as a function of promoter addition for the highly viscous ($>10^4$ at 90°C) Tar Sand Triangle sample is shown in Figure 7. Unlike Sunnyside Tar Sand, higher additions of promoter increase the quality of separation considerably for the sample from Tar Sand Triangle. The higher addition of promoter oil does not seem to disperse bitumen from the surface layer as is the case for the Sunnyside sample. These results reflect the highly viscous nature of the bitumen from the Tar Sand Triangle deposit.

Effect of pH

The coefficient of separation is shown in Figure 8 for Sunnyside tar sand as a function of pH, at an addition of 5.0 lb/ton promoter. As can be seen, the best separation is obtained at a moderately alkaline pH, between 7.5 and 9.0. When the pH exceeded 11, excessive froth formed during flotation. This pH dependence of the flotation response can be correlated with the apparent iso-electric point of the tar sand feed and bitumen, which was shown to be in the range of pH 7.8 to 8.3 (Figure 5). Furthermore, this is the pH range where a maximum contact angle between the air bubble and the bitumen surface was observed (Figure 4).

Dispersant Addition

Sodium-silicate has been used as a dispersant with a certain degree of success in many systems containing quartz as a gangue constituent

(Glembotskii, et. al., 1972; Colombo, 1980). In this regard, the coefficient of separation as a function of dispersant addition is given in Table 4. Small additions of sodium silicate seem to have beneficial effect on the quality of separation. However, higher levels of addition seem to have detrimental effect. The role of sodium silicate is rather complex and adsorption mechanisms are not completely understood. With regard to tar sand flotation, sodium silicate may act as a dispersing agent for the slimes in the pulp as well as a depressant for quartz.

Effect of Oxidation

As discussed earlier the bitumen concentrate obtained by the ambient temperature separation process is hydrophobic. As might be expected, surface alteration due to oxidation can have a detrimental effect on the quality of separation. It was observed during the research project that freshly ground tar sand floated better than the samples which had been exposed to the atmosphere for a few hours or days. The coefficient of separation as a function of time of exposure to the atmosphere for ground Sunnyside tar sands is shown in Figure 9. The reduction in the separation efficiency appears to be mainly due to surface oxidation, which takes place when the tar sand feed material is exposed to the atmosphere at room temperature. Probably the oxidation of hydrocarbons and formation of surface acidic groups results in a reduction of hydrophobicity and flotability of tar sand bitumen. Similar phenomenon is known to occur in coal flotation systems (Sun, 1954; Aplan, 1976).

Hot Water Processing of Ambient Temperature Concentrate

The concentrate from the ambient temperature experiments contains about 21% bitumen on a dry basis. Furthermore, water removal from the ambient temperature concentrate is readily achieved compared to the concentrate obtained from the hot water process. For example, after two hours drying under a lamp, no detectable amount of water was observed in the ambient temperature concentrate. On the contrary, after four hours drying under the lamp, water content in the hot water concentrate was determined to be 25 percent by weight, resulting from a colloidal dispersion of water droplets in the bitumen phase. Ease of water removal and uniformity of this concentrate makes it excellent feed material for subsequent processing. In this regard, two experiments were performed to establish the suitability of the ambient temperature concentrate as a feed material for the recently developed hot water process. Results from the hot water processing of the ambient temperature concentrate are given in Table 5. As can be seen, 99 percent of the bitumen was recovered at a grade of 45 percent, comparable with the results obtained by the two stage hot water processing of Sunnyside Tar Sand (Misra, 1981).

At this point, the ambient temperature separation appears to be an attractive process strategy for the highly viscous Sunnyside feed material. However, the grade of the concentrate, regardless of the processing routes followed, is found to be about 45 percent bitumen by weight on a dry basis. The size distribution of sand particles recovered in concentrates from different two stage separation experiments are presented in Figure 10. It is clear that fine sand particles are mechanically entrapped in the bitumen concentrate and limit the grade of the concentrate.

SUMMARY AND CONCLUSIONS

Physical separation of bitumen from Utah tar sand deposits (Sunnyside and Tar Sand Triangle) containing a relatively high viscosity bitumen phase can be accomplished by traditional size reduction and froth flotation techniques. Under certain conditions (grinding to a sand size distribution of 60% less than 100 μ m, 5.0 lb/ton promoter and 5.0 lb/ton dispersant) more than 90% of the bitumen can be recovered in a concentrate which itself is an excellent feed material for either the hot water or thermal process. As expected, in the absence of alkaline digestion, the flotation behavior and contact angle measurements of the tar sand sample indicated that the bitumen had a naturally hydrophobic character. The best flotation response was obtained at moderately alkaline pH, which correlates with the apparent isoelectric point of the bitumen as determined from titration curves.

Moreover, the rejection of greater than 60% of the sand, the uniformity of the concentrate, and the ease with which water can be removed from the concentrate make the ambient temperature process strategy attractive and cost effective in comparison to the hot water process. The most significant factor of the ambient temperature process is the energy efficiency. The energy required to achieve effective separation by this ambient temperature process is significantly less than the energy required for the recently developed hot water process, as shown in Figure 11. Calculations indicate that required energy input for phase disengagement by digestion in the hot water process is at least 45 kwh per ton for greater than 90% recovery; whereas, for the ambient temperature process, the energy input for phase disengagement by size reduction is substantially less, requiring only 13 kwh per ton for greater than 90% recovery. The findings of this investigation

add to the current physical separation process alternatives for tar sand deposits. A summary of these physical separation processes is presented in Table 6, which, together with strategies such as the sand reduction process and the spherical agglomeration process as well as other phase separations such as the oleophilic sieve (Kruyer, 1978) and the air sparged hydrocyclone (Miller, 1981), gives the design engineer many alternatives for process synthesis.

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6. Physical separation processes for Utah tar sands.

Table 1
Utah Tar Sand Deposits (Misra and Miller, 1981).

	In-Place Bitumen (billion bbl)	Average Bitumen Content (Wt. %)
Tar Sand Triangle	12-16	5.0
P.R. Spring	4.0-4.5	12.2
Sunnyside	3.5-4.0	9-10
Circle Cliffs	1.3	5.0
Hillcreek	1.2	8-9
Asphalt Ridge	1.1	13.1

Table 2

Contact Angle of Sunnyside Tar Sand (Core Sample) as a Function of pH
in the Absence and Presence of Various Promoters (250 mg/l).

pH	Contact Angle (degrees)					
	None	Naphtha (Coleman gas)	C_5H_{12}	C_7H_{16}	C_9H_{20}	$C_{10}H_{22}$
4	55	40	49	46	52	55
6	62	52	59	45	56	51
8	57	54	57	44	61	57
10	57	61	54	43	62	57
11	59	46	61	53	64	58

Table 3
Ambient Temperature Separation of Sunnyside Tar Sand.

Experimental Conditions

Grinding

Wetting agent: None
Percent solids: 70%
Sand size: 60% passing 100 μm

Flotation

Promoter (Coleman gas): 5 lb/ton
Dispersant: 5 lb/ton
Impeller speed: 900 rpm
Air flow rate: 9000 cc/min

Calculated Mass Balance

	Weight, %	Grade, %		Recovery	
		Tar	Sand	Tar	Sand
Concentrate	46.77	20.25	79.75	92.21	41.57
Tail	53.23	1.51	98.49	7.79	58.43
Feed		10.27	89.73	100	100

Coefficient of Separation = 0.50

Table 4
Effect of Dispersant Addition (Sodium Silicate)
on the Quality of Separation.

Sodium Silicate Addition, lb/ton	Coefficient of Separation
0	0.48
5	0.50
15	0.46
20	0.40

Table 5

Typical Experimental Results of Hot Water Processing of the
Concentrate Produced by Ambient Temperature Separation.

Experimental Conditions:

Digestion

Feed: Sunnyside Ambient Temperature Concentrate
 Temperature: 95°C
 Percent of solid: 70%
 Wetting agent: 0.2 M Na₂CO₃
 Diluent addition (kerosene): 0.2 cc/cc bit
 Conditioning time: 15 minutes

Flotation

Flotation cell: 38 liter cell
 Percent solid: 11% by weight
 Agitation: 1000 rpm
 Air flow rate: 10 lit/min

Calculated Mass Balance

	Weight, %	Grade, %		Recovery	
		Tar	Sand	Tar	Sand
Concentrate	58.97	45.07	54.93	99.18	44.24
Tail	41.03	0.54	99.46	0.82	55.75
Feed (Ambient conc.)		26.79	73.21	100	100

Coefficient of Separation = 0.55

Table 6
Physical Separation Processes for Utah Tar Sands.

Processing Strategy		Tar Sand Source and Percent Bitumen	Bitumen Viscosity at 90°C, Poises	Coefficient of Separation
Phase Dis- engagement	Phase Separation			
Low shear, hot water digestion	Gravity settler	Athabasca, Canadian (12)	2.5	0.9
		High grade Utah Tar Sands, Asphalt Ridge and P. R. Springs with diluent addition		Effective- ness limited due to emul- sification
High shear, hot water digestion	Modified froth flotation	Asphalt Ridge and P. R. Springs (10-12)	10	0.9
		Sunnyside (8-9) with controlled diluent addition		0.7
Liberation by size reduction	Traditional froth flo- tation followed by HWP of con- centrate	Tar Sand Triangle and Sunnyside (5-9)	>100	.5

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Fig. 1 Arrhenius-type plot illustrating the effect of temperature on viscosity for bitumen from various tar sand deposits.

Fig. 2 Particle size distribution for sands of Sunnyside tar sand and energy inputs.

Fig. 3 Bitumen recovery as a function of sand size distribution for Sunnyside tar sand.

Fig. 4 Contact angle curves of solvent refined Sunnyside and Asphalt Ridge bitumen as a function of pH (Misra and Miller, 1981).

Fig. 5 Change of pH of Sunnyside bitumen concentrate and feed in aqueous solution as a function of time.

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Fig. 8 Coefficient of separation as a function of pH with and without promoter addition.

Fig. 9 Coefficient of separation as a function of exposed time to the atmosphere at ambient temperature.

Figure 10. Particle size distribution of the sand in the concentrate from a typical ambient temperature flotation - hot water separation experiment. Also presented the particle size distribution of the sand in the concentrate of two stage hot water digestion experiment.

Fig. 11 Comparison of bitumen recovery for ambient temperature and hot water separation experiment as a function of energy input.

Separation of Bitumen from Utah Tar Sands by a Hot Water Digestion-Flotation Technique

J. E. Sepulveda and J. D. Miller

Tar sand deposits in the state of Utah contain more than 25 billion bbl of in-place bitumen. Although 30 times smaller than the well-known Athabasca tar sands, Utah tar sands do represent a significant domestic energy resource comparable to the national crude oil reserves (31.3 billion bbl). Based upon a detailed analysis of the physical and chemical properties of both the bitumen and the sand, a hot-water separation process for Utah tar sands is currently being developed in our laboratories at the University of Utah. This process involves intense agitation of the tar sand in a hot caustic solution and subsequent separation of the bitumen by a modified froth flotation technique. Experimental results with an Asphalt Ridge, Utah, tar sand sample indicated that percent solids and caustic concentration were the two most important variables controlling the performance of the digestion stage. These variables were identified by means of an experimental factorial design, in which coefficients of separation greater than 0.90 were realized. Although preliminary in nature, the experimental evidence gathered in this investigation seems to indicate that a hot-water separation process for Utah tar sands would allow for the efficient utilization of this important energy resource.

The projected increase in the ever-widening gap between the domestic energy demand and the domestic energy supply for the next few years has motivated renewed interest in energy sources other than petroleum, such as tar sands, oil shale and coal. Although a number of research programs on the exploitation of national coal and oil shale resources have already been completed, very few programs have been initiated on the processing of tar sand resources in the United States. In recognition of their significance as a domestic energy resource, investigators at the University of Utah have designed an extensive research program on Utah tar sands. An important phase of this program, and the main subject of this publication, is the development of a hot-water process for the recovery of bitumen from Utah tar sands, as a preliminary step toward the production of synthetic fuels and petrochemicals.

The term "tar sand" refers to a consolidated mixture of bitumen (tar) and sand. The sand in tar sand is mostly α -quartz as determined from X-ray diffraction patterns. Alternate names for "tar sands" are "oil sands" and "bituminous sands." The latter is technically correct and in that sense provides an adequate description.

Tar sand deposits occur throughout the world, often in the same geographical areas as petroleum deposits. Significantly large tar sand deposits have been identified and mapped in Canada, Venezuela and, the United States.¹

By far, the largest deposit is the Athabasca tar sands in the Province of Alberta, Canada. According to the Alberta Energy Resources Conservation Board (AERCB),^{2,3} proved reserves of

crude in-place bitumen in the Athabasca region amount to almost 900 billion bbl. To date, this is the only tar sand deposit in the world being mined and processed for the recovery of petroleum products. Great Canadian Oil Sands, Ltd. (GCOS) produces 20 million bbl of synthetic crude oil per year. Another plant being constructed by Syncrude Canada, Ltd. is expected to produce in excess of 40 million bbl of synthetic crude oil per year.

According to the Utah Geological and Mineral Survey (UGMS), tar sand deposits in the state of Utah contain more than 25 billion bbl of bitumen in place, which represent almost 95% of the total mapped resources in the United States.⁴ The extent of Utah tar sand reserves seems small compared to the enormous potential of Canadian tar sands. Nevertheless, Utah tar sand reserves do represent a significant energy resource comparable to the United States crude oil proved reserves of 31.3 billion bbl in 1976.⁵

Tar sands in Utah occur in 51 deposits along the eastern side of the state.⁴ However, only six out of these 51 deposits are worthy of any practical consideration (Fig. 1). As indicated in Table 1, Tar Sand Triangle is the largest deposit in the state and contains about half of the total mapped resources.

Information regarding the grade or bitumen content of Utah deposits is still very limited. The bitumen content varies significantly from deposit to deposit, as well as within a given deposit. In any event, the information available⁶⁻⁸ seems to indicate that Utah deposits are not as rich in bitumen as the vast Canadian deposits which average 12 to 13% by weight.⁹ Although many occurrences of bitumen saturation up to 17% by weight have been detected in the northeastern part of the state (Asphalt Ridge and P. R. Spring), the average for reserves in Utah may well be less than 10% by weight.

Separation Technology

As in any other mining problem, there are two basic approaches to the recovery of bitumen from tar sands. In one

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Fig. 1. Major tar sand deposits in the state of Utah.

case, the ore can be mined and transported to a processing plant where the bitumen is recovered. Alternately, the bitumen can be processed "in-situ." Over the last 50 years, a great variety of separation processes, including both surface mining and in-situ processes, have been proposed in the literature.⁹⁻¹¹ However, until recent years, little was known about the potential applicability of any of these processing strategies to Utah tar sands.

Based on the fact that the hot-water process is the only process whose technology is well developed and is currently being used in the primary separation of bitumen from Canadian tar sands; the main objective in this investigation was to quantify the performance of a similar process for Utah tar sands. In particular, research efforts were concentrated on the identification of the main operating variables which control the quality of the separation achieved by hot-water processing.

The hot-water process was first described by K. A. Clark in 1923¹² and has been repeatedly modified thereafter.¹³⁻¹⁵ As applied to Utah tar sands, this process basically consists of the separation and recovery of bitumen from tar sands by digesting the raw material with a hot aqueous solution containing a caustic wetting agent such as sodium hydroxide, sodium carbonate, or sodium silicate. The resulting strong surface hydration and shearing forces operative at the sand-bitumen interface give rise to the displacement and subsequent disengagement of the bitumen by the aqueous phase (Fig. 2). Once the bitumen has been displaced and the sand particles have been liberated, the two phases can be separated by a modified froth flotation technique based on the natural hydrophobicity exhibited by the free bituminous droplets. The name of the process arises from the fact that digestion is accomplished at temperatures just below the boiling point of water.

In practice, the application of the hot-water processing technique to Utah tar sands results in a two-stage process (Fig. 3). In the first stage, referred to as digestion, crushed tar sand is

Fig. 2. The hot-water process: schematic representation of bitumen displacement and phase disengagement during digestion.

contacted with the hot caustic solution in a stirred tank reactor, at constant temperature, for a specified digestion time. Because of the highly viscous nature of the bitumen in Utah tar sands, the impeller in the reactor must be designed so as to produce a high-shear force field capable of rupturing the bituminous film coating the sand particles (Fig. 2), so that the solid phase may become exposed to the caustic solution. Upon contact, the caustic solution wets the surface of the sand particles and the system reaches its desired equilibrium configuration, i.e., the solid and bituminous phases being separated by the aqueous phase. Ideally, at the end of the digestion stage, the bituminous phase not only has been displaced but also completely disengaged from the solid phase, as a result of the strong shearing action by the impeller in the digester.

The second stage, flotation, is based on the hydrophobic nature of the bitumen at moderate pH values. In the flotation cell, air bubbles attach to the free bituminous droplets and carry them to the top of the cell, while the hydrophilic sand particles settle to the bottom. The flotation cell is operated at relatively low stirring speed so as to reduce the contamination of the bitumen concentrate with very fine sand particles. In actual processing, the hydrophobic bitumen concentrate removed from the top of the flotation cell would be sent to a refining plant for upgrading. On occasions, relatively large lumps of nonfloatable, undigested tar sand may be found with the sand tailings. This material can be recovered from the tailings simply by screening. The scavenger concentrate so produced has a grade sufficiently high to either be recycled or refined as is.

The mechanism or means by which the bitumen is displaced from the surface of the sand particles is not yet well understood and, as a result, a useful theoretical framework does not exist. Furthermore, although similar in principle, the actual separation mechanisms in the processing of Athabasca and Utah tar sands appear to differ significantly. Because of the high moisture content of Athabasca tar sands, 3-5% by weight connate water, it has been postulated by Canadian investigators that the equilibrium structure of Athabasca tar sands consists of sand particles separated from the bitumen by a film of connate water surrounding the sand particles.^{3,9,10} Accordingly, the bitumen in Athabasca tar sands has already been displaced from the sand by the connate water. Under these conditions, bitumen separation reduces to a relatively simple phase disengagement process. Unlike Athabasca tar sands, Utah tar sands are so dry that their moisture content cannot be detected by standard analytical techniques. Obviously, in the absence of water, the bitumen is directly in contact with, and bonded to, the surface of the sand particles. Hence, hot-water processing of

Table 1. Extent of Utah Tar Sand Deposits.

Deposit	Location	In-Place Bitumen ⁽⁴⁾ (billion bbl)
Tar Sand Triangle	SE, Utah	12.5 - 16.0
P. R. Spring	NE, Utah	4.0 - 4.5
Sunnyside	NE, Utah	3.5 - 4.0
Circle Cliffs	SE, Utah	1.3
Hill Creek	NE, Utah	1.2
Asphalt Ridge	NE, Utah	1.0

Utah tar sands involves both bitumen displacement and phase disengagement phenomena (Fig. 2).

Several investigators^{16,17} have attempted to explain bitumen displacement based on a surface energy balance postulating that, in order for the bitumen to be displaced, the total free energy of the system must decrease. However, this thermodynamic approach attempts to describe only the final equilibrium state and, in doing so, it fails to account for possible physical and electrostatic kinetic barriers which seem to be operative in the system.^{16,17} Other investigators¹⁸⁻²¹ have analyzed the displacement phenomenon by consideration of a chemical reaction between the hydrated silica surface and the hydroxy radicals present in the caustic solution, which in turn results in the displacement of the bitumen from the sand particles. Although this second approach eventually could provide a more realistic description of the displacement mechanism and rate phenomenon, it is found to be very limited because of the complexity of the interactions between the different phases of the sand-bitumen-water system. As a result, the process designer is left with one alternative, namely, the development of empirical models based on laboratory and/or pilot plant extraction tests. This is, in essence, the method of approach adopted in this investigation.

Definition of the Research Problem

Ideally, the development of a new processing strategy should naturally arise from a thorough understanding of its fundamentals. However, as emphasized previously, a useful theoretical model capable of describing the different phenomena occurring during hot-water processing of tar sands does not exist.

In view of the foregoing consideration, the best alternate approach would be the direct application of the well-developed Canadian technology to Utah tar sands. However, because of significant differences in the physical and chemical nature of Canadian tar sands as compared to Utah tar sands, and because of considerable differences in climatic conditions between the two locations, the separation technology to be developed for the processing of Utah tar sands and the technology already being used for the processing of Canadian tar sands are expected to be substantially different. Under these circumstances, an independent investigation on the processing of Utah tar sands, based on laboratory and/or pilot plant separation tests, was considered to be a preferable approach.

Owing to the large number of variables controlling the performance of the hot-water process, the effect of each individual variable on the overall performance could not be studied separately, as this would involve considerable experimental effort. Instead, experimental design techniques in which the number of experiments is reduced to a minimum were used, in combination with the Box and Wilson optimization algorithm.²²⁻²⁵ The Box and Wilson algorithm for experimental optimization has been successfully applied in a wide variety of industrial research problems.²⁶⁻²⁸ In this

Fig. 3. Modified hot-water process for the separation of bitumen from Utah tar sands.

particular application, the primary objectives were to determine the optimum experimental conditions for the separation of the bitumen from the sand and to identify the main digestion variables controlling the quality of this separation. A detailed description of the Box and Wilson algorithm and its application to Utah tar sands may be found elsewhere.²⁹

Operation Variables Controlling the Performance of the Hot-Water Process: The number of variables affecting the performance of each of the two stages of the hot-water process (digestion and flotation) is relatively large. A listing of these variables is presented in Table 2.

In this particular study, flotation conditions were kept constant in all experiments, so that the effect of digestion variables on the overall system response could be studied first. With this experimental approach, flotation, while being an integral part of the process, was also used as an analytical tool for the evaluation of the effectiveness of the digestion stage.

Similarly, discrete digestion variables (feed source, wetting agent, and reactor design) were not varied during the experimental optimization process. However, once the optimum conditions were determined for an Asphalt Ridge sample, the effect of other feed sources on the quality of the separation was studied in a separate series of experiments.

As a first approximation to the processing of Utah tar sands, this investigation was mainly concerned with the equilibrium response of the system. Under these circumstances, dynamic variables such as digestion time and feed size did not deserve primary consideration, since they would not influence the quality of the separation at equilibrium.

Finally, based on the fact that bitumen viscosity decreases significantly with temperature (see Fig. 9), the temperature in the digester was kept constant at 95°C, just below the boiling point of water. The effect of lower temperatures on the quality of the separation was also studied in a separate series of experiments.

In summary, of all the operation variables listed in Table 2, only three are left for consideration, namely, the percent solids in the digester, the concentration of caustic in solution, and the intensity of agitation (stirring speed). In this regard, the term "percent solids" refers to the amount of tar sand (both bitumen and sand) with respect to the total mass of material in the system.

Fig. 4. Dean and Stark tube assembly.

Specification of an Objective Function for Optimization: The actual implementation of any optimization algorithm generally entails the representation of the economical or technical objective (maximize profit, minimize cost, maximize efficiency, etc.) in terms of a set of mathematical quantities. The resulting relationship is normally referred to as the objective function. In this particular application, the primary optimization objective was to maximize the quality of the separation achieved by hot-water processing of Utah tar sands.

Since the hot-water process is, in essence, a separation process, separation indices used to quantify the quality of the separation in other similar processes can also serve as a technical objective function for the system under consideration. In 1970, Schulz³⁰ published an excellent review of the most frequently used separation indices in the mineral industry. Because of its clear physical significance, the coefficient of separation (defined as the fraction of the feed material which undergoes a perfect separation while the rest of the feed is distributed unchanged into the respective product streams³⁰) provided an adequate, "one-parameter" description of the overall process performance and was selected as the objective function for process optimization.

The coefficient of separation can be simply evaluated as the difference between the recovery of the valuable component (bitumen) in the concentrate and the recovery of gangue (sand) in the same concentrate.

Experimental

The processing strategy used in laboratory hot-water separation tests is schematically represented in Fig. 3. Before

Table 2. Operation Variables Controlling the Performance of the Hot-Water Process

Digestion:	Discrete:	D1. Feed Source
		D2. Wetting Agents
		D3. Impeller and Reactor Design
	Continuous:	V1. Temperature
		V2. Percent Solids
		V3. Digestion Time
Flotation:	Discrete:	V4. Wetting Agent Addition
		V5. Feed Size
		V6. Intensity of Agitation
	Continuous:	E1. Cell Design
		E2. Flotation Reagents
		W1. Percent Solids
		W2. Intensity of Agitation
		W3. Temperature
		W4. Solution pH
		W5. Flotation Reagents Additions
		W6. Air Flowrate

Table 3. Average Bitumen Content of Utah Tar Sand Samples

Deposit	Average Bitumen Content (%, by weight)
Asphalt Ridge	13.1
P. R. Spring	12.2
Sunnyside	9.0
Tar Sand Triangle	5.0

each series of experiments was initiated, the tar sand samples were thoroughly mixed in large batches in order to homogenize the quality of the feed. A fraction of this material was then extruded down to smaller pieces ($\sim 3/8$ -in.) and fed to a 1-gal, stirred tank reactor where it was contacted with the hot caustic solution and stirred, at constant temperature, for a specified digestion time. The essential features of this reactor are an impeller with two opposing pitched blade turbines (4-in. OD), a torquemeter, an SCR speed controller, a tachometer, a reflux-takeoff condenser, and a temperature control/heating system. The amount of tar sand and solution added to the digester in each separation test was calculated so that the active volume of the reactor was close to a gallon in all of the experiments. At the end of the digestion stage, the bitumen had been displaced from the surface of the sand particles and could be separated from the dispersed sand in a conventional batch bench-scale flotation machine where the bitumen was floated with air.

In the flotation cell, the percent solids was reduced to about 20%, by weight, by the addition of an aqueous caustic solution at room temperature ($\sim 15^\circ\text{C}$). The alkalinity of the solution was adjusted in order to maintain the pH of the suspension above 10. This relatively high flotation pH allowed for the flocculation of the sand tails and a faster flotation response. Besides sodium hydroxide, no other reagent was added to the flotation cell. The intensity of agitation of the suspension was maintained at a relatively low level, compared to conventional mineral flotation practice, in order to avoid contamination of the concentrate with fine sand particles. The hydrophobic bitumen concentrate was removed from the top of the flotation cell while the hydrophilic free sand particles were recovered from the bottom of the cell.

Representative samples of the feed, concentrate, and tailings were analyzed to determine their composition with respect to bitumen, sand, and water. For this purpose, several Dean and Stark tube assemblies (Fig. 4) were set up in accordance with the procedure reported by the US Bureau of Mines.³¹ A weighed

Fig. 5. Scanning electron micrograph of an Athabasca, Canada, tar sand sample. Bitumen content: 16% by weight. $\sim 400X$.

Fig. 6. Scanning electron micrograph of an Asphalt Ridge, Utah, tar sand sample. Bitumen content: 13% by weight. $\sim 400X$.

sample, contained in a double thickness, cellulose extraction thimble, was placed in the neck of a specially designed receiver flask held by four indentations. About 200 ml of reagent grade toluene were added to the flask and heated to boiling. Toluene vapors dissolved the bituminous materials in the sample and also removed any trace of water present. The vapors were trapped by the condenser and returned to the system. Because of the immiscibility and different density of the two phases in the toluene-water system, water droplets settled through the condensate and were collected in the capillary tube, while the toluene was refluxed. After 4 to 6 hr, extraction reached completion and the volume of water in the sample was read on the graduated capillary. The cellulose thimble was then dried and weighed to determine the amount of solids left in it and the bitumen content was calculated by difference. The analytical technique proved to have very good reproducibility, the coefficient of variation being less than 1%.

Experimental Results and Discussion

Preliminary separation tests indicated that, under similar operating conditions, the quality of the separation was strongly dependent upon the nature of the tar sand. In fact, while excellent results, comparable to those obtained in the processing of Athabasca tar sands, were obtained with two high-grade Utah samples (Asphalt Ridge and P.R. Spring), hot-water separation tests of low-grade tar sands (Sunnyside and Tar Sand Triangle) were not at all successful. Accordingly, tar sand samples from these four Utah deposits were characterized in terms of their bitumen content, bitumen viscosity, and particle size distribution of the sand.

Average bitumen content of samples from four different Utah tar sand deposits are presented in Table 3. Although these samples may not be representative of the deposit as a whole, the grades reported in Table 3 are in good agreement with previous results which show that northeastern Utah deposits, and especially the Uintah Basin deposits (Asphalt Ridge and P.R. Spring) have higher bitumen content than Tar Sand Triangle in southeastern Utah.⁷

Scanning electron micrographs of tar sand samples from Athabasca, Canada, and three northeastern Utah deposits are presented in Fig. 5-8. As compared to the Sunnyside sample (Fig. 8), the bituminous film in the Athabasca, Asphalt Ridge, and P.R. Spring samples (Figs. 5-7, respectively) appears to be much thicker and continuous throughout the sample.

The viscosity of the bitumen in tar sands is of primary importance to the design of in-situ mining, recovery, upgrading, and material handling operations. Experimentally determined flow curves of Asphalt Ridge and Athabasca

Fig. 7. Scanning electron micrograph of a P.R. Spring, Utah, tar sand sample. Bitumen content: 12% by weight. $\sim 400X$.

bitumen, at various temperatures, demonstrated the Newtonian nature of both fluids.²⁹ Perhaps of more practical significance is the fact that the viscosity of the Utah (Asphalt Ridge) bitumen is about two orders of magnitude greater than the viscosity of the Canadian (Athabasca) bitumen in the temperature range studied, as illustrated in Fig. 9. This accounts for the fact that Athabasca tar sands can be digested in a conventional rotary drum, while Utah tar sands seem to require intense shear conditions.

Viscosity measurements of Athabasca bitumen at different temperatures are in good agreement with data previously reported in the literature.^{9,31,32} An apparent activation energy on the order of 28 kcal/mole was calculated from the data in Fig. 9, indicative of the fact that momentum transfer is accompanied by rather significant structural transformations, as temperature increases.

The particle size distribution of the solids in Utah tar sands was determined by conventional sieving techniques in the size range of 590 μm down to 37 μm . Particle size distributions of the sand in several Utah tar sand deposits are compared in Fig. 10. According to the Canadian size classification,^{9,32} the sands in Utah tar sand deposits are comparable in size to the Class II Athabasca sands which are the richest tar sands in the McMurray formation.³²

Preliminary Experimental Results: Preliminary results indicated that effective displacement and disengagement of bitumen from both Asphalt Ridge and P.R. Spring tar sand samples could be achieved by hot-water processing. The overall composition of the concentrate removed from the separation

Fig. 8. Scanning electron micrograph of a Sunnyside, Utah, tar sand sample. Bitumen content: 9% by weight. $\sim 400\times$.

cell ranged from 60 to 75% by weight bitumen, on a dry basis. Moisture content was around 40% by weight. The tailings had an unexpectedly low bitumen content of less than 0.5% by weight. The excellent quality of the tailings is well demonstrated by the scanning electron micrograph presented in Fig. 11, which is to be compared with the photograph of the original feed presented in Fig. 6. In these experiments, about 96% of the bitumen contained in the feed material was recovered in the concentrate and about 92% of the sand was rejected in the tailings. Typical results are presented in Table 4.

Identification of Main Variables and Process Optimization: The Box and Wilson Algorithm: In accordance with the experimentation strategy outlined previously, the Box and Wilson algorithm was applied to the recovery of bitumen from Asphalt Ridge, Utah, tar sands. The objective for optimization was to maximize the quality of the separation being characterized by the coefficient of separation. Maintaining all other digestion and flotation conditions constant, the coefficient of separation was assumed to be a function of only three

Table 4. Example of Hot-Water Separation Results with an Asphalt Ridge Tar Sand Sample

Experimental Conditions:

Digestion: Feed Source: Asphalt Ridge
 Wetting Agent: NaOH
 Temperature: 95°C
 Percent Solids: 70% by weight tar sands
 Digestion Time: 15 min
 NaOH Concentration: 0.58 mole/liter
 Feed Size: Extruded to $\sim 3/8$ in.
 Agitation: 750 rpm
 Flotation: Cell Design: Cylindrical
 Flotation Reagents: None
 Percent Solids: 20% by weight tar sands
 Agitation: 1000 rpm
 Temperature: 15°C
 Air Flowrate: 3000 (cc/min)
 Flotation pH: ~ 10.5

Calculated Mass Balance:

	Wt, % dry	Grade, % Tar	Grade, % Sand	Recovery, % Tar	Recovery, % Sand
Concentrate	19.05	64.82	35.18	96.39	7.69
Tail	80.95	0.57	99.43	3.61	92.31
Feed	100.00	12.81	87.19	100.00	100.00

Coefficient of Separation = 0.8870

Fig. 9. Arrhenius plot illustrating the effect of temperature on bitumen viscosity.

Fig. 10. Particle size distribution of sand from four different Utah tar sand deposits: Tar Sand Triangle, P.R. Spring, Sunnyside, and Asphalt Ridge.

digestion variables; the percent solids in the reactor (V_2), the wetting agent concentration (V_4), and the stirring speed (V_6). Furthermore, based on the Canadian experience with Athabasca tar sands,¹⁵ sodium hydroxide was selected as the wetting agent in all of the experiments. The experimental results obtained during the implementation of the Box and Wilson algorithm are summarized next. Detailed information on the subject may be found elsewhere.²⁹

Fig. 11. Scanning electron micrograph of Asphalt Ridge sand after hot-water extraction of the bitumen. $\sim 400X$.

Fig. 12. Quality of the separation achieved by hot-water processing as a function of the caustic concentration, for various percent tar sands in the reactor at 95°C. Asphalt Ridge sample.

The implementation of the Box and Wilson optimization algorithm required more than 60 extraction tests. Percent solids was varied from 50 to 80% by weight, NaOH concentration from 0.25 to 1.50 (mole/liter), and the stirring speed from 510 to 1250 rpm. The experimental results so obtained were correlated by multiple linear regression to obtain the second order experimental model:²⁹

$$CS = 0.9192 - 9.515 \times 10^{-4} V_2 + 1.641 \times 10^{-1} V_4 - 1.694 \times 10^{-4} V_6 + 2.048 \times 10^{-2} V_2 V_4 + 3.825 \times 10^{-6} V_2 V_6 - 1.824 \times 10^{-4} V_4 V_6 - 8.667 \times 10^{-5} V_2^2 - 1.350 V_4^2 - 3.250 \times 10^{-9} V_6^2 \quad (1)$$

Fig. 13. Quality of the separation as a function of the digestion temperature for the Asphalt Ridge sample at 75% solids and 0.58 mole/liter sodium hydroxide.

where CS represents coefficient of separation (fitted value); V_2 represents percent tar sands, by weight; V_4 represents NaOH concentration in mole/liter; and V_6 represents stirring speed in rpm.

Hypothesis tests, based on the analysis of variance of this model, suggested that, in the range of values studied, the quality of the separation does not seem to be significantly affected by the stirring speed (V_6). In fact, it can be demonstrated²⁹ that the "reduced" model:

$$CS = 0.6553 + 5.796 \times 10^{-3} V_2 - 1.369 \times 10^{-2} V_4 + 1.802 \times 10^{-2} V_2 V_4 - 1.008 \times 10^{-4} V_2^2 - 1.182 V_4^2 \quad (2)$$

which does not account for variations in V_6 , describes the experimental data as well as the "full" model (Eq. 1).

Further analysis of the data reveals that, in the range of 70 to 80% tar sands, the overall system response, characterized by the coefficient of separation, is not significantly affected by the percent tar sands in the digester, V_2 . In fact, above 70% solids, the polynomial expression:

$$CS = 0.5732 + 1.127 V_4 - 0.9698 V_4^2 \quad (3)$$

can be shown²⁹ to describe the experimental data as well as the reduced model correlation (Eq. 2). The quality of the data description by the reduced models is illustrated in Fig. 12 where experimental and fitted values are graphically compared. As indicated there, the maximum coefficient of separation is expected to be around 0.90 at a sodium hydroxide concentration of 0.58 mole/liter. Grades and recoveries are expected to be similar to those reported in Table 4.

The need for high shear digestion conditions in order to achieve both bitumen displacement and phase disengagement gives rise to a relatively high optimum percent solids in the digester (70-80%). Further, experimental results substantiate the hypothesis that a high intensity of agitation does not necessarily result in strong shearing conditions. In fact, as mentioned previously, process performance was shown to be independent of the stirring speed in the range of values studied (510-1250 rpm).

Fig. 14. Schematic representation of the effect of shear forces on the digestion of high and low grade tar sands.

Perhaps the most critical variable is the wetting agent concentration. A low caustic addition (below 0.4M) results in a tacky bitumen concentrate and a tail which still contains a significant amount of bitumen. On the other hand, an excessively high caustic addition (above 1M) gives rise to a strong chemical reaction at the bitumen-water interface. Under these conditions, the tar sand is disintegrated before any phase separation can actually occur.

Effect of Digestion Temperature on the Quality of the Separation: Each of the experiments reported in the previous sections was performed at 95°C. In order to test the hypothesis that the quality of the separation should deteriorate at lower temperatures because of the increase in bitumen viscosity, a series of experiments with Asphalt Ridge tar sand were performed at lower temperatures, setting all other variables at the optimum conditions previously determined. Experimental results presented in Fig. 13 indicate that a decrease in temperature has a detrimental effect on the quality of the separation achieved by hot-water processing. Even though the grade of the concentrate decreased only slightly, the recovery of bitumen from the sand (and hence, the coefficient of separation) was significantly diminished. At these low temperatures, the bitumen became very sticky and viscous. As a result, the bitumen adhered to the walls of the reactor and the flotation cell. Furthermore, large lumps of nonfloatable bitumen-sand agglomerates appeared with the sand tailings.

Effect of the Feed Source on the Quality of the Separation: While excellent results, comparable to those obtained in the processing of Athabasca tar sands, were obtained with the two high-grade Utah samples (Asphalt Ridge and P.R. Spring), hot-water separation tests of low-grade tar sands (Sunnyside and Tar sand Triangle) were not at all successful. Experimental results obtained with tar sand samples from these four deposits are

Fig. 15. Particle size distribution of the sand in the feed and products for a typical hot-water extraction test.

summarized in Table 5, where typical results obtained with Athabasca tar sands are also included, as reported in the literature.³⁴

Because of the low bitumen content, samples from Sunnyside and Tar Sand Triangle can be easily ground in a conventional tumbling mill. Such is not the case with samples from Asphalt Ridge and P.R. Spring deposits which due to their plasticity could only be reduced in size to a limited extent by extrusion. As compared to the Sunnyside sample (Fig. 8), the bituminous film in the Athabasca, Asphalt Ridge and P.R. Spring samples (Figs. 5-7, respectively) appears to be much thicker and continuous throughout the sample. With such samples, shear forces can be transferred to the bitumen-solid interface through this plastic bituminous matrix, so that rupture may occur at the interface which will allow for the aqueous solution to advance and wet the surface of the sand particles (Fig. 14a). Conversely, in the case of low-grade tar sands, where the bitumen is more like a thin, rigid coating around each sand particle (Fig. 8) rather than a continuous matrix, failure may occur within the bitumen phase and not at the interface, as postulated in the previous case. As a result, the bitumen remains attached to the sand particles and phase disengagement does not occur (Fig. 14b).

Under the assumption that the bitumen content of the digested pulp was a critical variable, a series of recycling experiments were performed in which tar sand samples from different deposits were mixed with bitumen concentrate prior to hot-water separation, so that the bitumen content of the mixture could be adjusted to any desired level. In this series of experiments, the bitumen concentrate was added directly to the fresh feed in the digester. However, visual observation of the digested pulp revealed that the fresh tar sands and the recycled bitumen concentrate were not mixed thoroughly. In fact, the experimental results presented in Table 5 demonstrate that the quality of the separation was not improved, as anticipated. Alternate techniques, such as heat treatment of the mixture, are currently being investigated by other members of the same research group.

Particle Size Classification during Hot-Water Processing: Particle size analyses of the feed and products after hot-water processing reveals that size classification of the sand particles occurs during the processing sequence. As shown by the size analysis data presented in Fig. 15, most of the fine particles are recovered in the bitumen concentrate whereas coarse particles are rejected to the tailings.

At the optimum digestion conditions, the quality of the separation will be controlled not only by the bitumen content of

Table 5. Effect of the Feed Source on the Quality of the Separation.

Experimental Conditions:

Temperature: 95°C

Percent Solids: 70%

Wetting Agent: 0.58 M, NaOH

Stirring Speed: 750 rpm

Summary of Results:

Source	Bitumen Content, %			Recovery, %		
	Feed	Conc.	Tails	Tar	Sand	CS
A. Ridge	12.8	64.8	0.6	96.4	92.3	0.887
A. Ridge (recycle)	14.6	65.3	0.5	97.1	91.2	0.883
A. Ridge (recycle)	18.3	62.8	0.4	98.3	86.9	0.852
P. V. Spring ^(*)	14.8	70.5	0.5	97.3	93.0	0.903
Sunnyside	8.9	21.5	1.6	89.0	68.2	0.572
Sunnyside (recycle)	12.7	26.0	1.6	93.3	61.6	0.549
T. S. Triangle	5.0	no products				
T. S. Triangle (recycle)	20.0	no products				
Athabasca ^(*)	14.3	94.7	1.7	90.0	99.2	0.892

* Wetting agent: 1.75 M sodium silicate

* Experimental conditions not reported.³⁴

the feed but also by the particle size distribution of the sand in the tar sand sample. For a given bitumen recovery, the influence of these two factors on the quality of the separation of a low-grade Sunnyside sample can be roughly estimated based on the results obtained with the Asphalt Ridge sample under similar conditions (Case 1 in Table 6). Notice that 7.7% of the sand in the Asphalt Ridge sample is recovered in the bitumen concentrate. If the size classification process is assumed to be ideal (i.e., there exists a critical separation size above and below which a given particle reports to either the tailings or the concentrate, respectively), it is found from Fig. 10 or 15 that this critical size must be approximately 100 μm in order to explain the previously mentioned result. Now, if the same critical size is assumed to be applicable for the Sunnyside sample (Case 2 in Table 6), where 35% of the sand is finer than 100 μm (Fig. 10), the estimated grades and recoveries shown in Table 6 are found to be in fairly good agreement with the experimental values. Although these highly idealized calculations do not attempt to provide an accurate description of the system, they do demonstrate the overall combined influence of the feed grade and the particle size distribution of the sand on the performance of the hot-water process.

Summary and Conclusions

Experimental results obtained in this investigation demonstrated that effective separation of bitumen from high-grade Utah tar sands can be achieved with a hot-water process, involving the addition of wetting agents, digestion of the tar sand under high shear conditions, and finally separating the bitumen from the sand by a modified froth flotation technique.

The processing strategy being developed for Utah tar sands is expected to differ significantly from the one being used in the processing of Athabasca tar sands, mainly because of considerable differences in the physical and chemical properties of the two materials. As compared to Utah tar sands, Athabasca tar sands are characterized by a higher bitumen content, a significantly lower viscosity (about two orders of magnitude lower), and the reported presence of an envelope of connate water separating the bitumen from the solid phase. Utah tar sands contain practically no water; thus, the bitumen is directly in contact with, and bonded to, the surface of the sand particles.

Main variables and optimum operating conditions of the

Table 6. Effect of Feed Grade and Particle Size Distribution on the Quality of the Separation^(*)

Case 1: Asphalt Ridge (Reference data)

Bitumen Content: 13.1%

"Fines" (>100 μm): 7.7% (Fig. 10 or 15)

	Weight, %	Grade, %		Recovery, %	
		Tar	Sand	Tar	Sand
Concentrate	19.0	64.8	35.2	96.4	7.7
Tail	81.9	0.6	99.4	3.6	92.3
Feed	100.0	12.8	87.2	100.0	100.0

Case 2: Sunnyside

Bitumen Content: 9.0%

"Fines" (>100 μm): 25% (Fig. 10)

	Weight, %	Grade, %		Recovery, %	
		Tar	Sand	Tar	Sand
Concentrate	36.9 (30.7)	21.5 (25.7)	78.5 (74.3)	89.0 (89.0)	31.8 (25.0)
Tail	63.1 (69.3)	1.5 (1.4)	98.4 (98.6)	11.0 (11.0)	68.2 (75.0)
Feed	100.0	8.9	91.1	100.0	100.0

* Calculated values in parenthesis.

digestion stage were determined for the Asphalt Ridge sample by the implementation of the Box and Wilson optimization algorithm. The quality of the separation, being characterized by the coefficient of separation, was found to be independent of the stirring speed in the range of values considered (510-1250 rpm). At the optimum digestion conditions (70-80% tar sands, 0.58 M NaOH, 95°C), coefficients of separation averaging 0.90 and bitumen recoveries over 96% are to be expected. Separation test data obtained at lower digestion temperatures substantiated the hypothesis that a decrease in temperature has a detrimental effect on the quality of the separation achieved by hot-water processing.

Variations in the quality of the separation obtained with materials from different deposits can be interpreted in terms of their physical properties, specifically the bitumen content and the particle size distribution of the sand. As discussed in the text, the grade of the tar sand must be high enough so that the bituminous film surrounding the sand particles exceeds a certain critical thickness for effective phase disengagement. In addition, the particle size distribution of the sand must be coarse enough so that the amount of fines entrapped in the bitumen phase as a result of the size classification process is minimized and the grade of the bitumen concentrate is maintained at an acceptable level.

Although preliminary in nature, the experimental evidence gathered in this investigation seems to indicate that a hot-water process for Utah tar sands would allow for the efficient utilization of this important energy resource.

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Data Bank for Geologic Field Work (GEOBANK) and Extension

Dan Chun

Abstract—To facilitate the efficient handling of large volumes of information generated by logging exploration drill cores, a computer data bank system (GEOBANK) has been developed to store and retrieve the normally difficult to handle geologic information as well as the physical testing data. The data bank systematized the logging of drill core by first developing a standard list of adjectives or descriptors (with the corresponding assigned numerical codes) for the various stratigraphic categories that are also assigned numerical codes. The system uses the "floating-slot" concept and handles the data

bank with one single input form.

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THE FLOTATION BEHAVIOR OF DIGESTED ASPHALT RIDGE TAR SANDS

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For presentation at the AIME Annual Meeting
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Abstract. Tar sand deposits in Utah represent more than 25 billion barrels of in-place bitumen, 96% of the known U.S. reserves. The technological development of a hot water processing strategy for the Canadian tar sands and the commercial production of synthetic crude oil from this natural resource suggest that similar success may be possible for the utilization of Utah tar sands to provide our country with a new domestic source of synthetic crude oil. In this regard an active research program to develop a hot water processing strategy for Utah tar sands has been sustained at the University of Utah for the past five years.

The hot water process for Utah tar sands differs significantly from that used for Canadian tar sands due to the inherent differences in the respective bitumen viscosities and the nature of the bitumen-sand association. These differences have led to the identification of certain design criteria necessary to achieve satisfactory phase disengagement during digestion. (8,9) Subsequent flotation of the digested tar sand is a subject of current attention and is considered in this contribution for the Asphalt Ridge tar sand deposit.

Although contact angle measurements of pure Asphalt Ridge bitumen indicate moderate hydrophobicity, air bubble attachment to the bitumen concentrate taken from a 37 liter flotation cell is not possible. This surprising result suggests that the flotation separation is dependent on air bubble entrapment rather than on attachment due to surface hydrophobicity. The occlusion of air bubbles in the bitumen is apparent from visual examination of the concentrate, especially at lower temperatures. It seems that a bitumen-bubble agglomerate forms in the impeller region of the flotation cell, the effective density of which is such to allow the agglomerate to float to the surface.

A factorial design of the major operating variables in the flotation separation indicated that the quality of separation was significantly dependent on the flotation temperature and to a lesser extent on the degree of agitation. For a flotation temperature of 77°C recovery of 96.7 percent was realized at a grade of 61.0 percent bitumen. The improved separation at higher flotation temperatures was found to be due to the decrease in bitumen viscosity resulting in more effective rejection of coarse sand from the concentrate.

Continuation of this research effort on the hot water processing of Utah tar sand has been planned with the ultimate goal being to provide the necessary technology base for the design of a demonstration plant for the hot water processing of Utah tar sand.

Introduction

Since the early 1970's, world events led the USA into a search for energy sources other than petroleum. This search has been directed toward nuclear energy, solar energy, geothermal energy, and synthetic fuels. Coal, oil shale and tar sands have been used to produce feedstock for synthetic fuels in South Africa, USA, and Canada respectively. The purpose of this paper is to report the results of research being done at the University of Utah on the separation of bitumen

from Utah tar sands by a hot water processing technique to produce a feedstock for synthetic fuel and petrochemical production.

It is understood that the term tar sands refers to a naturally occurring sandstone impregnated with a highly viscous crude hydrocarbon, a bitumen. (1) Early observers named this material tar sand after the asphaltic appearance of the deposit. Geologists referred to these same deposits as oil sands because they represented a potential source of oil. Generally, the sand component of tar sands is mostly quartz with some minor clay and calcareous constituents.

Major tar sand deposits occur in Canada, Venezuela and the USA as shown in Table 1. The largest of these are the Canadian deposits which contain 900 billion barrels of crude in-place bitumen. This is the only deposit in the world that is actually being mined and processed commercially to recover bitumen for the production of synthetic crude oil. It is important at this point to distinguish between the processing strategy used to separate bitumen from the Athabasca tar sands and the University of Utah hot water process for Utah tar sands.

Processing Athabasca Tar Sands

Dr. K.A. Clark working for the Alberta Research Council is credited with first describing the hot water process for Athabasca tar sands in 1923. The process he proposed has since undergone much evaluation and modification but contains the essential elements on which today's commercial ventures are based. In 1944 Dr. Clark set forth the fundamental features which characterize the hot water process. (2)

1. Bituminous sand is an aggregate of sand, clay, oil and water. Quartz is the major component of the sand but it contains other silicate minerals as well. The bitumen content varies from 6 to 17% by weight and is a viscous naphthenic compound with a specific gravity slightly greater than that of water. Athabasca tar sands have a water content of 3 to 5 percent by weight and this water occurs as a film separating the bitumen from the sand grains.

2. The bitumen surrounding the sand particles is displaced when the tar sand is mixed with water.

3. A greater concentration of dissolved and suspended substances in the water enhances its action as a wetting agent and displacement of the bitumen is more complete than if the solution were less concentrated.

4. Bubbles of air and water vapor present in the system become attached to the bitumen droplets and float them to the surface. However, only small bubbles less than a few millimeters in diameter are effective in floating the bitumen.

5. A clean and complete separation of bitumen from sand is impossible unless the tar sand is broken down and the bitumen is dispersed as small droplets.

From these fundamental features, several different process strategies were investigated, culminating in the development of plants by GCOS (Great Canadian Oil Sands Limited) and Syncrude Canada, Limited. Both plants have similar flow-sheets for bitumen recovery as described by Camp (3) and shown in Figure 1. Mining is accomplished with large bucket wheel excavators and/or drag

lines. The tar sand is then conveyed by a belt to the plant where it is fed to a rotating drum and mixed with hot water and steam. The tar sand lumps are reduced in size by ablation as each lump is warmed and surfaces slough off. Sodium hydroxide is added as a process aid to control pH. The residence time in the rotary drum is long enough to accomplish the required heat transfer to disintegrate each lump by heating and mechanical mixing. As a result the bitumen is displaced from the sand particles and the pulp is discharged at about 180°F. The conditioned tar sand is then screened to remove tramp materials and tar sand lumps.

The phase separation of bitumen from the sand is accomplished initially in a gravity settler, which is essentially a modified thickener. The tar sand is introduced into the feed well and bitumen floats to the surface of the settler where it is removed by radial arms. The major portion of the sand sinks to the bottom conical section of the thickener, is advanced to the center by rakes and is discharged as a tailing product. From the side of the thickener a middling stream is taken, which contains some fine mineral and bitumen particles. A portion of this stream is returned to the rotating drum for pulp density control. (4) The balance of the middling stream is fed to standard flotation cells which can be either tank type or trough type. (5)

Bitumen concentrate from the gravity settler and from the scavenger flotation cells are combined and further treated and upgraded to a synthetic crude oil. Bitumen concentrate produced in this manner contains about 84% bitumen and 16% mineral matter on a dry basis with a bitumen recovery of 90%. Hot water processing as described above has proved to be quite successful in processing Athabasca tar sands. Unfortunately this process is not so successful when applied to Utah tar sands.

Processing Utah Tar Sands

Utah Geological and Mineral Survey published a paper by H.R. Ritzman (6) in which he states there are 51 tar sand deposits in Utah. The 25 deposits in the Uinta Basin contain an estimated 10.81 billion barrels of in-place bitumen. Utah's reserves contain 25 to 30 billion barrels of bitumen representing about 96 percent of the bitumen saturated sandstone in the U.S. Table 1 lists the size of the six largest deposits in Utah and their geographical location is shown in Figure 2. A deposit containing one billion barrels is sufficient to produce 100,000 barrels of synthetic crude oil per day for 20 years based on a 70 percent yield of synthetic crude oil from bitumen. (7) This yield is not unreasonable as indicated from the GCOS operating experience. Unfortunately the process used for Athabasca tar sands does not result in an effective bitumen-sand separation when directly applied to Utah tar sands.

The characteristic differences between Athabasca and Utah tar sands have been chronicled in two previous papers from the Metallurgy Department at the University of Utah. (8,9) Unlike Athabasca tar sand, Utah tar sands contain no detectable indigenous water. Therefore the bitumen is bonded directly to the sand particles. Another difference between Athabasca and Utah tar sands is that the viscosities of the Utah

bitumens appear to be significantly greater than the viscosities of the Athabasca bitumen. For example, the reported viscosities of Asphalt Ridge bitumen are compared with the viscosities for Athabasca bitumen in Figure 3. (8,9,10)

Armed with this information concerning the differences between Athabasca and Utah tar sands a hot water process suitable for Utah tar sands was developed. (8,9) The results of these investigations led to the process strategy depicted in Figure 4. The criteria for effective phase disengagement during digestion were found to be a high shear force field, an appropriate addition of alkali wetting agent, and temperatures near the boiling point of water. In the case of tar sands containing highly viscous bitumen, such as the Sunnyside deposit, the addition of diluent may be necessary. It was found that effective phase separation could not be achieved with a gravity settler because the sand entrained by the bitumen resulted in an agglomerate having a higher density than water, hence the bitumen would not float. As a result, a flotation technique was used to effect phase separation and assess the quality of phase disengagement. These previous studies (8,9) have focused on determination of the optimum operating conditions for the digestion of Utah tar sands in an electrically heated stirred tank reactor. It is the purpose of this paper to report new experimental results regarding the flotation behavior of digested Asphalt Ridge tar sand.

Experimental Methods

Two experimental techniques were used to examine the flotation behavior of digested Asphalt Ridge tar sand. The literature discusses extensively the natural hydrophobicity of bitumen as well as air bubble-bitumen droplet collision and attachment phenomena. (11) In this regard, contact angle measurements were made at the bitumen surface as a function of temperature and aqueous phase composition. The second technique was to study the operating variables in the flotation step of the hot water process and determine their effect on the efficiency of phase separation.

Contact Angle Measurements

Contact angle measurements were made using a goniometer and optical bench manufactured by Ramé-Hart as shown in Figure 5. A special feature of the optical bench is the environmental chamber which allows for temperature control of the system. Besides the goniometer and environmental chamber, the system has, of course, a microscope with a scale magnifier, and an illumination source. A microsyringe is used to disperse air bubbles.

To measure a contact angle, the environmental chamber was filled with distilled water and the controller was set for the desired temperature. The bitumen sample to be examined was placed in a plastic bottle cap and allowed to settle until a smooth surface formed which was quite easily accomplished. The cap was then weighted with a steel ring and put in a 20mm x 20mm x 40mm cuvette to which the desired solution was then added. The cuvette was then placed in the environmental chamber and allowed to equilibrate at

the desired temperature. Then air bubbles were touched to the bitumen surface. When attachment occurred the contact angle was measured.

Hot Water Processing Experiments

Figures 6 and 7 show the equipment used for the hot water processing experiments. This equipment corresponds to the digestion and flotation stages of the flowsheet shown in Figure 4. The digester is a 3.8 liter stirred tank reactor with two opposing pitched blade impellers, a SCR speed controller and tachometer. The reactor is heated by an electric mantle that is controlled by a thermocouple in the reactor.

The digested pulp together with make up water is discharged into a 37 liter flotation cell made by Hazen Research Inc., similar in design to the Denver laboratory units. It is equipped with a urethane impeller and stator. Air is injected through the shaft of the impeller into the cell at a prescribed flowrate which is measured with a Gilmont rotameter. The speed of the impeller is set with an adjustable motor pulley sheave. In addition, the cell is equipped with a 1-1/2 inch bottom discharge ball valve. An advantage of this cell over similar designs is that the impeller mechanism can be raised and the cell tilted in its frame for easier cleaning.

To conduct a batch experiment 1.5 liters of a 0.3 M solution of sodium carbonate is put into the reactor and raised to temperature with the heating mantle. After the solution is heated to about 80°C, 4 kg of tar sand reduced in size to minus 3/8", is fed into the reactor through a feed port. During this time the impellers are rotated at 200 to 250 rpm to prevent plugging of the discharge port. When feeding is completed the pulp temperature in the reactor usually has reached 95°C, the desired digestion temperature. Then, the tar sands are digested at 750 rpm for 15 minutes.

After digestion the pulp is discharged into the flotation cell operating at a selected rpm and air flowrate. The cell contains about 33 liters of water at the desired temperature, and a specified amount of sodium carbonate. The bitumen floats immediately and is removed for three minutes, which is sufficient time to remove all but the very slow floating bitumen. Bitumen free sand is not hydrophobic and does not report to the concentrate. The tailings are discharged out the bottom valve of the cell at the end of each batch test.

Analytical Techniques

Samples of concentrate, tailings and feed are analyzed to determine bitumen, water, and sand content with the Dean and Stark tube assemblies, as shown in Figure 8, according to the procedures reported by the U.S. Bureau of Mines. (12) A known amount of sample is put in a tared cellulose thimble. The thimble is placed in the neck of a flask which contains about 200 ml of toluene. The toluene is heated to boiling. Toluene vapors dissolve the bitumen and remove any water that is present. The gas vapors condense in the reflux condenser and are returned to the graduated capillary. Because of the density difference, the water collects in the capillary while the toluene drips into the thimble

and is recycled. After extraction the volume of water is noted, the thimble containing sand is dried and weighed, and from this data the respective amounts of bitumen, sand, and water can be calculated.

Results and Discussion

Contact Angle Measurements

Bubble-particle attachment is considered to be one of the key factors controlling the process of froth flotation. The thermodynamic considerations of bubble-particle attachment have been discussed at length by several authors. (13,14,15) Even without consideration of heats of immersion, heats of adhesion, heat of bubble deformation and interfacial tensions which are involved in a detailed analysis of the attachment process, the contact angle is still a good indication of the hydrophobicity or degree of surface wetting. Figure 9 shows bubble attachment at a hydrophobic surface and the attendant contact angle, θ . (15) If the contact angle is less than 30° we can say that the solid has some hydrophobic character but frequently flotation is difficult. If θ is greater than 60° the surface is quite hydrophobic and flotation is rapid.

For Asphalt Ridge feed samples equilibrated with sodium carbonate solutions of pH 9 and pH 11 at 25°C, contact angles of 34° and 39° were observed. These results indicate a moderate hydrophobic character of the bitumen attached to the sand particles and may reflect the heterogeneous nature of the surface.

Two samples of toluene-extracted bitumen were then tested. The first sample was an Asphalt Ridge bitumen from the feed material used by Sepulveda and Miller. (8) The contact angles in sodium carbonate solutions of pH 9 and pH 11 were found to be 76° and 73°. The second sample was a bitumen extracted from the Asphalt Ridge feed material being used for the present study. In sodium carbonate solutions of pH 9 and pH 11 the measured contact angles were 60° and 69° respectively. These measurements were all made at a temperature of 25°C.

Then, to check the hydrophobic nature of the bitumen concentrate a sample from a hot water processing experiment was taken and a contact angle measurement was attempted immediately. At both pH 9.0 and pH 11.0 a bubble would not attach to the surface of the bitumen concentrate. This result is somewhat surprising in that it had been assumed bubble attachment to bitumen droplets was an important aspect of the flotation step. Some yet unpublished work by Misra shows that naturally occurring, untreated Sunnyside bitumen, found oozing out of the deposit, exhibits some natural hydrophobic character at a pH of 7.2, but at pH 9.0 and pH 11.0 a bubble would not attach to the bitumen surface.

Some authors have observed air bubble-bitumen droplet attachment in a flotation cell, while others postulate that a bitumen film rapidly envelops the air bubble encasing it and bringing the bitumen to the surface. (11) From hot water processing experiments it has been noted that for flotation temperatures below about 50°C the bitumen concentrate is spongy in appearance and floats in water quite readily even after removal from the flotation cell. This behavior was noted previously

by Sepulveda, but not reported. Above 50°C the less viscous bitumen does not float after being removed from the cell. The phase separation may be thought of as the flotation of an agglomerate of bitumen, fine sand, and entrapped air bubbles. The agglomerate is less dense than water and will float. Above 60°C the bitumen still entraps air bubbles but because of the decrease in bitumen viscosity the bubbles rapidly escape after the bitumen is removed from the air source. It is hoped that the nature of the bitumen surface can be better understood in the future from the study of its solubility during digestion and by identification of functional groups from Raman spectroscopy.

Because of the temperature dependence in the flotation recovery of the bitumen concentrate, contact angle measurements were attempted at temperatures above 25°C. Figure 10 shows a time sequence of photographs of an air bubble (1.0 mm diameter) attached to the surface of a toluene extracted bitumen at 45°C in a pH 11.0 sodium carbonate solution. Note how the bitumen seems to wet the air bubble and the lower viscosity at this temperature permits the buoyant force to stretch the bitumen resulting in failure after several minutes. At 35°C and 45°C the initial contact angles measured before stretching occurs are essentially the same as those measured at 25°C.

Hot Water Processing Experiments

Following the work of Sepulveda and Miller (8) which identified those conditions most favorable for the digestion of Asphalt Ridge tar sand, the objective of this phase of the research project is to identify those flotation variables and conditions which result in the most favorable phase separation. Traditionally, it is recognized that the degree of agitation and air flowrate are always important variables in a flotation process. From preliminary flotation tests it was noted that the temperature and sodium carbonate concentration also appeared to have an effect on the efficiency of bitumen recovery by flotation.

To test the effect of these four variables it was decided to use a two level, four variable factorial design with center point replication. The coefficient of separation was selected as the objective function to be maximized. The coefficient of separation (CS) is a one parameter description of the efficiency of separation for a two component system and physically represents the fraction of the feed material that undergoes perfect separation. Thus, an ideal separation would be represented by a coefficient of separation of unity, whereas if no separation is achieved the coefficient of separation would be zero. The coefficient of separation takes into consideration both grade and recovery and can be shown to be equal to the recovery of the valuable constituent in the concentrate minus the recovery of the gangue in the concentrate.

Table 3 presents the variables and their ranges used in this series of experiments, while the experimental results are tabulated in terms of the coded variable level and the coefficient of separation in Table 4. These values were used for the determination of a first order model of the flotation response surface of the following form,

$$y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \quad (1)$$

Multiple linear regression of this data allowed for the evaluation of the coefficients and equation (1) becomes,

$$CS = 0.8378 + 2.5 \times 10^{-2} X_1 - 1.13 \times 10^{-4} X_2 + 1.00 \times 10^{-2} X_3 - 2.75 \times 10^{-4} X_4 \quad (2)$$

From hypothesis testing it was found that this model describes the data within experimental error and represents a planar response surface. Analysis of variance and further hypothesis testing indicates that the effect of air flowrate and sodium carbonate are not statistically significant so the B_2 and B_4 can be taken as equal to zero. The reduced model,

$$CS = 0.8378 + 2.5 \times 10^{-2} X_1 + 1.00 \times 10^{-2} X_3 \quad (3)$$

also describes the data within experimental error. The effect of these process variables are being considered further with respect to the results obtained from the factorial design.

Temperature Study: Temperature appears to be the most significant variable and in this regard it was decided to measure the efficiency of separation as a function of flotation temperature at an air flowrate of 15 liters/min ($X_2 = 0$), a stirring speed of 1000 rpm ($X_3 = 1$) and a sodium carbonate concentration of 0.05 M ($X_4 = 0$). The results are presented in Table 5 and Figure 11 and it can be seen that higher flotation temperatures improve the quality of separation considerably. The data suggest a nonlinear increase of the coefficient of separation between 40°C and 60°C that the first order model does not predict. These results reflect the change in viscosity of the bitumen phase. At higher temperatures, the less viscous bitumen allows for better rejection of sand by drainage from the bitumen-air agglomerate.

Carbonate Addition: The next aspect of the flotation study was further examination of the effect of sodium carbonate addition. From a process design standpoint flotation at higher sodium carbonate additions may have certain advantages and in this regard the flotation response of the digested tar sand was determined up to 0.15 M sodium carbonate. All experiments have not been completed at this writing but Table 6 contains the preliminary results. It seems that higher sodium carbonate additions do improve the quality of separation but at these higher levels there is a voluminous froth that is not easily handled.

Concentrate Particle Size: During the temperature effect study it was observed that at lower temperatures entrapment of coarse sand in the bitumen might account for the poorer grade of the concentrate. To further examine this effect, the concentrates obtained at different temperatures were extracted to recover the sand which was then sized using a wet-dry sieving technique. The cumulative size distributions of the sand in the concentrates shift to finer distributions with increasing flotation temperature as shown in Figure 12. These results confirm the previous

hypothesis regarding improved sand rejection at higher temperature and, as would be expected intuitively, that such sand rejection is selective due to inertial considerations. This information will be particularly useful in subsequent upgrading steps of the bitumen concentrate.

Continuing Work: Further research on the flotation of digested Asphalt Ridge tar sands is scheduled to include a study of the effect of percent solids in the flotation step. Another important aspect of the program that will be examined is the liquid-solid separation of the tailings especially with regard to the slime content, -37 micron material. The feasibility and effect of recycling water from flotation to digestion is also slated to be investigated.

Summary

These results of a continuing study of the flotation behavior of digested Asphalt Ridge tar sand reveal some important features which had not been recognized previously. From efforts to determine the hydrophobic nature of bitumen surfaces by contact angle measurements, it was found that bitumen exhibited moderate hydrophobicity which for certain samples could be destroyed in alkaline solutions. Further, examination of the bitumen concentrate from a hot water processing experiment indicated that it was not hydrophobic even though it had been recovered in froth phase. This evidence along with observations concerning the structural nature of the bitumen concentrate led to the hypothesis that an agglomerate of bitumen and air form in the flotation cell rather than the air bubble being attached to a bitumen surface.

From the factorial design study of the following flotation variables; temperature, rpm, air flowrate, and carbonate addition it was found, for the range of the variables studied, that a first order model described the data within experimental error. Also, it was found from analysis of variance and hypothesis testing that the quality of separation was independent of air flowrate and carbonate addition under these conditions.

Preliminary experiments to determine if higher carbonate additions during the flotation step might have an effect on the quality of separation indicate that the separation may be improved at higher levels of carbonate addition.

Importantly it was found that the flotation temperature was the most significant operating variable and that increased temperature improves the recovery and grade of the bitumen concentrate. At higher flotation temperatures the concentrate loses its spongy structure and becomes more like a second liquid phase. Further, the sand of high temperature concentrates was found to have a finer size distribution due to the enhanced rejection of coarse particles from the less viscous bitumen.

Research will continue in the areas of carbonate addition, liquid-solid separation of tailings, percent solids and water recycling. The purpose of this research program is to ultimately be able to supply the laboratory data necessary for the design of a continuous pilot plant for the recovery of bitumen from Utah tar sand by a hot water processing technique.

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Table 1. World Reserves of In-Place Bitumen

Deposit	In-Place Bitumen (billions of barrels)
Canadian Tar Sands	900
Utah Tar Sands	25
Other U.S. Deposits (Principally California Kentucky, and New Mexico)	3
Venezuela	700
Africa	2
Europe	3

Table 2. Extent of Utah Tar Sand Deposits
and Their Average Bitumen Content

Deposit	Location	In-Place Bitumen (Billion bbls)	Average Bitumen Content, wt%
Tar Sand Triangle	SE, Utah	12.5 - 16.0	5.0
P.R. Spring	NE, Utah	4.0 - 4.5	12.2
Sunnyside	NE, Utah	3.5 - 4.0	9.0
Circle Cliffs	SE, Utah	1.3	-
Hill Creek	NE, Utah	1.2	-
Asphalt Ridge	NE, Utah	1.0	13.1

Table 3. Variable Ranges for First Order Factorial Design

Variable	Units	Coded Values		
		-1	0	+1
Temperature (X_1)	°C	30	50	70
Air Flow Rate (X_2)	liters/min	5	15	25
Agitation (X_3)	rpm	600	800	1000
Na ₂ CO ₃ (X_4)	moles/liter	0.025	0.05	0.075

Table 4. Experimental Conditions and Coefficients
of Separation for the 2^4 Factorial Design

Experiment No.	X_1	X_2	X_3	X_4	Coefficient of Separation
1	-1	-1	-1	-1	0.8824
2	1	1	-1	-1	0.8495
3	1	-1	1	-1	0.8773
4	-1	1	1	-1	0.8214
5	1	-1	-1	1	0.8757
6	-1	1	-1	1	0.7827
7	-1	-1	1	1	0.8206
8	1	1	1	1	0.8795
9	1	-1	-1	-1	0.8415
10	-1	1	-1	-1	0.8012
11	-1	-1	1	-1	0.8270
12	1	1	1	-1	0.8745
13	-1	-1	-1	1	0.7968
14	1	1	-1	1	0.8625
15	1	-1	1	1	0.8522
16	-1	1	1	1	0.8404
17	0	0	0	0	0.8254
18	0	0	0	0	0.8292

Table 5. Influence of Flotation Temperature on the
Coefficient of Separation

Operating Conditions: Air Flowrate 15 l/min Agitation 1000 rpm Na_2CO_3 0.05 M				
Temperature (°C)	Conc. Grade (% Bitumen)	Bitumen Recovery (%)	Coefficient of Separation	
			Experimental	Predicted
0	45.97	91.44	0.7773	0.7853
1	47.30	95.38	0.8074	0.7866
35	48.66	97.04	0.8222	0.8291
57	61.85	96.61	0.8760	0.8566
77	61.02	96.71	0.8858	0.8816

Table 6. Sodium Carbonate Effect on the
Coefficient of Separation

Operating Conditions: Temperature 60°C Air Flowrate 15 l/min Agitation 1000 rpm				
Sodium Carbonate (M)	Conc. Grade (% Bitumen)	Bitumen Recovery (%)	Coefficient of Separation	
0	60.51	95.59	0.8700	
0.05	61.85	96.61	0.8760	
0.15	63.05	96.94	0.8967	
0.30	-	-	-

Figure 1. Simplified Flowsheet of the Hot Water Recovery Process used for Athabasca Tar Sands.

Figure 2. Major tar sand deposits in the State of Utah.

80-100

Figure 3. Viscosity as a function of temperature for Athabasca and Asphalt Ridge bitumen.

Figure 4. University of Utah Hot Water Process for Utah Tar Sands.

Figure 5. Contact Angle Goniometer with environmental chamber.

Figure 6. Tar Sand digester - electrically heated 3.7 liter tank reactor.

11

8G-100

Figure 7. Digestion and separation stages illustrating the 37 liter flotation cell.

Figure 8. Dean and Stark tube assembly.

Figure 9. Idealized representation of the equilibrium contact angle formed in a three phase system.

Figure 10. The dynamic behavior of an air bubble attached to a bitumen surface at 45°C.

Figure 11. Influence of flotation temperature on the coefficient of separation at 0.05 M Na_2CO_3 and 1000 rpm.

Figure 12. The effect of flotation temperature on the size distribution of sand entrapped in the bitumen concentrate.

AB-1

Appendix IV

Simple Diagram of a Fluidized Bed Tar Sand Recovery Plant

Elements of the Material Balance

F.V. Hanson
LCSSFC
3/81

Relative Sand Loading at Varying Bitumen Concentration,
Fixed Bitumen Load

F.V. Hanson
LCSSFC

Elements of the Material Balance

F.V. Hanson
LCSSFC
3/81

Elements of the Material Balance

F.V. Hanson
LCSSFC
3/81

Overall System Material Balance

F.V. Hanson
LCSSFC
3/81

Elements of the Energy Balance

F.V. Hanson
LCSSFC
3/81

Flow Chart for Calculation Strategy

Effect of Input Bitumen Concentration on the Recycle Ratio

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Effect of Input Bitumen Concentration on the Daily Mass
Rate of Recycle Sand

F.V. Hanson
LCSSFC

Effect of Input Bitumen Concentration on the Combustor Temperature

F.V. Hanson
LCSSFC
3/81

%

	<i>Heat of Rxn</i>	<i>4.18</i>
	<i>ΔH of Liquid</i>	<i>14.02</i>
	<i>ΔH of Fluidizing Gas</i>	<i>.11</i>
	<i>ΔH of Product Gas</i>	<i>1.57</i>
	<i>Heat Loss</i>	<i>1.74</i>
	<i>ΔH of Flue Gas</i>	<i>41.88</i>
	<i>Heat Loss</i>	<i>10.21</i>
	<i>ΔH Rejected Sand</i>	<i>26.29</i>

Energy Output of Recovery System

$$B = G_p + L + C$$

$$\bar{C} = \frac{C}{F + R + C}$$

$$\% \text{ wt.} = \frac{B \times 100}{F + B}$$

$$q = R / F$$

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THE THERMAL RECOVERY OF A SYNTHETIC CRUDE FROM THE BITUMINOUS
SANDS OF THE SUNNYSIDE (UTAH) DEPOSIT

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ABSTRACT

The bituminous sand deposits of Utah are estimated to contain 25 billion barrels of oil in place and are the largest known petroleum resource of this type in the United States. The Sunnyside deposit, amenable to surface mining techniques, is estimated to contain 3.5-4.0 billion barrels of bitumen in place with an average bitumen content of approximately eight to nine percent by weight. An aboveground, fluidized bed thermal recovery process, specific to the Sunnyside sand, for the production of a synthetic crude has been investigated. A bench-scale unit operating at atmospheric pressure with a design throughput capacity of 2.25 kg/hr was developed. The experimental data were obtained in the temperature range 700 K to 800 K at solids retention times of 20.4, 27.2 and 31.4 minutes.

The light gas and the synthetic crude yields were quite dependent upon the temperature and the solids retention time. The amount of bitumen converted to coke was relatively insensitive to the process operating conditions and to the sand particle size. The maximum liquid yield, 70% (wt) of the bitumen fed, was obtained at 773 K and a solids retention time of 20.4 minutes for a feed particle size of 358.5 microns. The effects of feed particle size and of the particle size distribution on liquid yield were also determined.

INTRODUCTION

The depletion of the oil and gas reserves of the United States concomitant with an increasing demand for energy has created a supply-demand imbalance that has been temporarily alleviated by increased imports. A long range solution to this imbalance could be achieved by the production

of synthetic crudes from alternate fossil energy resources such as coal, shale and bituminous sands. The proven United States reserves of coal and shale are extensive (1) and a substantial number of research programs have been established that are aimed at the production and utilization of synthetic crudes derived from coal and shale. However, only a limited number of programs have been initiated in the United States aimed at the production and utilization of synthetic crudes derived from bituminous sands.

The major bituminous sand deposits of the world are located in Canada, Venezuela, Columbia, Trinidad-Tobago and the United States. The Utah bituminous sand deposits (25 billion barrels), small compared to the total sand deposits of Alberta, Canada, are nevertheless a significant resource. The Sunnyside (Utah) deposit was selected as the basis for the University of Utah investigation because of the high bitumen content (eight to nine percent by weight), the size of the resource (3.5-4.0 billion barrels in place) and the projected amenability of the resource to surface mining techniques (overburden/bituminous sand depth ratio <1).

The initial phases of our program relied on the extensive literature that reported the passage of the Canadian oil sand development programs from the laboratory to the commercial plant, that is, the GCOS (2) and the Syncrude, Ltd (3) processes. There are significant differences in the physical and chemical natures of the Canadian and Utah bituminous sands. The Utah deposits contain an average of 0.5% by weight connate water compared to an average of 4.5% by weight connate water for the Canadian deposits. In addition, the sulfur contents of the Utah bitumens are low compared to the Canadian bitumens (0.6% by weight for the Sunnyside deposit versus 3.5-4.0% by weight for the Canadian deposits). The connate water

content may affect the choice of the optimum processing technique for the recovery of the synthetic crude whereas the sulfur content will affect the choice of the optimum processing sequence for the upgrading of the recovered synthetic crude. These physical and chemical differences, combined with the difference in the geographical and climatic conditions of Utah and Alberta, may make it necessary to recover the bitumen or a synthetic crude from the bituminous sands of Utah by a uniquely different technique than that used to recover the bitumen from the Canadian sands.

The processing concepts currently under investigation for the recovery of a bitumen or a synthetic crude from bituminous sands include hot water extraction of the bitumen, thermal coking of the sand to produce a synthetic crude and solvent extraction of the bitumen. The hot water and the thermal coking techniques can be utilized in either an in-situ [steam injection is considered as an in-situ hot water technique (4)] or an aboveground mode of operation. The hot water extraction process as applied to the Sunnyside deposit has been discussed elsewhere (5); therefore, this report will focus on an aboveground, thermal coking process.

The aboveground thermal recovery of a synthetic crude from bituminous sands involves the mining of the deposit, the transportation of the mined sand to the processing site and the feed sand preparation (i.e. crushing, etc.). The thermal recovery techniques pose significant heat transfer problems due to the high temperatures (675-925 K) required for the release of the synthetic crude from the bituminous sand. This constraint can be relaxed by utilizing a fluidized bed and by recycling the hot sand from which the coke has been combusted. An integrated process in which the heat generated in the coke combustion unit is recycled to the fluid-bed coking unit should be energy self-sufficient provided the coked sand contains one

to two percent by weight carbonaceous residue.

Safonov, V. A. et. al. (6,7) used a fluidized bed coker to recover a synthetic crude from the Kirmaku bituminous sands. The sand was crushed to less than one centimeter diameter particles and fed to a fluidized bed reactor held at 733-753 K. The process yielded two percent by weight gas and 50-55% by weight synthetic crude based on the oil soluble bitumen on the sand. The balance was converted to coke which was burned to supply the thermal energy needed to liberate the synthetic crude. The liquid yield appeared to be insensitive to the sand residence time in this investigation, that is, the combined (gas plus liquid) yield of hydrocarbon was 53.6% by weight of bitumen fed at a sand residence time of 14.8 minutes and a coking temperature of 738 K and it was 52.3% by weight at a sand residence time of eight minutes and a coking temperature of 773 K.

The Lurgi process (8) for the recovery of a synthetic crude from bituminous sands, though not a fluidized-bed technique, has been successfully demonstrated using a bituminous sand from California. The report contains little quantitative data, however, synthetic liquid yields of approximately 80% by weight are claimed.

Peterson and co-workers (9-11) have used the fluidized bed technique to recover a synthetic crude from the Canadian bituminous sands. The pilot plant consisted of a fluidized bed coker coupled with a combustor in which the coke on the sand was burned. The hot sand from the combustor was recycled to the coking reactor as a heat carrier. The synthetic crude obtained in this process had an API gravity of 15 to 16 whereas the bitumen extracted by the hot water technique had an API gravity of seven to eight. The liquid yields were reported to be 70-80% by weight based on the bitumen fed.

A bench-scale investigation of the direct coking of an Athabasca sand has also been conducted by Filby et. al. (13). The data reported were corrected to a 697 K end point. The yields of coke, gas and naphtha increased at the expense of heavy gas-oil with increasing coking bed temperature. The bitumen converted to coke increased with coking bed temperature up to 773 K. Above 773 K the coke yield stabilized at approximately 20% by weight based on bitumen fed. The light gas, naphtha and coke yields increase at the expense of heavy gas oil as the vapor residence time in the coking zone increased. It was also concluded that the yield of synthetic crude and the quality of the liquid produced were independent of the residence time of the sand in the coking zone.

The absence of a water film between the bitumen and the sand particles in the bituminous sands of Utah and the occurrence of most deposits in the form of consolidated sandstones led to the speculation that the fluidization characteristics of the Utah sands as well as the synthetic crude yield and quality may be considerably different than might be expected when processing the Canadian sands in a fluidized bed coking unit. There have been no reports in the literature on the thermal recovery of synthetic crudes by a fluidized bed technique for the bituminous sands of Utah. Therefore, a bench-scale pilot unit was constructed at the University of Utah to obtain preliminary process variable data on the feasibility of an aboveground, fluidized bed coker for the production of synthetic crudes from the bituminous sands of Utah. The data obtained in these preliminary experiments are presented in this communication.

EXPERIMENTAL

A schematic of the experimental apparatus is presented in Figure 1.

At the start of each experiment the reactor (D) was charged with coked sand produced in the preceding experiment. This precoked sand was fluidized and the reactor was brought to the desired coking temperature and hydrodynamic and thermal stability were established in the bed. Nitrogen from the gas manifold (A) was used as the fluidizing medium and its flow rate was monitored with a calibrated rotameter (B). The nitrogen entered at the bottom of the reactor assembly (C) and passed through a calming section where it was preheated to the coking temperature. Pre-sized bituminous sand was fed to the reactor from the storage hopper (H) under free fall conditions by means of a screw feeder (F). Thermal energy was supplied to the systems by electrical resistance heaters. The nitrogen-synthetic crude vapor mixture passed from the reactor into the expansion chamber (E) where the vapor and sand particles disengaged. Entrained sand fines were removed by two cyclone separators (K_1 and K_2). The nitrogen-vapor mixture was passed through a cylindrical, fine-mesh filter (M) prior to entering the produce recovery train. The cyclones and the filter were maintained at 693 K and 653 K, respectively, to prevent condensation of the vapor. The product recovery train consisted of a water-cooled condenser (N), a cyclone (U) and a series of fiber mist absorbers (W) maintained at the ambient temperature. The synthetic crude absorbed by the cellulose fibers was stripped from the fibers by a suitable solvent (benzene, toluene, etc.). The non-condensable, non-absorbable light hydrocarbon gases were chromatographically analyzed, metered and vented.

The dynamic, fluidized bed depth was maintained constant by a solids flow valve (V-10) controlled by a differential pressure cell (Z) that continuously monitored the pressure drop across the bed.

The uncorrected material balances for each run exceeded 92% by weight of the bitumen fed to the reactor. The percent recovery ranged from 92 to 99% by weight. The liquid yields were corrected to account for (i) the liquid that was lost with the solvent during the vacuum stripping of the solvent-synthetic crude mixtures obtained from the fiber absorbers and (ii) the liquid that condensed on the screwfeeder outlet above the expansion chamber.

The chromatographic analysis of the light gases was performed on a Hewlett-Packard Model 5830A gas chromatograph using a Chromosorb 102 column (6.1 meters in length). A simulated distillation of the extracted bitumen and the liquid products produced in this investigation was done on a Hewlett-Packard Model 5734A gas chromatograph using a column packed with three percent Dexil 300 on Anachrome Q (46 centimeters in length). Additional details on the experimental apparatus and procedures can be obtained from reference (14).

RESULTS AND DISCUSSION

Effect of Temperature on Product Yield and Distribution

The yields of light gas (C_1-C_4), naphtha ($C_5-478\text{ K}$), middle distillate (478-617 K), heavy gas oil (617 K +), total synthetic crude (C_5^+), and coke are presented in Figure 2 and Table 1 as a function of the coking bed temperature. All yields are reported as weight percent based on the bitumen fed. The base operating conditions for the investigation were atmospheric pressure, a solids retention time of 27.2 minutes, a sand feed particle size of 358.5 microns and a coking bed temperature of 773 K.

The yield of the C_5^+ liquid passed through a maximum with temperature (61.2 wt % at 723 K), however, at the lower temperature (698 K) a solvent extractable liquid ("soft" coke) remained on the sand particles with the

coked bitumen (non-extractable "hard" coke). If this liquid is considered as unliberated synthetic crude then the C_5^+ liquid yield generally decreased with increasing temperature (dashed line, Figure 2). Although the liquid yields are low compared to the data of Peterson and Gishler (9) the trend is similar.

The "hard" coke yield increased with increasing temperature up to 723 K and remained approximately constant at 19-23% by weight based on bitumen fed above 723 K. A similar trend was observed by Filby *et. al.* (13) and despite the chemical differences in the natures of the Canadian and Utah sands and in the coking bed temperatures the weight percent bitumen converted to coke was about the same in both investigations.

The light gas production increased with increasing temperature at the expense of the 617 K + heavy gas oil, however, the increase in naphtha reported by Filby *et. al.* (13) was not observed with the Utah sands. This may be due in part to the difference in the chemical nature of the Canadian and Utah sands, or to the differences in operating conditions. The carbon dioxide in the light gas is believed to have been produced by the decomposition of carbonates in the sand matrix.

Effect of Temperature on Product Quality

Selected physical properties of the extracted bitumen and the effect of the coking reactor temperature on the physical properties of the synthetic crudes are presented in Table 2. The API gravity of the liquid decreased with increasing coking reactor temperature concomitant with an increase in the Conradson carbon residue. A marked decrease in the synthetic crude viscosity was observed as the coking reactor temperature increased. The simulated distillation data are discussed in terms of an

813 K (540°C) cut point. The amount of liquid boiling below 813 K (540°C) is greater at the lower coking reactor temperature and decreases with increasing temperature. The liquid boiling below 638 K (365°C) increases with increasing coking reactor temperature, an indication that the hydrocarbon species boiling above 698 (425°C) are undergoing thermal cracking at the higher reactor temperatures. A similar observation was reported by Peterson and Gishler (10).

Effect of Solids Retention Time on Yield

The solids retention time (θ , minutes) was defined as

$$\theta = 60 W/F$$

where W is the weight of solids in the bed, kg, and F is the sand feed rate, kg h^{-1} . In this investigation, the retention time was varied by increasing or decreasing the sand feed rate while keeping the bed weight and mass constant. The effect of solid retention time on the synthetic crude yield and coke make is presented in Table 3 and Figures 3 through 5. The yield of synthetic crude decreased with increasing retention time and the yield of light gas increased with increasing retention time at each temperature studied (Fig. 3 and 4). The amount of coke produced was relatively insensitive to changes in the solids retention time (~ 19 -23% by weight of bitumen fed). The increased solids retention time would appear to increase the residence time of the liberated hydrocarbon vapor in the coking zone thus leading to more extensive thermal cracking of the vapor.

Decreasing the solids retention time shifted the temperature at which the maximum liquid yield was obtained and increased the yield of liquid at the maximum temperature (Fig. 5). At a retention time of 20.4 minutes the maximum liquid yield was 67.4% by weight at 773 K whereas at a retention time of 27.2 minutes the maximum yield was 61.2% at 723 K.

Retention times below 20 minutes were not investigated due to a limitation in the reactor throughput capacity. If we can reasonably extrapolate the data obtained in this investigation a liquid yield of 80% by weight of bitumen fed would be obtained at a coking reactor temperature of 773 K with a solids retention time of 16 minutes. The solids retention time-liquid yield data in the literature lead to conflicting interpretations, that is, Matchen and Gishler (12), Safonov et. al. (6) and Filby et. al. (13) reported no effect of sand retention time on liquid yield. Rammler (8) observed that the plant capacity (directly related to feed rate) has a definite influence on the liquid yield in the Lurgi-Rührgas direct coking process when processing a Canadian sand.

Effect of Particle Size and Particle Size Distribution on Yield

The effects of particle size and particle size distribution of the feed sand on the yield and product distribution are presented in Table 4. The particle size data were acquired at a coking bed temperature of 773 K and a solids retention time of 20.4 minutes. A reduction in sand particle size from 358.5 microns to 253.5 microns had little or no effect on the liquid yield and on the product distribution. However, a significant shift in product distribution was observed when the sand particle size was increased from 358.5 microns to 507.5 microns. The light gas yield increased from 11.3 to 26.7% by weight of bitumen fed while the C_5^+ liquid yield decreased from 67.4 to 51.8% by weight. Thus a substantial portion of the C_5^+ hydrocarbon was thermally cracked to lighter species, in particular, C_1 - C_3 gases. We speculate that a fraction of liberated hydrocarbon vapor was "trapped" in the pore structure of the larger particles. The diffusion time for these species to transfer from the internal region of

the sand particles to the bulk fluid phase was therefore increased. This increased residence time within a microscopic thermal cracker (i.e., the pore structure of the sand) led to conversion of the higher molecular weight species to C_1 - C_4 gases.

A single experiment was made with a wide cut feed sand (Tyler Sieve: 20-150 mesh fraction) to determine the effect of the sand size distribution on the liquid yield. The yield was similar to that obtained with the smaller feed sand particles, that is, 63.5% by weight liquid and 17.9% by weight C_1 - C_4 gases. A size distribution analysis on the sand indicated that 65% of the feed sand was finer than 358.5μ and it would be expected to exhibit yields more nearly like the smaller feed sand particles ($\leq 358.5\mu$) than like the larger particles ($\geq 507.5\mu$).

CONCLUSIONS

- * An aboveground, fluidized bed thermal process for the recovery of a synthetic crude from bituminous sands of the Sunnyside (Utah) deposit could be a feasible alternative to a modified hot water process.
- * Synthetic crude (C_5^+ liquid) yields in excess of 80% by weight of bitumen fed might be attainable at solid retention times below 20 minutes.
- * The consistency of the coke yields indicates a commercial or large scale pilot plant could be maintained in thermal balance regardless of the coking bed temperature, the feed sand retention time or the feed sand particle size.
- * The process variable data obtained in this exploratory investigation indicate the size of a commercial thermal coking unit for the recovery of a synthetic crude from

bituminous sands would be consistent with engineering technology currently employed in the petroleum industry.

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Table 1
Effect of Temperature on Yield and Product Distribution

Experiment Number	Sunnyside Feed				
	56	52	54	53	55
Coking Reactor Temperature, K	698	723	748	773	798
Retention Time of Solids, min.	27.2	27.2	27.2	27.2	27.2
Feed Sand Particle Size, μ	358.5	358.5	358.5	358.5	358.5
Gas Make, LPH at STP	7.3	7.3	10.6	14.5	16.0
Synthetic Crude Yield, gm/hr	19.8	23.9	18.4	22.2	22.9
Mass Balance (Weight Percent)					
CO ₂	1.2	1.3	1.8	1.5	2.7
C ₁ - C ₃	12.5	10.8	18.1	21.0	22.9
C ₄	4.1	4.0	5.9	6.5	6.7
C ₅ ⁺ Liquid	51.0	61.2	55.1	47.5	45.0
Coke	31.2	22.6	19.2	23.5	22.8
	(15.8)*				

* Weight percent of soft coke determined by solvent extraction.

Table 2

Properties of Synthetic Crude from Sunnyside Bituminous Sand

Coking Reactor Temperature, K				723	748	773	
Retention Time of Solids, min.				27.2	27.2	27.2	
Feed Sand Particle Size, μ				358.5	358.5	358.5	
Property							
Gravity, $^{\circ}$ API at 293 K				17.45	14.92	12.69	
Viscosity, Centipoise at 298 K				198 $\pm$ 4	133 $\pm$ 2	81 $\pm$ 1	
Conradson Carbon, (wt %)				3.2	5.3	7.3	
Extracted Bitumen				Synthetic Crudes			
Temperature, K				723	748	773	
Cut							
Fraction	Point	% Total	% Cumulative	% Total	% Cumulative	% Total	% Cumulative
1-7	200	0.91	0.91	3.25	3.25	4.71	4.71
8	225	0.21	1.12	2.81	6.07	3.56	8.27
9	250	0.49	1.61	3.52	9.59	4.73	13.00
10	275	0.79	2.40	4.92	14.51	5.43	18.43
11	305	1.30	3.70	6.44	20.94	5.92	24.35
12	335	1.93	5.63	7.04	27.98	6.13	30.48
13	365	2.81	8.44	7.78	35.76	6.43	36.91
14	395	3.23	11.67	8.27	44.03	6.58	43.49
15	425	3.49	15.16	9.04	53.07	6.95	50.44
16	455	4.52	19.78	9.38	62.45	6.78	57.22
17	485	5.71	25.49	10.82	73.27	7.33	64.55
18	515	4.29	29.78	9.14	82.41	6.70	71.25
19	538	2.66	32.44	6.35	88.76	4.50	75.75
Residue		67.56	100.00	11.24	100.00	24.25	100.00

Table 3

Effect of Solids Retention Time on the Yield and Product Distribution

Sunnyside Feed

Experiment Number	68	52	61	66	53	64	67	55	65
Coking Bed Temperature, K	723	723	723	773	773	773	798	798	798
Retention Time of Solids, min.	31.4	27.2	20.4	31.4	27.2	20.4	31.4	27.2	20.4
Feed Sand Particle Size, μ	358.5	358.5	358.5	358.5	358.5	358.5	358.5	358.5	358.5
Gas Make, LPH at STP	9.3	7.3	7.7	15.9	14.5	9.0	14.3	16.0	12.2
Synthetic Crude Yield, gm/hr	25.1	23.9	32.6	23.1	22.2	44.0	22.8	22.9	41.1
Mass Balance (Weight Percent)									
CO ₂	2.3	1.3	0.9	2.8	1.5	1.3	5.2	2.7	1.6
C ₁ - C ₃	15.2	10.8	8.3	26.8	21.0	8.7	23.3	22.9	11.8
C ₄	4.3	4.0	2.6	8.0	6.5	2.6	6.8	6.7	4.1
C ₅ ⁺ Liquid	55.8	61.2	50.4	42.8	47.5	67.4	42.2	45.0	61.8
Coke	22.5	22.6	37.9	19.7	23.5	20.0	22.5	22.8	20.6
			(20.9)*						

* Weight percent of soft coke determined by solvent extraction.

Table 4
Effects of Feed Particle Size
on Yield and Product Distribution
Sunnyside Feed

Experiment Number	<u>71</u>	<u>64</u>	<u>69</u>	<u>59</u>
Coking Bed Temperature, K	773	773	773	773
Retention Time of Solids, θ_{avg} , min	20.4	20.4	20.4	25.5
Feed Sand Particle Size, μ	253.5	358.5	507.5	162.0
Rate of Bitumen Feed to Reactor, gm/hr	75.5	82.8	91.0	76.5
Gas Make, LPH at STP	9.2	9.0	21.9	11.9
Synthetic Crude Yield, gm/hr	40.8	44.0	40.6	32.0
Mass Balance (Weight Percent)				
CO ₂	2.3	1.3	2.3	1.3
C ₁ - C ₃	9.7	8.7	20.6	13.6
C ₄	2.9	2.6	6.1	4.3
C ₅ ⁺ Liquid	65.1	67.4	51.8	63.5
Coke	20.0	20.0	19.2	17.4

Figure 1 - Fluid Bed Coker for Bituminous Sands

Figure 2. Effect of Reactor Temperature on Product Yield and Distribution for Sunnyside Feed.
 Retention Time of Solids, θ_{avg} = 27.2 mins.
 Feed Sand Particle Size, d_p = 358.5 microns.

Figure 3. Effect of Retention Time of Solids, θ_{avg} , on the Yield Pattern for Sunnyside Feed.

Reactor Temperature, $T = 773\text{K}$

Feed Sand Particle Size, $d_p = 358.5$ microns

Figure 4. Effect of Retention Time of Solids, θ_{avg} , on the Yield Pattern for Sunnyside Feed.

Reactor Temperature, $T = 798$ K

Feed Sand Particle Size, $d_p = 358.5$ microns

Figure 5. Effect of Retention Time on the Optimum Temperature for Maximum Yield of Synthetic Crude.

Feed Sand Particle Size, d_p = 358.5 microns

AB-2

REPORT OF FERWG SITE VISIT TO THE
LARAMIE ENERGY TECHNOLOGY CENTER, LETC
(April 27, 1981)

The following FERWG members participated at a review of the DOE programs dealing with recovery of oil from tar sands: S. S. Penner, A. G. Oblad, J. Clardy, A. E. Kelley, and D. D. Whitehurst (for P. B. Weisz). H. R. Anderson from DOE Headquarters also attended the discussions.

After a brief welcome by the Laboratory Director (A. Decora) and an LETC overview by J. Weber, L. Marchant and his colleagues outlined past, current and proposed future studies funded through LETC and dealing with recovery of bitumens from tar sands.

The program overview was presented by L. Marchant. Resource assessment was discussed by P. Dana; L. Marchant then reviewed R&D relating to reservoir access. This discussion was followed by B. Sudduth with an overview of recovery techniques and processes; L. Johnson reviewed the LETC work on recovery using in situ combustion, while L. Romanowski discussed steamflood experiments for underground recovery. Problems and procedures for permitting were summarized by T. Owen and environmental studies by R. Poulson.

1. Funding Levels

The LETC work on tar sands is funded during 1981 at \$5.7M, with \$5.1M spent in house; the anticipated funding level for 1982 is \$5.0M. Funding levels by area are approximately divided as follows: ~\$0.5M each for resource assessment (resource characterization and reservoir evaluation) and reservoir access (drilling, well completion and stimulation, mining); about \$0.3M each are allocated for product preparation

(separation, upgrading) and environmental studies (monitoring, characterization, control, and disposal methods); major expenditures of about \$2M are allotted to field recovery projects (thermal recovery, alternate extraction techniques).

The studies performed by LETC are well documented in numerous publications. In the following sections, we summarize briefly some technical features that were of particular interest to the participating FERWG members.

2. Resource Assessments

Resource assessment of tar sands deposits has been incidental to other exploration and, therefore, the estimated U.S. resource base may be larger than it is now estimated to be.

3. Water Requirements and Availability

Using current technology and practices, about 5B of water are required per barrel of bitumen produced. Total water availability from the White River Dam and Reservoir Project is estimated to be 75-130,000 acre-feet/year, whereas about 13,400 acre-feet per year are required for a 57,000 BPD commercial facility.

4. R&D Programs and Plans

Studies on resource assessment include fundamental work on rock mechanics, examinations of perforation of casing supports to study the influence on regional hydrology, and updating of the definitive Monograph 12 dealing with all aspects of tar sands resources and recovery. Associated with this work is the development of diagnostic instruments. There is particular need for a tool to pick up loose sand for characterization. Informal liaison exists with an active API drilling program to assess resources.

At the current stage of development, it is not clear whether bitumen recovery by underground combustion or by steam flooding is the preferred technology. It should be noted that reverse combustion led to recovery of about 50% of the carbon present during the second test (about 10% is used for processing while ~40% remains deposited in the bed), whereas the first test with steam flooding produced a yield of only 5%. The expectation is that the currently planned second test with steam flooding will show significantly improved performance over the first test.

The reverse combustion front produced by reflection during underground testing was 3 to 5 ft thick, with maximum temperatures falling in the range 1000-1500°F. The test duration (1977-78) was 183 days, about 25% of the total oil present was recovered, and 51% of the incoming air was accounted for. The reflected forward combustion wave did not propagate uniformly. A computer model at Intercamp was used for verification of field studies.

During the steam-flood experiments, less oil was found in the lower, more permeable regions than in the upper, less permeable layers. The steam-injection temperature was 467°F and the steam-injection pressure was 460 psia. In unconfined field patterns, probably only 50% of the injected steam or combustion gases is utilized to mobilize the oil in place.

5. Cost Estimates

Preliminary cost estimates have been made. With 50% oil recovery, air injection of 300 SCF/ft³, and a rate of return of 20%, a product sales price of \$39/B at a production cost of \$25/B has been obtained prior to upgrading. Sensitivity studies show that the production cost increases from \$25/B to about \$40/B if (a) the percentage recovery falls from 50 to 30% or (b) the air requirement is raised from 300 to 450 SCF/ft³.

6. Upgrading

Upgrading of tar-sand bitumen has been successfully accomplished.

7. Environmental Research

A major focus of the environmental program has been permitting operations for the LETC field tests. There was relatively little work on the generic environmental problems associated with different technologies or the applicability of existing control technologies. The most important environmental concern was suggested to be the detailed characterization of specific sites, which was thought to be potentially limiting and to control questions about air and water environmental impacts.

8. Long-Term R&D Needs

R&D recommendations include further work on resource assessment and exploration, definition of the mineable fraction (which is currently estimated to be about 15% of the total resource), adaptation and development of drilling techniques for use by small operators. Both water and air qualities must be carefully monitored. The gases produced on combustion drive are low-Btu gases and handling, utilization or disposal procedures must be evolved for large-scale production. Viscosity-temperature data should be specified for bitumens with varying asphaltene and other hydrocarbon contents. The behavior and compatibility of mixtures, produced by blending bitumens and other tar-sands products with pipeline oil, require investigation.

Other fundamental studies, including the determination of improved physico-chemical data characterizing the resource and improvements of quantitative models for comparisons with field investigations, were briefly discussed.

AB-3

FERWG REVIEW OF
DOE PROGRAMS ON ENHANCED OIL RECOVERY (EOR)
QUEEN MARY, LONG BEACH, CALIFORNIA
(May 22, 1981)

The following FERWG members participated at a review of the DOE programs on heavy oil recovery: F. W. Camp, J. Clardy, F. Holzeiz (for A. E. Lewis), F. X. Mayer, S. S. Penner, J. Ross, R. P. Sieg, and D. D. Whitehurst (for P. B. Weisz). The review was arranged by G. W. Dean and G. Stosur of DOE. The agenda is enclosed. In addition, W. E. Showalter of Union Oil presented an overview of the Union Oil developmental programs dealing with oil recovery from tar sands and heavy oils.

Participants included J. F. Kaufmann (DOE, Office of Energy Research) and R. Roberts (DOE, Office of Advanced Research/Fossil Energy), the listed speakers, and L. O'Brien (Union Oil).

It is expected that most FERWG members will participate at a three-day program review* on EOR, which will be held in San Francisco during the last week of July.

*The DOE Conference on Enhanced Oil Recovery will be held at the Sheraton Palace Hotel in San Francisco on July 28, 29 and 30, 1981.

AGENDA

HEAVY OIL RECOVERY PROGRAM REVIEW

May 22, 1981

Fossil Energy Research Working Group III A (1981)

Black Lion Room, B Deck

- 8:30 Coffee - Refreshments
- 9:00 Welcome - Introductions George Stosur
- 9:15 Overview of Field Demonstation Projects
- Steamflooding, In Situ and Caustic G.D. Peterson
- Steam with Additives G.W. Dean
- 10:15 Sandia National Labs Projects
Downhole Steam Generator
- Thermal Well Completions
- Thermal Front Tracking
- Steam Quality Measurements
- 11:15 University of California, Berkeley W.H. Somerton
- Mobility and Reactive Tension Agents
- Role of Clays in EOR
- 12:00 LUNCH - Catered
- 12:30 Bartlesville Energy Technology Center D. Sutterfield
- Heavy Oil Processing and Characterization
- 1:00 University of Southern California
- Correlation of Petroleum Component Properties T.F. Yen
- Chemical Additives with Steam L.L. Handy
- Scaled Physical Model Facilities F. Chassemi
- 2:15 Stanford University Petroleum Research Institute W.E. Brigham
- Flow Property Research
- In Situ Combustion Studies
- Steam Additives
- Well to Well Formation Evaluation
- 3:30 OPEN DISCUSSION
- 4:00 Tour of the Sandia DHSG Field Site
- 5:00 ADJOURN

AB-4FERWG SITE VISIT TO THE
BARTLESVILLE ENERGY TECHNOLOGY CENTER, BETC .
(June 11, 1981)

FERWG members J. Clardy, A. E. Lewis, A. E. Kelley, S. S. Penner, and J. Ross visited the Bartlesville Energy Technology Center (BETC) on June 11, 1981. G. Stosur and E. J. Lievens, Jr., of DOE/Fossil Energy (Washington) participated in the discussions. The following BETC staff members and visitors were present: J. Allsup (BETC), F. W. Burtch (BETC), A. Crawley (BETC), J. Dooley (BETC), R. L. Folstein (BETC), W. Good (BETC), H. R. Johnson (BETC), Y. Ksander (The Engineering Societies Commission on Energy), H. W. Parker (The Engineering Societies Commission on Energy), D. Sutterfield (BETC), D. Ward (BETC), and T. Wesson (BETC).

The conference agenda is summarized in Table 1.

BETC has been a petroleum research center since 1918 and is currently the DOE lead laboratory dealing with enhanced oil recovery, advanced petroleum technology, the fuel-engine interface, liquid-fuel cycles, and the relations between recovery and end use. BETC has outstanding experimental facilities and a unique and continuing tradition for the collection of thermodynamic and other fundamental data relating to oil characterization.

The following topics were reviewed by Harry Johnson and his colleagues: market demands; fuel utilization; processing technologies; thermodynamics; extraction; enhanced oil recovery, including discussions of huff and puff and other steam flooding procedures, CO₂ flooding, flooding with other chemicals (e.g., micellar solutions introduced as detergents to facilitate oil removal from sand grains), in-situ combustion; resource assessments; analytical procedures and distillate characterization; utilization research.

Table 1.

Agenda

8:30	Welcome
8:45	BETC Overview
9:00	EOR Overview
9:30	Extraction Overview
10:15	Processing and Thermodynamics Overview
11:15	Utilization Overview
11:45	Lunch - Flame Restaurant
1:30	Extraction Lab Tour
2:15	Processing and Thermodynamics Lab Tour
3:00	Utilization Lab Tour
3:15	Individual Discussion
4:30	Adjourn

The BETC data center is now operational and provided on demand the compilations of properties of heavy oils and costs for heavy oil facilities reproduced in Tables 2 and 3, respectively.

1. Environmental Research and Programs at the Bartlesville Energy Technology Center (BETC)

Workers at the Bartlesville Energy Technology Center have issued two reports dealing with environmental studies. The first deals with toxicity of chemical compounds used for enhanced oil recovery and the second is an environmental regulations handbook. The toxicity studies showed relatively little to be concerned about. In fact, some of the agents employed (e.g., xanthan gums) are widely used in the fast food industry. The one possible exception relates to various petroleum sulfonates, which are prepared by treating petroleum fractions with sulfuric acid. These tend to show modest, detergent-like toxicities. The real risk is judged to be small. They are tightly bound to the underground minerals and are used sparingly for economic reasons. An accidental surface spill could be troublesome but this was judged to be an area adequately covered by good engineering practices and no research needs have been identified.

Ames toxicity tests done with the standard protocol (i.e., incubation with a liver enzyme cocktail and measurements of reversion of histidine deficient Salmonella colonies) showed activity from some of the oil fractions. As is usually the case, this activity seemed to follow the nitrogen-containing compounds and could be reduced with hydrotreating. More and better testing was suggested as a research area.

Another area that was touched upon involves scrubber sludges. In California, where EOR is being conducted with surface-generated steam, air pollution standards demand scrubbing. There is a practical problem of disposing of this scrubber sludge. The use of

BARTLESVILLE ENERGY TECHNOLOGY CENTER CRUDE OIL ANALYSIS DATA BASE
A SHORT REPORT FROM SELECTED DATA

DATAFILE: 11-JUN-81 16:01:45

SEARCHKEY RANGE
LOC ALABAMA
LOC 1.000 - 123.000
APIG 8.000 - 12.000

SORTED BY APIG
RANGE OF VALUES: 8.322 - 11.864

NUMBER OF ANALYSES: 27

Table 2

DATA ON HEAVY OILS

SAMPLE	LOC	FIEL	APIG	PRPT	SULF	NITR	KERO	GSOL	VLD	RESID
B54221	MEXICO	MONTE	8.322	60.000	5.800	0.451	0.000	12.861	6.000	64.300
B55167	CALIFORN	ZACA	8.877	90.000	5.650	0.676	0.000	12.331	0.431	72.500
B24757	OKLAHOMA	SCOTTS D	9.718	60.000	1.320	0.000	4.000	16.400	15.836	53.600
B77069	CALIFORN	CAT CANY	10.000	80.000	6.980	0.746	0.000	12.273	0.000	69.290
B 534	ANGOLA	NOT KNOWN	10.142	0.000	0.440	0.000	0.000	3.650	20.923	65.400
B54207	MEXICO	ERAND	10.284	55.000	5.380	0.407	0.000	12.600	0.000	72.400
B75013	VENEZUEL	MONAGAS	10.284	80.000	3.140	0.535	0.000	13.900	11.878	59.100
B69088	CALIFORN	HUNTINGT	10.426	60.000	1.420	0.882	0.000	9.550	4.853	74.790
B77018	CALIFORN	PAKIS VA	10.426	85.000	1.710	0.936	0.000	12.900	17.029	58.800
B23464	CALIFORN	KERN RIV	10.711	65.000	1.230	0.000	0.000	8.368	16.236	62.000
B69079	CALIFORN	QUAPALUP	10.854	70.000	4.110	0.649	0.000	14.146	5.751	57.300
B 533	ANGOLA	NOT KNOWN	10.854	0.000	0.430	0.000	0.000	3.620	35.850	52.900
B69082	CALIFORN	RAILROAD	10.997	75.000	1.600	0.797	0.000	10.850	3.878	73.300
B54220	MEXICO	CHAFACAD	11.141	45.000	5.380	0.422	0.000	13.406	0.000	62.500
B56028	CALIFORN	SAN ARDO	11.141	80.000	2.250	0.913	0.000	11.550	1.600	72.600
B77023	CALIFORN	HASLEY C	11.141	80.000	5.490	0.955	0.000	23.200	4.830	59.700
B71034	ARKANSAS	NEW LONG	11.141	60.000	5.960	0.317	2.200	11.594	0.000	61.300
B59190	VENEZUEL	BOSCAN	11.285	65.000	5.530	0.610	2.000	11.450	0.000	68.700
B71024	VENEZUEL	BOSCAN	11.285	95.000	5.540	0.604	0.000	12.600	0.000	66.800
B 993	MEXICO	GONZALO	11.574	40.000	5.290	0.000	2.600	13.772	0.889	62.400
B55132	CALIFORN	GATO RID	11.719	45.000	5.930	0.747	0.000	13.560	4.989	63.200
B 1107	CALIFORN	MIDWAY-S	11.864	40.000	1.630	0.000	0.000	10.384	20.887	55.600
B24756	OKLAHOMA	LYNN	11.864	60.000	2.360	0.000	0.000	14.859	17.742	51.300
B55114	CALIFORN	MIDWAY C	11.864	60.000	1.670	0.882	0.000	13.843	11.606	61.500
B66099	CALIFORN	WILMINGT	11.864	60.000	1.730	0.720	0.000	13.350	9.482	63.400
B66100	CALIFORN	WILMINGT	11.864	55.000	1.700	0.664	0.000	14.831	11.013	61.900
B 565	WYOMING	WARR SPR	11.864	15.000	2.610	0.000	2.900	14.460	0.000	51.500

Table 3

-473- NO ERRORS HAVE OCCURRED

-479- LOWEST SELECTED RECORD COMMON TO ALL REPORTS

DATA ON HEAVY OIL RECOVERY

TERTIARY PROJECTS COST REVIEW REPORT

NUMBER	LAB ENGR EST COST	SURF EQUIP INSTAL COST	MISCIBLE FLUID DISPLACEMENT DOWNHOLE COST	DRILLING COST	PREFLUSH FLUID COST	TERTIARY FLUID COST	ANNUAL OPNS MAINT COST
SF008				\$27,554,000.00		\$245,000,000.00	
SF015	\$200,000.00		\$420,000.00	\$4,566,000.00		\$652,000.00	\$3,226,400.00
SF035	\$200,000.00	\$475,000.00	\$108,000.00	\$7,854,000.00		\$3,778,000.00	\$582,000.00
SF041		\$200,000.00		\$42,360,000.00		\$51,300,000.00	\$18,200,000.00
SF043	\$474,000.00			\$5,450,000.00		\$1,080,000.00	\$1,050,000.00
SF044		\$9,700,000.00		\$7,100,000.00	\$800,000.00		
SF063			\$4,540,000.00		\$452,000.00	\$15,500,000.00	\$1,940,000.00
SF082	\$300,300.00	\$100,000.00	\$70,000.00	\$900,000.00		\$11,280,043.00	\$432,000.00
SF130	\$20,000.00	\$315,600.00	\$306,000.00	\$376,800.00		\$5,483,800.00	\$1,336,000.00
SF135		\$1,240,000.00	\$2,027,000.00	\$1,470,000.00		\$44,422,000.00	\$24,477,000.00
SF154	\$500,000.00	\$1,068,000.00	\$531,900.00	\$2,111,800.00		\$7,815,280.00	\$964,833.00
SF155	\$500,000.00	\$2,300,000.00	\$1,400,000.00	\$4,300,000.00		\$11,400,000.00	\$800,000.00
SF161	\$500,000.00	\$250,000.00	\$120,000.00	\$500,000.00		\$1,500,000.00	\$100,000.00
SF166	\$500,000.00	\$250,000.00	\$120,000.00	\$500,000.00		\$1,500,000.00	\$100,000.00
SF167		\$31,713,000.00		\$11,150.00			
SF169	\$50,000.00	\$500,000.00	\$200,000.00	\$2,000,000.00		\$70,000,000.00	\$500,000.00
SF171	\$35,000.00	\$2,409,900.00	\$3,274,850.00	\$10,967,550.00		\$130,307,400.00	\$2,806,200.00
SF184	\$150,000.00	\$722,000.00	\$471,000.00	\$1,370,000.00		\$22,740,000.00	\$875,000.00
SF199	\$500,000.00	\$3,300,000.00	\$250,000.00	\$2,500,000.00		\$100,000,000.00	\$6,000,000.00
SF216	\$500,000.00	\$2,300,000.00	\$1,630,000.00	\$7,120,000.00	\$5,148,000.00	\$11,021,000.00	\$428,000.00
SF219	\$2,000,000.00	\$165,600,000.00	\$6,000,000.00	\$71,500,000.00		\$840,000,000.00	\$35,200,000.00
SF223							
SF238	\$44,000.00	\$200,000.00	\$90,000.00	\$5,800,000.00			\$2,035,000.00
SF245	\$170,000.00	\$450,000.00	\$145,000.00	\$125,000.00		\$500,000.00	\$70,000.00
SF272	\$200,000.00	\$42,000,000.00				\$195,000,000.00	\$3,100,000.00
SF273	\$200,000.00	\$7,250,000.00	\$1,400,000.00	\$2,200,000.00		\$78,000,000.00	\$2,100,000.00
SF274	\$200,000.00	\$13,000,000.00	\$2,300,000.00	\$9,200,000.00		\$161,000,000.00	\$1,900,000.00
SF275	\$200,000.00	\$18,700,000.00				\$85,000,000.00	\$2,400,000.00
SF281A	\$300,000.00	\$140,000.00	\$70,000.00	\$550,000.00		\$126,000.00	\$490,000.00
SF281B	\$70,000.00	\$20,000.00	\$70,000.00	\$70,000.00		\$550,000.00	\$110,000.00
SF290	\$200,000.00	\$8,000,000.00	\$1,500,000.00	\$2,400,000.00	\$300,000.00	\$49,000,000.00	\$3,700,000.00
SF291	\$200,000.00	\$20,000,000.00	\$5,000,000.00	\$5,000,000.00	\$500,000.00	\$140,000,000.00	\$3,300,000.00
SF292	\$200,000.00	\$13,600,000.00				\$25,000,000.00	\$2,400,000.00
SF293	\$200,000.00	\$14,400,000.00				\$40,000,000.00	\$1,200,000.00
SF302	\$500,000.00	\$80,000,000.00	\$30,000,000.00	\$44,000,000.00		\$450,000,000.00	\$18,000,000.00
SF307	\$75,000.00	\$300,000.00	\$400,000.00	\$500,000.00	\$20,000.00	\$9,000,000.00	\$250,000.00
SF310	\$500,000.00	\$531,000.00	\$1,513,000.00	\$2,284,000.00	\$30,000.00	\$4,500,000.00	\$1,000,000.00
SF313	\$1,000,000.00	\$61,971,000.00	\$22,583,000.00	\$13,600,000.00		\$321,600,000.00	\$16,520,000.00
SF314	\$1,000,000.00	\$134,400.00	\$14,500,000.00	\$6,300,000.00		\$24,400,000.00	\$20,000,000.00
SF315	\$1,000,000.00	\$28,643,000.00	\$2,901,000.00	\$5,600,000.00		\$57,600,000.00	\$5,770,000.00
SF316	\$1,000,000.00	\$7,482,000.00	\$4,374,000.00			\$22,000,000.00	\$2,000,000.00
SF317	\$1,000,000.00	\$28,050,000.00	\$9,004,000.00	\$4,500,000.00		\$104,004,000.00	\$6,050,000.00
SF318	\$1,000,000.00	\$42,412,000.00	\$2,500,000.00	\$20,000,000.00		\$120,000,000.00	\$10,000,000.00
SF319	\$1,000,000.00	\$24,036,000.00	\$6,503,000.00	\$2,491,000.00		\$135,960,000.00	\$6,160,000.00
SF320	\$1,000,000.00	\$145,287,000.00	\$15,467,000.00	\$220,000.00		\$470,000,000.00	\$17,000,000.00
SF324							
SF334	\$1,071,000.00	\$428,000.00	\$1,200,000.00	\$7,000,000.00	\$50,000.00	\$700,000.00	\$100,000.00
SF349	\$200,000.00	\$1,069,000.00	\$380,000.00	\$2,750,000.00		\$2,535,000.00	\$30,000.00
TOTALS	\$19,381,300.00	\$803,627,900.00	\$150,325,750.00	\$350,124,300.00	\$7,500,000.00	\$4,369,685,523.00	\$240,045,433.00
- TERTIARY PROJECTS COST REVIEW REPORT -							
AVERAGES	\$484,532.50	\$18,689,020.93	\$4,062,858.11	\$8,977,546.15	\$937,500.00	\$101,620,593.56	\$5,582,917.05
OCCURRENCES	40	43	37	39	6	43	43

down-hole steam generators is attractive in this environment.

A problem that is emerging and will require substantial effort is water availability and purity. There is a potential for contamination of fresh water aquifers by EOR activities and BETC is initiating work on this problem. A research program similar to that described in the FERWG oil shale report may be needed. Work is currently being done to (1) determine the rates of migration of EOR compounds in the oil reservoir, (2) establish the degradative pathways of EOR compounds, (3) establish the adsorption of EOR compounds, and (4) determine the three-phase relative mobilities in porous media.

The work on heavy oil processing and characterization described by D. Sutterfield is summarized in Appendix AB-4, Appendix I.

AB-4

Appendix I

by D. Sutterfield (BETC)

HEAVY OIL

PROCESSING AND CHARACTERIZATION

PROCESS TECHNOLOGY PRE-PROCESSING OF LIQUIDS

PROBLEMS IN CHANGING FEEDSTOCK FROM LIGHT PETROLEUM TO HEAVY PETROLEUM

- HIGHER CONCENTRATIONS OF HETEROATOMS (N,O,S)
- MORE METALS
- MORE AROMATICS
- MORE RESIDUUM
- DECREASED FEEDSTOCK AND PRODUCT STABILITY
- MORE PROCESS ENERGY REQUIRED TO MAKE CURRENT SPEC FUELS

HEAVY OIL PROCESSING CHARACTERISTICS

GRAVITY

4-18 °API

NICKEL

10-105 PPM

VANADIUM

0-820 PPM

SULFUR

0.5-6 WT. PCT.

NITROGEN

0.1-1 WT. PCT.

RESIDUUM

35-75 WT. PCT.

CRUDE OIL	GRAVITY, ° API	VISCOSITY, SUS 100°F	WT%	
			SULFUR	NITROGEN
SWAN HILLS	39.8	37	0.11	0.056
GACH SARAN	29.3	72	1.57	0.226
WILMINGTON	19.4	470	1.59	0.631
CERRO NEGRO	8.2	> 6000	3.85	0.170

HEAVY OIL PROCESSING

- NO SINGLE BEST CHOICE
- TWO BASIC CATEGORIES FOR PROCESSING RESIDUUM
DESULFURIZATION
CONVERSION
- TYPICAL SCHEME FOR RESIDUUM
DELAYED OR FLUID COKING
HYDROTREAT COKER DISTILLATE
HYDROCRACK

ELEMENTS	CERRO NEGRO	PRUDHOE		WILMINGTON
		BAY		
V	560	18.7		48.5
Cr	<10.6	2.4		<3.7
Mn	<4.9	1.9		<2.2
Fe	108.0	1.1		40.0
Co	23.3	<7.1		<13.1
Ni	118	9.3		60.4
Cu	<1.3	0.5		0.8
Zn	0.9	0.9		1.8
As	<0.5	<0.5		<0.4
Hg	<1.2	<0.9		<0.9
Pb	<1.6	<1.4		<1.4
Th	<1.4	<1.2		<1.2
U	<2.3	<2.1		<2.1

HEAVY OIL PROCESSING

- NO SINGLE BEST CHOICE
- TWO BASIC CATEGORIES FOR PROCESSING RESIDUUM
DESULFURIZATION
CONVERSION
- TYPICAL SCHEME FOR RESIDUUM
DELAYED OR FLUID COKING
HYDROTREAT COKER DISTILLATE
HYDROCRACK

R & D NEEDS

HEAVY OILS

- PROVIDE IMPETUS FOR HEAVY OIL CONVERSION INDUSTRY IN U.S. (DOE RFP)
 - JAPAN & SOME EUROPEAN AND AFRICAN COUNTRIES ARE WORKING HARD ON HEAVY OIL CONVERSION PROCESSES
 - NEEDED FOR CONSERVATION AND EFFICIENT USE OF RESOURCE
 - RAPID TRANSITION TO HEAVY CRUDES
- METALS REMOVAL AND RECOVERY
 - GUARD CHAMBERS
 - CHEMICAL EXTRACTION

PROCESS TECHNOLOGY

- PROVIDE COMPARATIVE DATA FOR UPGRADING HEAVY CRUDES
- CORRELATE CHARACTERIZATION DATA WITH RAW MATERIAL SOURCES, AND FINISHED PRODUCTS
- METALS REMOVAL AND RECOVERY
- PROCESSING PROBLEMS ASSOCIATED WITH PRODUCTION OF EOR CHEMICALS

THERMODYNAMICS

**OBJECTIVE: TO FACILITATE UPGRADING OF HEAVY OIL BY THERMODYNAMIC STUDY TO
INDICATE OPTIMUM CONDITIONS FOR ORGANIC NITROGEN COMPOUND REMOVAL**

WHY REMOVE NITROGEN COMPOUNDS

- THEY POISON CATALYSTS
- THEY LEAD TO INSTABILITY AND GUM FORMATION IN FUEL STORAGE
- THEY FORM NO_x UPON COMBUSTION IN ENGINES

MEASUREMENTS ON NITROGEN COMPOUNDS

- COMBUSTION CALORIMETRY
- HEAT CAPACITY CALORIMETRY
- VAPOR PRESSURE MEASUREMENT
- FAR INFRARED AND RAMAN SPECTROSCOPY

PROCESS TECHNOLOGY

STABILITY

- MAJOR CONCERN BOTH FOR CRUDES AND PRODUCTS
- TRANSPORTATION
- DETERMINES SEVERITY OF REFINING

STRUCTURAL EFFECTS ON SEDIMENT FORMATION

STRONGLY DELETERIOUS

>

MODERATELY DELETERIOUS

>

RELATIVELY HARMLESS

R — H, CH₃, C₆H₅

RNH₂

ArNH₂

RCONH₂

RCH

ArCN

PROCESS TECHNOLOGY

TEST FUELS (REFERENCE FUELS) PROGRAM NEEDED FOR:

- TIMELY FUELS/ENGINES SYSTEMS DEVELOPMENT
- COOPERATIVE EFFORTS WITH DOD
- REDUCING PROCESS ENERGY FOR ALTERNATE CRUDES
- PROVIDING INTERFACE FOR PRODUCTION, PROCESSING, AND END-USE TECHNOLOGY INTERCHANGE

PROCESS TECHNOLOGY

HEAVY OILS: GENERIC MARKET STUDY CONCLUSIONS

- DEMAND FOR RESIDUAL OIL WILL DROP 50 % BY 2000
- EXISTING REFINERIES ARE DEFICIENT IN FACILITIES NEEDED TO UPGRADE HEAVY ENDS (ESPECIALLY IN GULF COAST AREA).
- SEVERE SHORTAGES OF DISTILLATE FUELS (300 MB/D) ARE FORECAST FOR 2000 WITH CURRENT REFINERY CONFIGURATIONS.

HEAVY OIL PROCESSING

ANTICIPATED CONTRACTS	STATUS
HRI	NEGOTIATING PATENT RIGHTS
UOP	SUBSTITUTE PROPOSAL SUBMITTED 4/17
WALK, HAYDEL (A/E)	READY FOR SIGNATURE
UNKNOWN (MARKET STUDY)	TO BE DECIDED

NEEDS FOR CHARACTERIZATION DATA

- PROCESS DESIGN
- PROCESS TAILORING
- PROCESS MONITORING
- ENVIRONMENTAL IMPACT

TYPES OF CHARACTERIZATION DATA

- PHYSICAL PROPERTIES
 - DENSITY
 - VISCOSITY
 - DISTILLATION DATA
- THERMOPHYSICAL-THERMODYNAMIC PROPERTIES
 - VAPOR-LIQUID EQUILIBRIUM DATA
 - HEAT CAPACITIES
 - ENTHALPY
 - FREE ENERGY
- CHEMICAL PROPERTIES
 - ELEMENTAL ANALYSES
 - MOLECULAR WEIGHT DISTRIBUTIONS
 - COMPOUND CLASS ANALYSES
 - COMPONENT ANALYSES

COMPOUND-TYPE DISTRIBUTION IN WILMINGTON370-535° C BASES

FRACTION NO.	DOMINANT CHEMICAL CLASSES	TYPICAL pK _a FOR CLASSES	WT PERCENT IN BASE EXTRACT	
			CATION, ANION	ANION, CATION
1	HYDROCARBONS, SULFUR COMPOUNDS	NA	4.6	4.6
2	PYRROLES	<1	19.0	14.9
3	THIAZOLES, ANILINES	2.5-5	16.8	15.8
4	PYRIDINE TYPES	4.5-6	58.1	61.7
5	AMINES, DIFUNCTIONAL	<6(?)	2.0	3.3

SRC II BASE FRACTION #3

Z SERIES	POSSIBLE COMPOUND	CARBON NUMBER		RELATIVE	WT% BASE FRACTION
		INITIAL	FINAL		
- 7N		14	20	0.85	0.107
- 9N		14	20	0.77	0.097
-11N		11	18	1.92	0.240
-13N		12	22	7.62	0.953
-15N		13	22	6.53	0.816
-17N		13	22	60.56	7.570
-19N		15	20	9.28	1.160
-21N		16	22	1.66	0.208
-23N		17	20	1.42	0.177

COMPOUND-TYPE DISTRIBUTION IN CERRO NEGRO CRUDE OIL

		WT PERCENT			
DISTILLATE		SATURATES MONOAROMATICS DIAROMATICS POLYAROMATICS ACIDS BASES			
200-425° C	38.07	24.84	23.41	12.49	1.08 0.88
425-550° C	15.52	24.94	25.23	28.91	5.60 2.67
550-700° C	6.89	15.36	22.95	39.75	8.68 6.37
>700° C	1.18	2.85	13.87	29.17	32.49 27.13

COMPOUND-TYPE DISTRIBUTIONS IN CERRO NEGRO CRUDE OIL BASES

FRACTION NO.	DOMINANT CHEMICAL CLASSES	WT PERCENT IN BASE EXTRACT		
		200-425° C	425-550° C	550-700° C
1	HYDROCARBONS, SULFUR COMPOUNDS	5.2	2.3	1.8
2	PYRROLES	19.1	27.6	23.5
3	THIAZOLES, ANILINES	20.2	17.8	22.1
4	PYRIDINE TYPES	50.7	50.4	51.7
5	AMINES, DIFUNCTIONAL	4.7	1.8	1.0

METHODS FOR HYDROCARBON GROUP TYPE ANALYSES

• SATURATES

LOW RESOLUTION, 70 eV MASS SPECTROMETRY

FIELD IONIZATION MASS SPECTROMETRY

• AROMATICS, ACIDS, AND BASES

HIGH RESOLUTION, LOW VOLTAGE MASS SPECTROMETRY

HIGH RESOLUTION, FIELD IONIZATION MASS SPECTROMETRY

HIGH RESOLUTION, LOW VOLTAGE, PROBE MICRODISTILLATION
MASS SPECTROMETRYWEIGHT PERCENTS OF ACIDS, BASES, SATURATES, MONOAROMATICS, DIAROMATICS,
AND POLYAROMATICS FOR SELECTED PETROLEUM DISTILLATE FRACTIONS.

SAMPLE	SATURATES	POND	VIZ		WEAK		STRONG	
			AROMATICS DI	POLY	ACIDS	BASES	ACIDS	BASES
S. SWAN HILLS								
370-515°	64.66	11.06	5.12	17.62	1.57	1.40		
515-675°	46.47	8.45	9.42	29.12	2.10	4.43		
+675°	4.84	9.52	9.83	48.96	2.40	2.64	3.19	18.63
GACH SAPAH								
370-515°	50.20	7.32	10.54	28.37	1.36	2.21		
515-675°	27.33	10.47	11.28	43.75	1.41	5.72		
+675°	0.75	7.78	4.74	42.19	2.36	8.73	2.69	33.37
WILKINSON								
370-515°	35.87	16.30	11.44	26.39	4.60	4.63		
515-675°	15.70	9.15	14.76	47.55	5.35	10.31		
+675°	2.30	1.55	3.03	38.25	6.49 ^a	46.30 ^a		

^aSTRONG AND WEAK ACIDS AND BASES WERE COMBINED AND NOT QUANTITATED SEPARATELY.

AB-5FERWG-IIIA
DISCUSSIONS ON HEAVY OILS
SUNEDCO, DALLAS, TEXAS
(June 12, 1981)

FERWG member F. W. Camp arranged a one-day review and evaluation on heavy oil recovery at SUNEDCO offices in Dallas, Texas. The following FERWG members participated: F. W. Camp, J. Clardy, A. E. Lewis, A. E. Kelley, F. X. Mayer, S. S. Penner, R. P. Sieg, W. C. Skinner, as well as G. Stosur (DOE/Fossil Energy, Washington). In addition to the principal speakers listed on the Agenda shown in Table 1, W. Winsauer (Exxon, Houston) participated in the discussions.

PRESENTATIONS AND DISCUSSIONS

1. Overview (E. W. Malmberg, SUNEDCO)

In his overview of enhanced recovery methods for heavy oils, E. W. Malmberg (Sun Production Company) commented on steam flooding, in situ combustion, caustic flooding, CO₂ flooding, and the use of surfactants and polymers. His viewgraphs are reproduced in Tables 2-6 and in Fig. 1.

Malmberg emphasized the heavy current steam-injection costs for EOR, which require for cycling (huff and puff) about 1B of fuel energy for every 2B of fuel produced. The steam override and breakthrough problem has been well indentified with steam-drive recovery. Mobility control polymers may be injected to produce gelling agents that lead to increased resistance in the steam override region and thereby produce more extended access to the heavy oil reservoir. Chemicals used for applications of this type include lignosulfonates marketed by AMOCO, as well as polymers sold by Phillips. Foam generating agents are also used. Down-hole steam generators are being tested to overcome depth limitations of conventional steam-injection

procedures. Sun Oil had four in situ combustion projects that were classified as "successful" prior to 1973 but none is being continued today (cf. Table 5).

Sulfonates are believed to be so stably adsorbed that their use does not constitute an environmental hazard. On the other hand, corrosion by SO_2 formed during in situ combustion is an operational problem and a potential health hazard. Structural conformance is a special problem in enhanced recovery with chemicals.

Experience with CO_2 flooding is summarized briefly in Table 3. Up to about 65% of the CO_2 may be recycled in carefully run tests. Reference to Table 3 shows that the Aminoil Huntington Beach Field, California, with 18°API oil was estimated to require 10 MCF of CO_2 per B of oil produced. In studies performed by Phillips at Lick Creek Field, Arkansas, on 17°API oil, a sequence of cycle- CO_2 -drive-WAG (water-assisted-gas)-water drive was followed. Of 23.3 MMB (23.3×10^6 barrels) in place, the primary plus a weak water drive led to a recovery of 4.5 MMB while the CO_2 phase produced 3.7 MMB of which 3.1 MMB (13% of original oil in place = OOIP) were attributed to incremental production associated with the CO_2 flood alone.

Experience with caustic flooding is summarized in Table 4. Caustic flooding on 15-20°API oil produced extreme fingering, which was improved by adding polymer to the caustic in order to achieve improved mobility matching. Current work deals with conformance-mobility matching and with the behavior of saline solutions.

Thermal methods are summarized in Table 5. Reports from the Cities Services Co. claim ~52% recovery of OOIP while the SUNEDCO experience was 10-20% recovery. Recovery is evidently strongly reservoir-specific for a given EOR technique. Reports from ARCO indicated only about 10% recovery in some fire-flooding tests.

Important problem areas for cost-effective implementation of EOR deal with the heavy front-end investment costs that are required for injection and the long lead times required before recovery is achieved. The current status of the windfall profits tax is of limited value for enhanced oil recovery because it generally does not contribute to front-end, high-risk costs. Technical and scientific uncertainties involve mobility (conformance) matching between flooding agents and oil in place, availability and effective utilization of water resources, and understanding of the geology and geochemistry of the reservoir and its contents.

2. Saner Ranch Fireflood Tests (B. G. Holmes, Mobil Production Company)

Studies performed between 1964 and 1968 in South-West Texas on the Saner Ranch, San Miguel Sands, by the Mobil Production Co., were summarized by B. G. Holmes. His viewgraphs are reproduced in Tables 7-9 and in Figs. 2-12.

Table 7 shows a program overview. Figure 2 illustrates schematically the in situ combustion process. Figures 3-6 show, respectively, the location of the Saner Ranch in West Texas, the project area, the locations of injection and production wells, and an isopachous map of the project area. An induction-electric log for a well is reproduced in Fig. 6. Cumulative oil (in MB = 10^3 bbls) and gas (in MMCF = 10^6 CF) are shown as functions of cumulative air injection (in MMMCF = 10^9 CF) in Fig. 7. Production data (in BPD = bbl per day) of oil and water as functions of time are shown in Fig. 8; cumulative oil production (in MB) is plotted as a function of time in Fig. 9. Temperature surveys vs. depth for three time period show extension and retraction of maximum temperature profiles (Figs. 10-12). Product oil characteristics are summarized in Table 9 and indicate 8-11^oAPI oil with 8-9% S, 0.22% N, 9.75% H, a viscosity at 60^oF of 1260 CP, and a Conradson carbon ratio of 15-17%.

The estimate for available resources by Mobil Production was 0.5 to 1×10^9 B, whereas a later estimate by Conoco is 3 to 4×10^9 B for the Saner Ranch property. The oil is located about 1500 ft from the surface on a massive syncline. Water and oil were intermingled with an original oil saturation of $\sim 50\%$. The net pay depth achieved was 32.5 ft at a reservoir pressure of 1100 psi and a rock permeability of 1000 MD. About 390 B of fuel and 14.4 MMCF of air were required per acre-foot processed. The original oil in place was at 100°F . A combustion temperature of 1100°F was attained in beds of 30% porosity. Air injection pressures of about 2500 psi were required initially and were subsequently decreased, with air pressure levels of ~ 1500 psi during combustion.

Some of the product oil was sold to Tesoro Oil Co. and a truckload was delivered to Exxon for a 5 cents/B charge for disposal. Upgrading would have yielded acceptable and salable product at $\$4.09/\text{B}$ during 1968 (i.e., about $\$1.00$ above market value). About $8-9\%$ of the total oil in place was recovered, corresponding to about 40% of the oil exposed to the combustion wave.

This program was judged to be uneconomical in 1968 and the lease was subsequently abandoned by Mobil Production Co.

3. Saner Ranch Steam-Flooding Tests (E. L. Oshlo, Conoco)

Conoco picked up the leases some years after they were abandoned by Mobil. Revised resource estimates were made as follows: 3 to 4×10^9 B of oil in place with -2°API gravity, $>10^6$ CP reservoir viscosity, $>10\%$ S. Huff and puff recovery was ineffective because the reservoir did not transmit pressure. Recovery was accomplished by using FAST (= fracture-assisted steamflood technology) in which a patented technology involving a steam flood ($\sim 650^\circ\text{F}$) is employed after horizontal fracturing. The net pay region was estimated to be about 40 ft in thickness and to be

broken up by intermittent, dense streaks. Porosities were ~20-30%. The reservoir is divided into upper and lower lobes.

The original Conoco pilot plant was designed to produce 130,000 B but actually yielded nearly 169,000 B for 1.8×10^6 B of steam and 0.6×10^6 B of water injected at 1400-1900 psi; 80% quality was used for the steam. The average remaining residual saturation in the upper lobe is estimated to be ~18%. Significant coke deposition occurred.

FAST (1981 U.S. patent #4,265,310) is appropriate for use when competent rock layers occur above and below the fracture zone. Thermal efficiencies should reach 80%, with small heat losses from the bed.

The following R&D areas were identified:

- i. verification of tar-recovery performance;
- ii. demonstration of commercial feasibility for a large fluidized bed combustor for steam generation (50,000 lbs/hr, 50×10^6 Btu/hr) that is currently being built for Conoco;
- iii. development of upgrading procedures for the tar (using, for example, Conoco's delayed coke unit, Gulf's resid desulfurizer, the H-oil hydrocracker, Exxon's flexicoker, partial oxidation to produce methanol);
- iv. steam costs must be reduced to improve the thermal ratio in recovery, which may perhaps be accomplished by utilizing high-sulfur coal for steam generation.

Current work is in progress on a 7.5-acre area with a 7-spot pilot to confirm the FAST process. Heavy oil technology is far less demanding than tar-sand technology insofar as capital,

personnel and input energy are required. Capital cost estimates for a commercial-scale facility will probably fall in the range of \$50,000 (1980 dollars) per daily barrel of production from tar sands.*

Considerable discussions by participants on the relative merits of in situ combustion and steam flooding did not yield conclusive statements. The time for heavy oil recovery is propitious now but was premature in 1968.

Current field operations in the U.S. may be summarized by the statement that steam flooding yields about 10 times as much oil (i.e., ~300,000 BPD) as in situ combustion (~30,000 BPD).

4. Downhole Steam Generation (R. Eson, Chemical Oil Recovery Company)

There is a considerable resource in place below about 2500 ft, where conventional methods for steam injection become uneconomical. Downhole steam generation will also reduce air pollution. Oil-to-steam ratios are ± 0.2 with downhole generation. Because the pH is ~2.7, corrosion inhibitors were needed on a test well. Normal injection pressures (~230 psia) were employed in an above-ground Kern County test operation. An indirectly heated steam source has been designed for downhole steam generation with heat transfer to the steam chamber. The system employed has evolved from a 1969 Phillips patent.

Discussions included comparisons and relative merit assessments for downhole steam generation and in situ combustion, which produces partial fractionation and upgrading.

*A detailed report by E. L. Oshlo on oil recovery from tar sands is appended to this report (cf. Appendix I).

5. Heavy Oil Upgrading (J. Fitch, Chemical Oil Recovery)

DOE has funded three field tests involving additions to steam consisting of (a) ancillary materials, (b) petroleum sulfonates to produce micellar foams, (c) materials producing foams that are stable at elevated temperatures. A total of about 35 foam-steam mixtures is in use.

Foams added to steam are expected to reduce the permeability of the override channeling zone, thereby increasing bed access for steam and improving total oil recovery. Treatment options include sequential foam injection, continuous foam injection, the sequential use of foam-polymer combinations, the use of lignin liquors to produce permanent permeability reductions in flow channels.

Experimental results indicate that actually permeability reductions occur everywhere in the flow channels. Studies were performed on 40-ft thick oil layers with ~1525 ft depth at the top of the oil-bearing zone; the oil was 13⁰API. The original resource amounted to ~1640 B/acre-ft. Field data collected included information on production rates, oil temperatures, dispersal of chemical and radioactive tracers, injection profiles, cores, open and cased hole logs, steam-foam flow patterns. Recovery was increased by up to 125 BPD at an incremental cost of about \$3/B.

Fundamental problems involved in EOR using the specified procedures were briefly discussed.

6. Heavy Oil Upgrading (F. X. Mayer, Exxon)

FERWG member F. X. Mayer reviewed procedures for heavy oil upgrading, after emphasizing the site-specific nature of these processes. Process options include carbon rejection as in fluid coking or flexicoking, delayed coking, deasphalting; H₂ additions as in hydrodesulfurization and hydroconversion; process combina-

tions as in combined hydrotreating and coking or catalytic cracking and in combined deasphalting and hydrodesulfurization.

The survey included material presented in the following three Exxon publications: "Extension of Residfilling Technology to Hydroconversion" by E. S. Ellis, J. Sosnowski, R. L. Hood, M. G. Luzaraga, and K. L. Riley; "Novel Catalyst and Process for Upgrading Residual and Heavy Crudes" by R. Bearden and C. L. Aldridge; "Current Developments in Fluid and Flexicoking Technology" by D. E. Allen, W. J. Metrailler, S. Wiechert, and R. C. King.

The viewgraphs shown by F. X. Mayer are reproduced in Tables 10-23 and Figs, 13-27.

CONCLUSIONS

The presentations at SUNEDCO in Dallas provided an excellent overview of some of the current issues relating to heavy oil recovery. Members of FERWG will return to this topic during the annual EOR review (July 28-30, Sheraton Plaza Hotel, San Francisco, CA).

AB-5

Tables and Figures Reproduced
from Viewgraphs Presented
at SUNEDCO Discussions

FOSSIL ENERGY RESEARCH WORKING GROUP-IIIA (1981)

Heavy Oil Recovery

Dallas, June 12, 1981

Agenda

8:30	-	Coffee
9:00	-	Welcome and Introductions, F. Camp
9:15	-	Overview: EOR/Heavy Oil Recovery E. W. Malmberg Sun Production Company
10:00	-	Early Experiments in Recovery of South Texas Tar Sands B. G. Holmes Mobil Production Research
11:00	-	Current Tests in Recovery of South Texas Tar Sands E. L. Oshlo Conoco
11:45	-	Lunch (Catered)
12:30	-	Downhole Steam Generator Rod Eson Chemical Oil Recovery Co.
	-	Heavy Oil Recovery Jon Fitch Chemical Oil Recovery Co.
2:00	-	Heavy Oil Upgrading F. X. Mayer Exxon Research & Development Laboratory
3:00	-	FERWG Business Meeting S. S. Penner Chairman, FERWG-IIIA

CURRENT PROBLEMS

MOBILITY MATCH

WATER SOURCES

IMPROVED RESERVOIR CONFORMANCE

UNDERSTANDING OF OIL PROPERTIES - GEOCHEMISTRY

ECONOMICS - TIME SCALE

Table 3
HEAVY OIL/CARBON DIOXIDE

CHARACTERISTICS**APPROACHES**

SWELLING OF OIL

CYCLE

REDUCTION OF VISCOSITY

DRIVE

INPUT OF ENERGY

NO EXPECTATION OF MISCIBILITY EFFECTS

EXAMPLES

1. DOCHESTER GAS - KRAMER FIELD - ORANGE CO., CALIF. 20° API

CYCLE - TERMINATED - UNECONOMIC; \$3.41/MCF FOR CO₂.

2. AMINOIL - HUNTINGTON BEACH FIELD 18° API

CYCLE; ANTICIPATE 10 MCF/BBL YIELD.

3. PHILLIPS - LICK CREEK FIELD, ARKANSAS 17° API

SEQUENCE: CYCLE - CO₂ DRIVE - WAG - WATER DRIVE.

OOIP 23.3 MM BBLs.

PRIMARY PLUS WEAK WATER DRIVE 4.5 MM BBLs.

TOTAL FROM CO₂ PHASE 3.7 MM BBLs.

INCREMENTAL CO₂ 3.1 MM BBLs.

ROUGHLY 13% OOIP → CONFORMANCE.

HEAVY OIL/CAUSTIC FLOODING**WILMINGTON FIELD - EXPERIMENTAL STUDIES**

15-20° API OIL; ACID NUMBER 2.5; 90 CPS.

CAUSTIC FLOOD ONLY - EXTREME FINGERING

**CAUSTIC PLUS POLYMER - IMPROVEMENT WHEN
MOBILITY MATCH IS ACHIEVED.**

WATER PROBLEM.

CURRENT WORK

- SAME CONFORMANCE/MOBILITY PROBLEM,
BUT PUT POLYMER IN CAUSTIC, RECOVERY
IS DECREASED.

**BEHAVIOR IN 1% NaCl CONTRARY TO
GENERALIZATIONS.**

INTERFACIAL TENSION STUDIES - VERY COMPLEX

STEAM INJECTION

DRIVE: STEAM OVER-RIDING, BREAKTHROUGH.
SUPRI PROJECT: SUNTECH IV.

IN SITU COMBUSTION: SUN HAD 4 PROJECTS CLASSIFIED AS
"SUCCESSFUL" ON REVIEW-PRIOR TO 1973.
NONE ARE BEING CONTINUED.

POTENTIAL INTEREST: OXYGEN OFFSTREAM FROM NITROGEN INJECTION
PROJECTS. FORDOCHE FIELD.
ARCO PROJECT NORTH CENTRAL TEXAS.

Table 6

ENHANCED RECOVERY METHODS FOR HEAVY OIL**THERMAL****STEAM****IN SITU COMBUSTION****CAUSTIC FLOODING****CARBON DIOXIDE****CURRENT PROBLEMS**

Table 7

SANER RANCH FIREFLOOD TESTSAN MIGUEL SAND

1964 - 1968

. THE FIREFLOODING PROCESS

. SANER RANCH LOCATION

. RESERVOIR CHARACTERISTICS

. THE PILOT TEST

. PRODUCED OIL CHARACTER

. FINAL RESTRAINTS

Table 8

SANER RANCH - SAN MIGUEL SAND CHARACTERISTICS

MASSIVE ZAVALLA SYNCLINE	
NET PAY, FT	- 32.5
ORIGINAL OIL SATURATION, %	- 50.0
VIRGIN OIL VISCOSITY, CP	- UNDETERMINED (HIGH)
RESERVOIR PRESSURE, PSI	- 1100.0
PERMEABILITY, MD	- 1000.0
OIL GRAVITY, °API	- 7.0
FUEL REQUIREMENT, BBLS/ACRE-FT	- 390.0
AIR REQUIREMENT, MM SCF/ACRE-FT	- 14.4
ORIGINAL RESERVOIR TEMPERATURE, °F	- 100.0
ESTIMATED RESERVOIR COMBUSTION TEMPERATURE, °F	- 1100.0
POROSITY, %	- 30.0

Table 9

SANER RANCH PRODUCED OIL CHARACTERISTICS

GRAVITY, °API	-	8 - 11
SULFUR, WT %	-	8 - 9
NITROGEN, WT %	-	0.22
HYDROGEN, WT %	-	9.75
CCR, WT %	-	15 - 17
OLIENSIS SPOT	-	POSITIVE
THIN FILM OVEN LOSS, %	-	4.3
OIL VISCOSITY @ 60 °F, CP	-	1260

Fig. 1. MILLER & JONES TULSA SYMP. 1981

Fig. 3

Fig. 4 SANER RANCH

MAVERICK COUNTY, TEXAS

MAP 1

Fig. 5 SANER RANCH ISOPACHOUS MAP

GROSS SAN MIGUEL SAND

Maverick County, Texas

C.I. 10'

Fig. 6 INDUCTION-ELECTRIC LOG
SANER RANCH WELL NO. B-1

Fig. 7 SANER RANCH PILOT AREA

Fig. 8 SANER RANCH EVALUATION

SANER RANCH "B" LEASE
IN-SITU COMBUSTION PILOT

Fig. 9 CUMULATIVE OIL PRODUCTION
SANER RANCH PILOT AREA

Fig. 10 TEMPERATURE SURVEY
SANER RANCH WELL NO. B-2

Fig. 11 TEMPERATURE SURVEY
SANER RANCH WELL NO. B-5

Fig. 12 SANER RANCH WELL NO. B-8

Presentations by

F. X. Mayer

Exxon Research and Development Laboratories
P.O. Box 2226, Baton Rouge, Louisiana 70821
at Sunedco, Dallas, Texas
(June 12, 1981)

Table 10

SOME HEAVY FEED UPGRADING PROCESS OPTIONSCARBON REJECTION

FLUID COKING/FLEXICOKING
DELAYED COKING
DEASPHALTING

HYDROGEN ADDITION

HYDRODESULFURIZATION
HYDROCONVERSION

PROCESS COMBINATIONS

HYDROTREATING + COKING
HYDROTREATING + CATALYTIC CRACKING
DEASPHALTING + HYDRODESULFURIZATION

Table 11

PROPERTIES OF HEAVY CRUDE

	<u>JOB0</u>	<u>COLD LAKE</u>	<u>ATHABASCA BITUMEN</u>	<u>HVY. ARABIAN 1050°F+</u>
GRAVITY, °API	8	11	8	4
SULFUR, WT. %	3.9	4.5	4.5	5.3
NITROGEN, WT. %	0.7	0.7	0.4	0.4
METALS, V + Ni, PPM	560	250	270	230
ASPHALTENES, WT. %	18	18	20	25
CARBON/HYDROGEN	8.0	8.0	8.1	
1050°F+, VOL. ON CRUDE	48	42	45	27

Table 12

HYDROPROCESSING FOR HEAVY FEED UPGRADING

<u>TECHNOLOGY</u>	<u>TECHNOLOGY FEATURES</u>	<u>COMMENT</u>
LC-FINING/LUMMUS H-OIL/HRI	GAS/LIQUID EXPANDED BED	80-90% CONVERSION CLAIMED
CHIYODA	FIXED BED HDS + DEASPHALTING WITH ASPHALTENE RECYCLE	
BUNKER FLOW/SHELL	MOVING BED HDS, DEMET	MARUZEN PROTOTYPE BEING DESIGNED
RESIDUUM HDS/GULF, CHEVRON, UNION, UOP, EXXON, IFP	FIXED BED RESIDUUM HDS	SOME 1050°F+ CON- VERSION OBTAINED. CAN BE COMBINED WITH OTHER TECHNOLOGY.
CANMET/EMR-CANADA	SLURRY REACTOR, Fe/COAL THROWAWAY ADDITIVE	HIGH 1050°F+ CON- VERSION CLAIMED
AURABON/UOP	DEMETALLIZATION IN SLURRY REACTOR WITH RECYCLE	VENEZUELAN DEMO. BEING DESIGNED
M-COKE/EXXON		HIGH CONVERSION OB- TAINED IN PILOT PLANTS

Fig. 13

WORLD RESIDUUM CONVERSION CAPACITY
1980 AND ANTICIPATED BY MID 80'S
(VACUUM RESIDUUM PORTION OF FEED)

Fig. 14

FREE WORLD DISTRIBUTION
OF NET ADDED RESIDUUM CONVERSION CAPACITY

1980 - MID 80'S

(VACUUM RESIDUUM PORTION OF FEED)

Fig. 15

DESULFURIZATION ACTIVITY MAINTENANCE FOR RT-228
IS BETTER THAN FOR RT-2 AT HIGH TEMPERATURE

Fig. 16

RESIDFINING OF DEASPHALTED OIL

TEMPERATURE REQUIRED FOR CONSTANT DESULFURIZATION

Fig. 17

DEASPHALTING GIVES LOW YIELDS

Fig. 18

CONTAMINANT LEVEL IN DAO INCREASES
WITH INCREASING YIELD

Fig. 19

METALS LEVEL IN DAO INCREASES
WITH INCREASING YIELD

Table 13

SOLVENT DEASPHALTING/HYDROTREATING
OF MIDDLE EAST CRUDE

PROCESS	1000°F+ DEASPHALTING	RESIDFINING [®] OF DEASPHALTED OIL
PRODUCT	DEASPHALTED OIL	FEED TO CATA- LYTIC CRACKING
IBP CUT POINT (°F)	1000+	650+
YIELD ON VACUUM RESIDUUM (VOL. %)	77.9	76.3
GRAVITY (°API)	14.0	19.5
SULFUR (WT. %)	2.88	0.43
NITROGEN (WT. %)	0.31	0.20
CONRADSON CARBON RESIDUE (WT. %)	8.2	2.6
METALS (WPPM)		
NICKEL	7.3	0.07
VANADIUM	18.3	<0.01
CHEMICAL H ₂ CONSUMPTION (SCF/B)		525

Table 14

CATALYST IS IMPORTANT CONSIDERATION IN HYDROPROCESSING

- EXXON HAS DEVELOPED RT FAMILY OF PROPRIETARY CATALYSTS
- CATALYSTS FOR HDS AND HYDROCONVERSION
 - RT-2, RT-228, RT-621
 - GOOD ACTIVITY/ACTIVITY MAINTENANCE
- CATALYST SELECTION DEPENDS UPON FEEDSTOCK AND DESIRED CONVERSION
 - SMALL PORE CATALYST
 - LARGE PORE CATALYST

Fig. 20

CONVERSION ADVANTAGE MEASURED FOR RT-228

Table 15

LIGHT ARAB VACUUM RESIDUUM

RT-621 CATALYST, 92% HDS, HIGH CONVERSION OPERATION

<u>LIQUID PRODUCT FRACTION</u>	<u>PRODUCT QUALITIES⁽¹⁾</u>			
	<u>S (WT. %)</u>	<u>N (WT. %)</u>	<u>V/Ni (WPPM)</u>	<u>CCR (WT. %)</u>
C ₅ /650°F	0.03	0.03	--	--
650/1050°F	0.31	0.16	0.3/0.4	0.63
1050°F	0.94	0.24	9/9	17.8
<u>FEEDSTOCK FRACTION</u>				
650/1050°F	2.39	0.08	0.09/0.09	0.7
1050°F+	4.34	0.38	116/25	20.3

(1) QUALITIES REPRESENT AVERAGE-OF-RUN CONDITIONS.

Table 16

LIGHT ARAB ATMOSPHERIC RESIDUUM

RT-228 CATALYST, 94% HDS, HIGH CONVERSION OPERATION

<u>LIQUID PRODUCT FRACTION</u>	<u>PRODUCT QUALITIES⁽¹⁾</u>			
	<u>S (WT. %)</u>	<u>N (WT. %)</u>	<u>V/Ni (WPPM)</u>	<u>CCR (WT. %)</u>
C ₅ /650°F	0.03	0.02	--	--
650/1050°F	0.05	0.04	0.16/0.20	0.2
1050°F+	2.71	0.36	38/17	22.1
<u>FEEDSTOCK FRACTION</u>				
650/1050°F	2.39	0.08	0.09/0.09	0.7
1050°F+	4.34	0.38	116/25	20.3

(1) QUALITIES REPRESENT END-OF-RUN CONDITIONS.

Table 17

HEAVY ARABIAN VACUUM RESIDUUM

NEW CATALYST, 93% HDS, HIGH CONVERSION OPERATION

<u>LIQUID PRODUCT FRACTION</u>	<u>PRODUCT QUALITIES⁽¹⁾</u>			
	<u>S (WT. %)</u>	<u>N (WT. %)</u>	<u>METALS V/Ni (WPPM)</u>	<u>CCR (WT. %)</u>
C ₅ /650°F	0.03	0.04	--	--
650/1050°F	0.24	0.15	0.1/0.4	0.45
1050°F+	0.82	0.27	25/18	12.6
<u>FEEDSTOCK FRACTION</u>				
650/1050°F	2.94	0.09	0.04/0.19	0.9
1050°F+	6.0	0.48	205/64	27.7

(1) QUALITIES REPRESENT START-OF-RUN CONDITIONS.

Fig. 21

SIMPLIFIED FLEXICOKING FLOW PLAN

Fig. 22

FLEXICOKING FOR HYDROGEN/SYNTHESIS GAS

Table 18
FLEXICOKING YIELDS

<u>FEED</u>	<u>HEAVY ARAB</u>		<u>ATHABASCA BITUMEN</u>
	<u>ATMOS. RESIDUUM</u>	<u>VACUUM RESIDUUM</u>	
<u>YIELDS ON FEED</u>			
C ₄ -, WT. %	8.5	12.3	7.6
NAPHTHA, LV%	11.1	14.5	17.9
DISTILLATE, LV%	25.6	18.0	23.4
GAS OIL, LV%	44.5	26.4	42.1
COKE GAS (STD. m ³ /m ³)	1000	2100	900

Table 19
FLEXICOKING QUALITIES

<u>FEED</u>	<u>HEAVY ARAB RESIDUUM</u> <u>ATMOS.</u>	<u>VACUUM</u>	<u>ATHABASCA</u> <u>BITUMEN</u>
<u>NAPHTHA</u>			
CUT RANGE, °CVT	----C ₅ /177----		C ₅ /221
SULFUR, WT. %	0.9	1.1	2.2
NITROGEN, WPPM	40	70	60
<u>DISTILLATE</u>			
CUT RANGE, °CVT	----177/343----		221/343
SULFUR, WT. %	2.8	3.4	3.2
NITROGEN, WPPM	690	950	800
<u>GAS OIL</u>			
CUT RANGE, °CVT	-----343/510-----		
SULFUR, WT. %	4.4	5.8	4.5
NITROGEN, WT. %	0.28	0.46	0.26
CONRADSON CARBON	2.5	4.8	1.8
Ni + V, WPPM	0.8	1.7	0.9

Table 20

ENGINEERING STUDIES ILLUSTRATE ATTRACTIVE TECHNICAL FEATURES OF DUAL GASIFICATION			
	FLEXICOKER TYPE		
	CONVENTIONAL	DUAL GASIFICATION	
REACTOR FRESH FEED, M ³ /HR	_____	345	_____
FEED CON CARBON, WT. %	_____	20.5	_____
GROSS COKE, KG/HR	_____	9.5 x 10 ⁴	_____
% COKE GASIFIED BY AIR	}	95	70
% COKE GASIFIED BY STEAM			25
LOW BTU GAS RATE	BASE		0.8 BASE
TOTAL HEAT LEAVING WITH LOW BTU GAS	BASE		0.6 BASE
HYDROGEN PRODUCED	NONE		~TWICE COKER HYDROTREATING REQUIREMENTS

Fig. 23

Table 21

SMALL INTERPARTICLE DISTANCE KEY FACTOR IN M-COKE CATALYSIS				
<u>PROCESS</u>	<u>VOL.% CAT IN REACTOR</u>	<u>CATALYST SIZE</u>	<u>NO. PARTICLES PER CM³ OIL</u>	<u>DISTANCE BETWEEN PARTICLES, CM</u>
M-COKE	0.5-1.0	1-3 MICRONS	10^8-10^{10}	~ 0.001
EXPANDED BED	~ 50	$\sim 1/32$ IN.	~ 350	~ 0.060

Table 22

M-COKE (MICROMETALLIC COKE) CATALYSTS KEY TO PROCESS		
FEED	+ METAL COMPOUND (OIL SOLUBLE) OR DISPERSIBLE)	$\xrightarrow[\text{H}_2 + \text{H}_2\text{S}]{427+^{\circ}\text{C}}$ M-COKE (DISPERSED IN REACTOR OIL)
<ul style="list-style-type: none"> ● MICRON SIZED PARTICLES (1-3 MICRONS) ● TRACE QUANTITIES SUFFICE (WPPM METAL ON FEED RANGE) ● PARTICLES COMPRISE METAL SULFIDE IN CARBONACEOUS MATRIX ● NUMEROUS METALS CAN BE USED (Ni, Co, Fe, Mn, W, Mo, Ti, Cu, Cr, V) 		

Fig. 24

Fig. 25

Table 23

M-COKE GIVES HIGH YIELD OF LIQUID PRODUCTS			
● CONTINUOUS UNIT DATA			
● OPERATION AT 90-92% 566+°C CONVERSION			
FEEDSTOCK:		<u>TOPPED COLD LAKE</u>	<u>ARAB VACUUM RESID</u>
<u>YIELDS, VOL.% ON FRESH FEED</u>			
TOTAL C ₄ + LIQUID		104.7	105.8
C ₄ -566°C LIQUID		99.5	98.1
C ₅ -188°C NAPHTHA		28.9	22.5
188°C-343°C DISTILLATE		47.8	35.4

Fig. 26

Fig. 27

AB-5

Appendix I

PRESENTATION TO THE INTERSTATE

OIL COMPACT COMMISSION

Tar Sands Subcommittee

Casper, Wyoming

June 28, 1981

by

Eric L. Oshlo - Project Manager
Conoco Inc.

As far as true tar sands are concerned, most of today's activities have involved mining. Conoco has taken a different tack and utilized in-situ methods. As such, a great deal of interest has been generated by our South Texas Tar Sands Project ever since some of our activities and 1st pilot results have come to light. The project is located about 100 miles southwest of San Antonio, Texas in Maverick and Zavala counties. Our actual pilot locations are in extreme northeastern Maverick County about 30 miles northeast of Eagle Pass and the Mexican border.

Before I discuss what we have accomplished, it might be helpful to review the properties of the material with which we are dealing:

-2° API Gravity

10 wt% Sulfur

1 million centipoise reservoir viscosity

180° F. Pour Point

When you put all these properties together, you end up with a material like a stiff putty. At ambient conditions, it will exhibit some plastic flow properties if left uncontained. To the best of our knowledge this is the most dense and viscous hydrocarbon being produced anywhere in the world with in-situ methods.

We began working with this tar resource in the mid 1970's when we attempted a Huff and Puff operation. It quickly became obvious that cyclical stimulation would not work due to the reservoir's inability to readily accept an injected fluid or transmit pressure.

Our researchers then proposed a new process that is basically a blending of high pressure steam flooding and horizontal fracturing techniques. We called the process, Fracture Assisted Steamflood Technology, and in the best spirit for acronyms, promptly shortened that to "FAST". We put the FAST process to the test in our Street Ranch pilot starting in late 1977. It was a 5 acre 5 spot pattern which had a center injector, 4 corner producers and 2 observation wells.

The San Miguel-4 sand is about 1520 feet deep at the pilot location. It had about 40 feet of net pay and was interlaced with several impermeable lime streaks. Porosity and tar saturation

averaged 27% and 50%, respectively. The sand is very unconsolidated and permeability is about 1 darcy. The reservoir is split into two primary lobes by what we call the "Orange" dense streak. This is the only streak that we think covers a wide enough area to form an effective vertical flow barrier. Although the 4 Street Ranch production wells were perforated in both lobes, we concentrated our efforts in the upper lobe since the lower lobe was missing in the center injection well. Tar in place within the 5 acre fence line was around 204,000 barrels in both lobes.

Our goal was to produce 130,000 barrels from the pilot. We did quite a bit better - ultimately producing 169,000 barrels before shut down in June of 1980. Monthly average rates peaked at around 300 BPD in 1978. Production from February to June 1980 was attributable to water injection which was intended to scavenge residual reservoir heat. As a sidelight it is interesting to note that although the sand is very unconsolidated, we did not attempt any sand control and had no sand production problems.

Recovery of a material like this tar is obviously very energy intensive. Over the 26 month period, we injected 1.8 million barrels of steam and then 620,000 barrels of water; or for those of you that like ratios, 10.6 barrels of steam were injected per barrel of tar produced.

With a steam to oil ratio this high, the overall energy balance is important. We tracked our thermal efficiency by watching the ratio of the energy in the produced tar to the energy required to generate the steam. On a cumulative basis, about 1.6 BTU's of tar were produced for each BTU of fuel input. However, it is important to understand that no attempt was made in this pilot to optimize steam injection. By doing so, we believe we can improve our energy gain significantly.

Having seen all this production, the question was: "Where did it come from?" and "What did we actually accomplish?" During the summer of 1980, we drilled 8 post pilot core wells, seven within the pilot fence line, to try and answer these types of questions.

Core well No. 14 is inline with a producer and 75 feet from the injector. Log and core analysis showed recovery of up to 80% of the tar and significant coking of the residual tar at this location. The figure below shows initial saturation, residual saturation (broken into tar and coke), and saturation percentage recovered. The significant coking action is what we feel prevented sand production problems. The figure also illustrates the good vertical conformance we achieved.

SATURATION CHANGES BASED UPON LOG ANALYSIS IN JSR #14

Our initial tar saturation; as mentioned, averaged 48%, but averaged closer to 53% in the upper lobe.

Our residual saturations averaged 18% in the upper lobe and 23.5% overall. The small saturation change in the lower lobe was expected since no steam was injected below the dense streak.

All of this translates into recovery of 109,000 barrels from inside the pilot area; 90,000 barrels from the upper lobe and 19,000 barrels from the lower lobe.

The tar recovery contours in the upper lobe center around the injection well as would be expected. Also as expected from the low residual saturation point values and core well No. 14 results, we estimate recovery of up 90% of the tar-in-place near the injector.

As you can imagine, a great deal of discussion went into drawing a set of conclusions from all this information. Once the dust had settled, we came up with the following:

- (1) Of the 169,000 barrels produced, 109,000 or (65%) came from the 5 acre pilot area.
- (2) Of that, 90,000 came from the upper lobe and represented over 66% of the original tar-in-place in the upper lobe in the pilot area.
- (3) Total affected area in the upper lobe was 14 acres.
- (4) Total upper lobe recovery was 149,000 barrels, with only 19,000 being recovered from the lower lobe.
- (5) Upper lobe residual saturation with the pilot was as low as 5% at some points and averaged 18.4% overall.
- (6) The "Orange" dense streak, although not continuous, effectively stopped significant steam migration into, and tar recovery from, the lower lobe.
- (7) The observed in-situ coke deposition helps consolidate the sand and prevent sand production problems.
- (8) Tar recovery can be realized from below the fracture plane if vertical permeability exists.

That is what we accomplished in the Street Ranch pilot. Let's now turn our attention to the FAST process and how it works. The process, which was finally patented in May 1981, was developed as an operating theory first.

The steps start out with production well preparation. The producing wells are horizontally fractured through a notch and then steam stimulated to create a zone of fluid tar around the well bore. The entire interval is then perforated. The fractures are small enough to prevent communication between producers. The injector is then fractured into communication with each of the producers in order to create a flow path through the immobile tar. This frac is followed immediately with high rate steam injection at above frac pressure to float the fracture. Heat is transferred vertically and serves to mobilize the surrounding tar. As an example, injection rates at Street Ranch were about 3400 BPD. This high rate is continued until the entire area has been heated sufficiently to mobilize the tar. First production is seen during this step due to tar being swept from the fracture to the producers. After the reservoir has been preheated, matrix flow is established to displace as much tar as possible.

Once the FAST process began to prove itself in the field, we realized the need to reduce it to mathematics for a patent application and transfer to other reservoirs. The aim was to

define the steam injection rate in terms of acreage, reservoir thickness and the thermal efficiency of the reservoir heating process. Eventually it was reduced to:

$$Q = 1812 A/h \exp. (.02739 \times TE_{RH})$$

in English units for steam where:

Q = Steam injection rate in BSPD

A = Pilot area in acres

h = Reservoir height in feet

TE_{RH} = Reservoir heating thermal efficiency in %

In the patent, this has been broadened to cover fluids other than steam. The patent applies for all combinations of injected fluid, rate, acreage, and thickness where the thermal efficiency exceeds 40%. The 40% lower limit for a matrix type flood.

The primary application of FAST, we believe is in reservoirs that contain extremely viscous tar, or are thin enough that heat losses to the confining strata are a problem.

The primary requirements for applying FAST are competent confining strata to prevent fluid loss, and shallow enough depth to where frac pressure does not exceed the practical steam generator pressure limit of 2450 psig. Normally this is around 2300 feet.

We have been very encouraged by the performance of the FAST process and the Street Ranch pilot. However, we still feel that confirmation of our results is only one of several technical hurdles to be cleared before a commercial operation can be considered.

We intend to prove that our results were skill and not luck in our new Saner Ranch pilot. It is a $7\frac{1}{2}$ acre inverted 7 spot pattern with 6 observation wells. The surface facilities are much more complex than in the first pilot. For example, separate separation trains have been provided for each well and much more elaborate instrumentation has been installed. The facilities have also been located away from the well pattern to examine steam quality losses and other steam transmission factors. Construction has been completed and steam stimulation is underway.

A second major hurdle is to improve our Thermal Ratio or demonstrate the ability to produce large volumes of steam cheaply. Generating cheap steam usually means the use of solid fuels. Recent articles have discussed the use of fluidized bed combustion to generate steam in the oil patch from high sulfur low quality coals. One of the primary advantages of FBC technology is the ability to use high sulfur fuels without requiring stack gas scrubbing. Also the lowered combustion

temperatures avoid ash fusion problems with low quality fuels.

Last year Conoco contracted with Struthers Thermo-flood to design and fabricate a 50 MMBTU/hr. fluidized bed combustion utilizing technology by Battelle Institute. Fabrication is complete and erection at the site is underway. We plan to start it up in September.

The third major hurdle to commercialization that we see is upgrading. What do you do with this stuff after you get it in the tank? We are looking at a range of alternatives but I will not try to discuss them here. Upgrading technology is a separate subject all its own.

As you can see, I feel we have an exciting and challenging project on our hands. Attempting to commercialize this activity will require enormous amounts of leadtime, capital and manpower. Unlike more conventional heavy oil activities, tar sands projects will compete with other synfuels projects for available capital and manpower. As such, I believe tar sands activities should be considered as being synfuels projects rather than any extension of heavy oil activities.

Ultimately, I feel the real hurdles are financial and not technical. I believe that government and industry officials who want to encourage tar sands activities can help the most, not

by obtaining grants and research dollars, but by using their influence to create the proper economic environment. An example is the current effort to have tar sands activities exempted from Windfall Profit taxation. This one single item could prevent commercialization of a project such as ours. We believe tar sands projects using in-situ recovery methods should be treated the same as those which use mining techniques: Our tar at -2° API gravity is after all actually heavier than the 7° - 8° API gravity tar being mined at Athabasca.

AB-6

FERWG PARTICIPATION AT THE
1981 ANNUAL HEAVY OIL/EOR CONTRACTOR
REPORTS - PROCEEDINGS
SHERATON-PALACE HOTEL, SAN FRANCISCO, CALIFORNIA
(July 28-30, 1981)

The following FERWG members attended the 1981 annual EOR Contractors' review meeting: S. W. Benson, J. Clardy, S. S. Penner, and R. P. Sieg; the following ex officio members also attended the conference: H. R. Anderson, F. Holzer, and A. E. Lewis. After the conclusion of the presentations, the FERWG representatives participated in an informal discussion of R&D needs in EOR organized by Gordon Dean (DOE/Oakland) and attended by the following other DOE/Oakland Fossil Energy Division staff members: A. Leighton, H. Lechtenberg, G. Peterson, G. Standley: J. H. Duerksen (Chevron/La Habra) represented L. Thrasher.

The discussions centered on a listing of 12 new efforts or increased activities with identified rankings in three categories, perceived needs, and the presumed government role. This listing was prepared by G. Dean and his colleagues and is reproduced in in Table 1. Supporting statements and a written description were supplied for each project area. The discussions relating to long-term R&D needs will now be summarized briefly.

HEAVY OIL R&D PROJECTS

While industrial priorities properly emphasize near-term returns on investment, which may only be secondarily affected by total resource recovery over the long term, governmental priorities must include considerations of long-term supply stability for the nation, employment levels, foreign trade balances, national security factors, etc. As the result, governmental R&D priorities will be consonant with company priorities over the

Table 1 Rankings of Heavy Oil R&D Projects, prepared by G. Dean et al (DOE/Oakland); H = high, M = medium, L = low.

Project	Rank	Need	Government Role
Steam additives	1	H	H
Down-hole steam generation	1	H	H
Alkaline flood	1	H	H
Horizontal holes	1	H	H
Formation particle dynamics	2	M	H
Front mapping	2	H/M	H
High temperature packers and insulation	2	H	H/M
<u>In situ</u> combustion	3	M	M
Flow properties	3	H/M	M
Steam quality measurement	3	M/L	M
O ₂ enriched steam drive	3	M	M
Advanced concepts	NA	NA	NA

long term but may differ significantly over the near term. Generally, fundamental research of generic character, that is applicable to a wide spectrum of technologies and resources, will provide preferred returns on federal investments. With these goals in mind, new R&D needs may be identified for current and developing technologies.

1. Steam Additives

The purpose of steam additives is to improve recovery efficiency with steam injection. Recovery efficiency will be improved if (a) greater sweep efficiency is achieved and (b) more oil is recovered from the swept volume. While flow models are available that have been serving as a basis for achieving increased recovery efficiency, each of the following fundamental areas of study needs substantial analysis and effort: (a) physicochemical studies (including thermochemical and rate measurements) referring to interactions between steam, steam additives, and oil-bearing sands; (b) physicochemical studies involved in surface adsorption, desorption, and substitution; (c) effects of physical and chemical properties of fluid mixtures on flows through porous media; (d) the interplay between fluid-dynamic phenomena and physicochemical properties (density, viscosity, surface properties) in producing channeling and instabilities during flows through porous media; (e) phase separations in steam-additive-oil-sand mixtures as functions of temperature and pressure; (f) studies of the mechanisms and rates of gel deposition on injection with steam and additives and of the subsequent degradation of encapsulated foams.

2. Down-Hole Steam Generation

Each of the following R&D programs will contribute to better understanding and improved oil recovery in the long-term utilization of down-hole steam generators: (a) combustion research (including equipment changes, use of preheaters, recirculation, etc.) to allow direct utilization of oil-field crude in down-hole steam generation; (b) long-term environmental impact assessments (involving both gaseous effluents and residue stability) with down-hole steam generation; (c) quantitative studies on the efficacy of mixtures of steam and combustion products in enhancing oil recovery.

3. Alkaline Floods

The fundamental studies suggested by the use of alkaline floods for EOR are similar to those previously enumerated under Item 1, Steam Additives. Three subjects are of special interest for future study: (a) the in situ generation of surfactants to mobilize trapped oil and generate oil-in-water and/or water-in-oil emulsions; (b) the use of mobility control agents to improve recovery performance greatly; (c) the determination of caustic consumption/adsorption mechanisms and the prediction of resulting pH loss during an actual field flood.

4. Mine-Assisted Steam Injection

These studies relate especially to improved steam contact with the reservoir. The use of horizontal and/or deviated holes, tunnels, and other means of access will directly expose a substantially greater portion of the reservoir to injected steam or other process fluid. The problem of maintaining integrity against

collapse in holes that are horizontal or only slightly inclined is critical, especially until these are cased. Also, the design of configurations using optimum combinations of holes, tunnels, etc. for maximum oil recovery should be pursued.

5. Formation Particle Dynamics

In practice, the uncontrolled flow of spent sand may represent a serious impediment to achieving lasting output improvements. Fundamental problems relate to the flow of reacting fluids through porous media, constitutive equations for the original sand and for the spent sand, and the fluid dynamics of multiphase flows through porous media under defined pressure, temperature, and composition gradients. Problems of this type cannot now be modeled under controlled conditions and invite long-term investigations by competent scientists.

6. Thermal-Front Mapping

In each of our previous FERWG studies, we have emphasized the importance of developing well-calibrated instrumentation for needed in situ diagnostics to allow iterative comparisons between field measurements and computer models designed to describe the physical phenomena under study. EOR offers particular challenges in this respect because of the lack of homogeneity in relatively inaccessible reservoirs. The suggested uses of HFEM (High Frequency Electromagnetic) and CSAMT (Controlled Source Audio Magnetotelluric), as well as application of tracer techniques and other procedures, merit strong support. Priority should be given to measurements with good spacial resolution that have been carefully calibrated under well defined conditions and adequately tested in inhomogeneous media. A wide range of reservoir geometries and properties should be studied.

7. High Temperature Packers and Insulation Systems

The problem of effectively delivering heat from the surface to the formation using high quality steam demands innovative systems such as efficiently insulated tubing strings to deliver the steam to the well bottom with minimum heat loss and effective packers to prevent steam movement up to the well annulus. The high temperature environments under which packers and other downhole components must function for prolonged periods of time pose severe problems. Interactions between packers and tubulars under conditions of differential thermal expansion may cause early and frequent equipment failures.

8. In Situ Combustion

Fireflooding involves combustion processes in porous, multi-phase media that have not been adequately studied and are accordingly poorly understood. The wide spectrum of fundamental phenomena from exothermic oxidation reactions on porous beds, mass and heat transfer with mobilization of oil, and movement of the resulting multiphase mixtures through reservoirs represent a significant challenge to combustion scientists and reservoir modelers alike. A long-range, fundamental research effort in these fields merits substantial support if fireflooding is to become more than an empirical field effort for enhanced oil recovery.

9. Reservoir Properties Research

Although it is well known that most fluid rock properties are dependent on confining temperature and pressure, there are uncertainties as to what effects changes in temperature or pressure have on these properties. Fundamental research efforts in

these areas are needed because significant changes of properties will substantially affect evaluations of thermal recovery processes.

10. Steam Quality Measurements

While it should be relatively easy to develop techniques for characterizing steam quality at injection (e.g., by the use of multicolor infrared absorption measurements), the design of systems of this type for down-hole monitoring (e.g., through the use of fiber-optical systems) represents an interesting challenge. In general, a separate allocation is appropriate for DOE research funds to assist in the development of needed instrumentation.

11. Oxygen-Enriched Thermal Recovery

Work with oxygen-enriched air represents an obvious and important special case of studies to achieve enhanced oil recovery.

12. Advanced Concepts

In a field as poorly understood, as empirically based, and as practically important as EOR, there must be room for innovation. The remaining total resource is sufficiently large to justify long-term studies without specified constraints other than that competent people should concentrate their research efforts to achieve improved recovery under environmentally acceptable conditions.

13. Comments on Environmental Constraints in Oil Recovery from Heavy Oil Sources

James F. Norton of the Radian Corporation discussed environmental constraints to thermally enhanced oil recovery (TEOR). The discussion was, in principle, nationwide but actually dealt only with the Kern County, CA area in detail because environmental issues are most sharply drawn there. The EPA, California Air Resources Board, and County agencies all set standards for SO_2 , NO_x , particulate matter, and hydrocarbon emissions. Current control technology adds about \$0.5-1.0/B for SO_2 and \$0.5/B for NO_x controls. The technology used involves air scrubbers for surface steam boilers. These seem to work well but there is a supply problem because most of the equipment for control technology is fabricated for commercial boilers and is too large for existing steam boilers. If current air standards are violated, which Norton believes is a likely occurrence, and all boilers must be retrofitted with the best available control technology, the estimated cost will be \$6-9/B. There is an additional problem resulting from sludge generation by existing controls, which will exhaust the locally available disposal areas within a few years. Disposal of scrubber sludge is the largest cost item in SO_2 control. Using a highly optimistic set of assumptions, Norton predicted a factor of two increase in TEOR in the Kern County area, without violating current air quality standards. However, he emphasized that difficulties associated with permitting requirements, offsets and commercial availability of control technology made no increase in TEOR a more realistic prediction for the future.

The level of technical understanding in this study appeared to be incomplete. Thus, Norton did not foresee a significant environmental impact of downhole steam generators. Based on work at the Sandia Laboratory, this statement is not true because air emissions are actually substantially reduced.

There is a need for environmental evaluations of impacts associated with use of the next generation of recovery and technology.

AB-7

FERWG SITE VISITS TO
AOSTRA (EDMONTON, CANADA), SHELL IN SITU RECOVERY
(PEACE RIVER, CANADA), AND SYNCRUDE AND
SUNCOR (FORT MC MURRAY, CANADA) TO DISCUSS
OIL RECOVERY FROM TAR SANDS
(August 4-6, 1981)

The following FERWG members, ex officio members and guests participated in the discussions and site visits: H. R. Anderson, S. W. Benson, J. Clardy, E. L. Cook (Mobil, for P. Weisz), J. Deutch, A. Holzer, J. M. Hopkins, A. E. Kelley, L. C. Marchant (DOE/Laramie), A. G. Oblad, S. S. Penner, K. Phillips (Rand Corp.), R. Roberts, R. P. Sieg, J. P. Watson (DOE/Washington); J. Hopkins accompanied the group to Syncrude and Suncor while K. Phillips did not participate in these site visits.

1. Discussions at AOSTRA, Edmonton (August 4, 1981)

The presentations and discussions held at AOSTRA are summarized in Table 1. Copies of the viewgraphs used during the AOSTRA presentations are reproduced in Appendix I. A good overview of AOSTRA activities is given in the "Fifth Annual Report and Five-Year Review" of the Alberta Oil Sands Technology and Research Authority, AOSTRA, Edmonton, 1981.

Reference to Appendix I shows that the following principal topics were discussed: roles of the provincial and dominion governments in the commercial developments of oil recovery from tar sands; supporting R&D in provincial and university laboratories; recovery technologies; Athabasca resources; how to proceed from bench-scale tests through the initial and prototype pilot stages to a commercial plant; drilling patterns

Table 1

DISCUSSIONS AT AOSTRA (EDMONTON)
 HEAVY OIL/OIL SAND PROGRAM
 FOSSIL ENERGY RESEARCH WORKING GROUP (FERWG)
 AUGUST 4, 1981

Held at: Alberta Oil Sands Technology & Research
 Authority
 5th Floor, Highfield Place
 10010 - 106 Street
 Edmonton

9:00 - 9:15 INTRODUCTIONS

AOSTRA - C. W. Bowman
 Department of the Environment - J. Defir
 Northeast Commissioner - R. V. Henning
 Energy Resources Conservation Board - R. Evans
 FERWG - S. S. Penner

9:15 - 9:30 AOSTRA PRINCIPLES - C. W. Bowman

9:30 - 9:40 RESOURCE BASE - M. A. Carrigy

9:40 - 10:00 IN SITU PROJECTS - R. S. Phillips

10:00 - 10:20 EXTRACTION & UPGRADING - L. R. Turner

10:20 - 10:40 UNIVERSITY PROGRAMS - L. G. Hepler

10:40 - 11:00 ROLE OF ENERGY RESOURCES CONSERVATION
 BOARD - R. Evans

11:00 - 11:20 ROLE OF NORTHEAST COMMISSIONERS OFFICE -
 R. V. Henning

11:20 - 11:40 ROLE OF ALBERTA DEPT. OF THE ENVIRONMENT -
 J. Defir

11:40 - 12:15 DISCUSSION PERIOD

12:15 - 1:30 Sandwich Lunch

1:30 p.m. DEPART FOR ALBERTA RESEARCH COUNCIL
 (L. G. Helper accompanied the group)

and procedures for in situ recovery and current in situ pilot operations; AOSTRA financial and R&D support for ongoing programs and AOSTRA data base management system; oil recovery from near-surface deposits, including mining, bitumen extraction, upgrading treatment of tailings and the use of wastewater ponds; environmental and socio-economic problems in resource exploitation.

The discussions at AOSTRA were followed by a visit to the laboratories of the Alberta Research Council, where basic supporting research is in progress on all aspects of tar-sand mining, oil extraction, upgrading, and waste disposal.

2. Visit to the In Situ Operations at Peace River (August 5, 1981)

Rick Lea, project coordinator for Shell Canada Resources Ltd. (which is the operator of the Peace River In-Situ Pilot Project and owns* 18.75% of the plant) presented a detailed and illuminating account of the activities at Peace River. Recovery is being achieved from depths between 500 and 700 ft. A complete description of designs, operations and performance achieved is summarized in Appendix II. Recovery is obtained by use of a repeating 7-spot injection and recovery pattern involving 24 recovery wells (of which 20 are actually in operation), 7 injection wells, and 12 observation wells for monitoring performance and the in situ recovery operations.

Examination of representative field data obtained provides unambiguous evidence of extensive heterogeneities in the underground deposits. For example, recovery of 1600 BPD through

*The remaining holdings in the Peace River pilot are distributed as follows: Shell Explorer Ltd., 18.75%; Amoco Canada Petroleum Co., 12.5%; AOSTRA, 50%.

20 wells corresponds to an average of 80 BPD while actually occurring flows varied from a minimum of near zero BPD to a maximum of ~450 BPD. Important design details may be found in Appendix III.

Plant operation is centrally controlled and monitored. A real-time data link provides direct inputs to the Shell analysis group in Calgary (Ian Henderson, Director) where reservoir models are compared with in situ data outputs that are then used to refine and improve the physical inputs for modeling of the Peace River in situ operations. The pilot plant is being used to develop improved understanding of in situ recovery processes, as is evidenced by the stress on monitoring field performance and relating the results to reservoir modeling under steam-flow conditions.

3. Visits to the Commercial Operations at Syncrude and Suncor in Ft. Mc Murray (August 5, 1981)

Both the Syncrude (designed for production of ~125,000 BPD) and Suncor (currently designed for ~45,000 BPD and soon to increase by 13,000 BPD) plants utilize the extraction procedures pioneered and developed by the Canadian subsidiary of the Sun Oil Corp., which now bears the name of Suncor.

Extensive site visits and discussions with operators at both plants indicate that the initially troublesome surface-mining operations are now being performed successfully. Year-round, twenty-four hours per day, mining of tar sands proceeds unless temperatures drop below -35°F. The wheel and bucket excavators have been provided with improved teeth so that normal operations may proceed for weeks before teeth replacements become necessary. Conveyor belts, which move the mined tar sands to the extraction units, can be mended within 2 or 3 days when they are torn. The large equipment used for the mining operations is commercially available from German or U.S. vendors.

FERWG did not view or discuss in detail the extraction and upgrading procedures used at Ft. Mc Murray. These techniques are, however, well known to specialists in these areas. The upgrading procedure used involves fluidcoking and produces large amounts of coke which contains about 9% of sulfur and is being stored since material of this type is not marketable. Sulfur is being produced by use of the commercial Klaus process and is sold to fertilizer manufacturers in the Orient.

The tailing ponds contain highly alkaline emulsions of bitumens which settle out very slowly (settling times are estimated to be of the order of decades) and are highly toxic to birds. Birds are kept away by the use of scarecrows and (during migration) firing of chemical cannons. Approaches and concordant fatalities among birds are said to be rare ("four during the last season" for one of the large tailing ponds at Suncor, which adjoins the Athabasca River). Successful reconstitution of a tailing ponds has not yet been achieved but is scheduled within 10 to 15 years. The ponds are tight and control measurements have not indicated measurable leakage of toxic materials. The tailing ponds at Suncor will hold $30 \text{ to } 40 \times 10^6 \text{ B}$ of bitumen.* Economically acceptable recovery procedures for this valuable material remain to be developed. Methods for the dry recovery of tailings produced during bitumen recovery are under development but have not yet been found suitable for application.

It is possible that the long-term storage of large amounts of high-sulfur coke and of highly alkaline water emulsions of bitumen relates to the most troublesome aspects of oil recovery

* At a production rate of 10^5 BPD, a residue of 8% of bitumen in water for 350 stream days will produce $2.8 \times 10^6 \text{ B}$ of bitumen in water per year.

from tar sands as currently practiced in Alberta. Of these, the former can be readily eliminated by using improved hydro-treating techniques while the latter is likely to present a problem also in the utilization of Utah tar sands if low-temperature recovery is achieved in caustic water solutions. Alternatives such as direct retorting or solvent extraction of bitumen from tar sands involve harsher and probably more costly extraction procedures but will not require large wastewater tailing ponds. While the design and implementation of a commercially viable approach has been demonstrated at Syncrude and Suncor, the proper configuration for an optimal extraction procedure remains to be invented for the Alberta tar sands, as well as for tar sands in the U.S.

4. Government-Industry Cooperation

A persistent problem in governmental support of energy R&D concerns the principles that should govern cooperative R&D programs. On the one hand, the government seeks to strengthen the private incentive to develop, demonstrate, and adopt new technology. This objective points towards governmental R&D programs that permit patents, know-how, and potential future returns to remain entirely or largely with the private company partner. On the other hand, the government has an interest to recover for the benefit of the taxpayer a fair share of any future returns (technology or profit) that can reasonably be attributed to flow from the cooperative project. The appropriate balance between

these two objectives of federal energy R&D cooperative programs, to increase private incentive and to protect public equity, can be achieved through several alternative mechanisms. AOSTRA presents one interesting mechanism for achieving this balance that is presently not pursued in the U.S.

The AOSTRA model for technology development consists of the following principles: (a) 50/50 cost sharing with 50/50 management representation. (b) License free use of developed technology for major project participants and for minor project participants that may be admitted at 10% cost sharing. (c) Protection of technology developed. (d) Equal shares in licensing fees that may flow from the developed technology, with the commitment to make the technology (including pertinent company background technology) available on business-like terms. Thus, AOSTRA may be regarded as an organization that is primarily concerned with technology development and (joint) project management but is also as a venture capital firm.

The AOSTRA objectives do not differ from DOE objectives for tar sands technology development. Further, it can be argued that, in theory, DOE has a larger number of mechanisms and hence greater flexibility to carry out cooperative R&D projects. The major difference from the mechanisms presently employed by DOE is that the DOE Laboratories, Energy Technology Centers, or operations offices do not provide a practical opportunity to undertake a joint venture with industry where costs, technology, and future benefits are shared on a mutually agreeable basis. Over time, such an organization will not only stimulate a great deal of new technology and protect the taxpayers' legitimate interest, it can also accumulate important technical expertise.

The impressive feature of AOSTRA's program is the wide range of major concerns that have been willing to enter into cooperative projects. These firms include the Canadian companies of Shell, Amoco, Gulf, Union, Exxon, BP, Sun, etc. Some of

the U.S. counterparts of these companies have not been particularly willing to enter into cooperative technology development projects with DOE in the fossil area. AOSTRA could be an interesting model for DOE to consider in some areas of fossil energy, e.g. shale-oil recovery, if it intends to undertake a sustained technology development program (in contrast to a more costly demonstration or commercialization program). Within the DOE context, the AOSTRA model should not be viewed as requiring a new organization but rather as an example of a new mechanism that could be available for fossil technology development programs.

It is interesting to note that, in addition to cooperative projects with industry, AOSTRA has a small (\$6M/year) university program (including research projects, fellowships, and professorships) that is designed to support their long-range technology interests. Moreover, AOSTRA has successfully encouraged its industry partners to contribute 5% each of the cost of this university program. Such industry-government-university cooperative programs have not proven easy to establish in DOE.

Why has the DOE not adopted an AOSTRA mechanism for technology development? This question deserves attention. Even more importantly, it would be interesting to explore the use of the AOSTRA model as a step in the commercialization of synthetic fuels.

AB-7

Appendix I

COPIES OF VIEWGRAPHS USED AT

AOSTRA/FERWG

TECHNICAL DISCUSSIONS

August 4, 1981

Edmonton, Alberta

THE ALBERTA OIL SANDS TECHNOLOGY AND RESEARCH AUTHORITY

- **AN ALBERTA CROWN CORPORATION.**
- **DEVELOPMENT OF NEW TECHNOLOGY FOR:**
 - **OIL SANDS**
 - **HEAVY OIL**
 - **ENHANCED RECOVERY**
- **10 YEAR BUDGET (1975 - 1985) IS \$250 MILLION.**

AOSTRA METHOD

- **50/50 DEMONSTRATION
PROJECTS WITH INDUSTRY.**
- **UNIVERSITY SUPPORT:**
 - **RESEARCH CONTRACTS**
 - **PROFESSORSHIPS**
 - **SCHOLARSHIPS
& FELLOWSHIPS**
- **STRONG UNIVERSITY/INDUS-
TRY/GOVERNMENT LINKS.**
- **AOSTRA OWNS AND
CONTROLS TECHNOLOGY.**

- Inventors need protection
- Why support "free lunchers"
- Canada needs technology to trade
- On cost shared basis
- At fair market value on completion

TOTAL 1359×10^9 bbls

LIGHT OIL 33
HEAVY OIL 40
WABASCA 38
PEACE RIVER 64
COLD LAKE 160

DEVONIAN
CARBONATE
ROCKS 312

ATHABASCA 712

mounting frame

BITUMEN & HEAVY OIL RESERVOIRS IN ALBERTA

OIL SAND DEPOSITS CONTAINING BITUMEN

DEPOSIT

RESERVOIR

1. ATHABASCA

2. COLD LAKE

3. PEACE RIVER

4. WABASCA

SANDSTONE

5. GROS MONT

CARBONATE

TIMING AND COST OF BITUMEN DEVELOPMENT

Drilling Patterns

5 spot

7 spot

9 spot

LOCATIONS OF AOSTRA FIELD PILOTS

- HEAVY OIL
- OIL SANDS
- CARBONATE TREND
- AOSTRA FIELD PILOTS

BITUMEN IN-SITU PILOTS

LOCATION	OPERATOR	METHOD	SIZE
ATHABASCA	AMOCO	COMBUSTION	NINE 5 SPOTS
COLD LAKE	GULF	STEAM	HORIZONTAL WELLS
PEACE RIVER	B.P.	STEAM THEN COMBUSTION	FOUR 5 SPOTS
CARBONATE	SHELL	STEAM	SEVEN 7 SPOTS
	UNION OIL	STEAM	ONE 5 SPOT

HEAVY OIL PILOTS

LOCATION	OPERATOR	METHOD	SIZE
VIKING	PETRO CANADA	STEAM	TWO 5 SPOTS
KINSILLA	ALBERTA ENERGY	VS. COMBUSTION	ONE 5 SPOT
SUNHILD		COMBUSTION	

AOSTRA INPUT TO PILOTS

- **50% OF ALL COSTS.**
- **50% VOTE IN MANAGEMENT COMMITTEES.**
 - **STAFF**
 - **PROFESSORS AND SCIENTISTS**
 - **CONSULTANTS**
- **AOSTRA TECHNICAL REPRESENTATIVES.**

In Situ Projects

Project	Completion Date	AOSTRA Commitment \$ Millions	Costs To Date AOSTRA Share \$ Millions
<u>In Situ Oil Sands</u>			
Peace River - Shell	Dec. 31/85	63.0	48.4
Gregoire Lake - Amoco	Dec. 31/81	25.2	21.1
Marguerite Lake - BP	Dec. 31/85	36.9	8.9
Surmont - Numac/Gulf	Dec. 31/79	1.7	1.5
Advanced Steam - HBOG	Dec. 31/81	0.1	.04
Gulf Surmont - Gulf	Dec. 31/81	4.8	2.4
TOTAL		<u>131.7</u>	<u>82.34</u>

**Costs To Date
AOSTRA Share
\$ Millions**

**AOSTRA
Commitment
\$ Millions**

Completion Date

Project

Carbonate

**Buffalo Creek -
Union**

Dec. 31/81

9.3

6.6

Heavy Oil

**Kinsella -
Petro-Canada**

Dec. 31/81

9.5

6.5

Suffield - AEC

Dec. 31/85

5.0

2.1

**Pumping Study -
Pengalta**

June 30/82

0.1

.02

TOTAL

14.6

8.6

AOSTRA DATA BASE MANAGEMENT SYSTEM

- **PROVIDES FOR STORAGE AND RETRIEVAL OF PILOT DATA.**
- **PERMITS TRANSFER OF DATA TO THIRD PARTIES.**
- **GENERATES DATA PLOTS AND TABULAR REPORTS.**
- **PROVIDES DATA INPUT FOR MATHEMATICAL SIMULATIONS, ETC.**

CONSULTIVE PARTICIPANTS (C.P.)

- **THIRD PARTIES (C.P.) CAN GAIN ON-GOING ACCESS TO PROJECTS.**
- **C.P. IS SIMILAR TO INDUSTRY PARTNER**
 - **NO VOTING RIGHTS**
 - **CAN OFFER SUGGESTIONS TO PROJECT**
- **C.P. PAYS 10% OF CAPITAL & OPERATING COSTS.**

NEAR-SURFACE ATHABASCA DEPOSITS

MINING OVERBURDEN REMOVAL

CONCERNS

- 1. MINING COSTS, CAPITAL AND OPERATING, A MAJOR PORTION OF TOTAL PROJECT.**
- 2. OVERBURDEN REMOVAL CONTRIBUTES SIGNIFICANTLY TO HIGH MINING COST.**

GOALS

- 1. PRELIMINARY STUDIES INDICATE HYDRAULIC DREDGES MAY PROVIDE LOWER COST OVERBURDEN REMOVAL.**

ACTION

- 1. UNIVERSITY PROGRAM — GEOTECHNICAL PROPERTIES OF CLAY CONSTITUENTS.**
- 2. FUTURE RESEARCH — SUBJECT OF CONTINUING DISCUSSIONS WITH INDUSTRY AND DREDGING COMPANIES.**

VG - 3

NEAR-SURFACE ATHABASCA DEPOSITS

BITUMEN EXTRACTION AOSTRA'S MAJOR OBJECTIVES

- **REDUCE SIZE OF, OR, ELIMINATE
TAILINGS PONDS.**
- **INCREASE AMOUNT OF WATER
AVAILABLE FOR RECYCLE.**
- **REDUCE BITUMEN LOSSES TO
TAILINGS.**
- **IMPROVE BITUMEN RECOVERY
FROM LOW GRADE OIL SANDS —
WITH HIGH CLAY CONTENT.**

VG - 4

NEAR-SURFACE ATHABASCA DEPOSITS

CLARIFICATION OF TAILINGS

CONCERNS

- 1. CLAY FINES SUSPENDED IN TAILINGS.**
- 2. CONTINUOUS TAILINGS PONDS ENLARGEMENT.**
- 3. LARGE PONDS RENDER UNDERLYING OIL SANDS INACCESSIBLE.**
- 4. LARGE PONDS POSE ENVIRONMENTAL HAZARD.**
- 5. AMOUNT OF RECYCLED WATER RESTRICTED.**

GOALS

- 1. DEVELOP TECHNOLOGY TO REMOVE OR PROMOTE SETTLEMENT OF TAILINGS FINES.**
- 2. CLAY PRODUCT SHOULD BE WELL CONSOLIDATED.**
- 1. RECYCLED WATER SHOULD HAVE
< 3 — 5% SOLIDS.**

RETORTING - DRY DISTILLATION

CHARACTERISTICS OF RETORTING

- 1. EXTRACTION AND PRIMARY UPGRADING IN ONE OPERATION.**
- 2. DRY TAILINGS**
 - NO PONDS REQUIRED
 - NO BITUMEN LOSS TO TAILINGS
- 3. YIELDS INSENSITIVE TO FEED QUALITY.**
- 4. MAY BE ENERGY SELF-SUFFICIENT.**

PROCESSES INVESTIGATED

- 1. TACIUK PROCESSOR — UMATAC INDUSTRIAL PROCESSES LTD.—**
 - ROTARY KILN CONCEPT
 - ALL EXTRACTION — PRIMARY CONVERSION IN ONE VESSEL
 - LARGE PILOT OPERATION (6-8 TONS/HOUR) UNDERWAY SINCE 1978. WORK CONTINUES.
- 2. LURGI-RUHRGAS PROCESS — LURGI MINERALÖL-TECHNIK**
 - TECHNIQUE COMMERCIALIZED ON OTHER FEEDS
 - MORE EQUIPMENT REQUIRED
 - RESULTS OF PILOT TESTS BEING EVALUATED.

RAW BITUMEN TO USEABLE PETROLEUM PRODUCTS

AOSTRA'S MAJOR OBJECTIVES

- **INCREASE LIQUID YIELD.**
- **IMPROVE ENERGY EFFICIENCY.**
- **REDUCE ENVIRONMENTAL
IMPACT.**
- **PROCESSES THAT ARE ECONOMIC
OVER BROAD RANGE OF
CAPACITIES.**
- **MANUFACTURE OF
PETROCHEMICALS FROM
BITUMEN AND HEAVY OILS.**

VG - 12

RAW BITUMEN TO USEABLE PETROLEUM PRODUCTS

CONVERSION TO PETROCHEMICALS

- **CONVENTIONAL FEED FOR OLEFINS AND AROMATICS — ETHANE, NAPHTHA, IN FUTURE WILL BE SCARCE AND COSTLY.**
- **BITUMEN AND HEAVY OILS MAY BE CRACKED DIRECTLY TO YIELD PETROCHEMICALS.**
- **AOSTRA CARRIED OUT TESTS OF THE MITSUBISHI HEAVY OIL CRACKING PROCESS — WITH BITUMEN AND ALBERTA HEAVY CRUDES.**
- **PERFORMANCE AND PRODUCT YIELDS DETERMINED.**
- **COMPARATIVE EVALUATION MADE WITH CONVENTIONAL PROCESSES.**
- **OPPORTUNITIES FOR FURTHER RESEARCH BEING DEVELOPED.**

RAW BITUMEN TO USEABLE PETROLEUM PRODUCTS

HEAVY OIL UPGRADING PROGRAM

- **SEVERAL PROCESSES — NEW AND/OR IMPROVED,
OFFERED TO REPLACE COKING TECHNOLOGY
AND**
- **TO SATISFY ONE OR MORE OF AOSTRA'S
UPGRADING OBJECTIVES**
- **PERFORMANCE MUST BE DEMONSTRATED ON
LARGE SCALE BEFORE COMMERCIAL USE**
- **AOSTRA INVITED INDUSTRY PARTICIPATION
IN COMPREHENSIVE EVALUATION OF SEVERAL
PROCESSES**
- **GOAL — TO CONSTRUCT AND OPERATE
DEMONSTRATION PLANT FOR SELECTED
PROCESSES**

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THE ALBERTA OIL SANDS TECHNOLOGY AND RESEARCH AUTHORITY

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- **DEVELOPMENT OF NEW TECHNOLOGY FOR:**
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 - **SCHOLARSHIPS
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- Inventors need protection
- Why support "free lunchers"
- Canada needs technology to trade
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TOTAL 1359×10^9 bbls

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COLD LAKE 60

DEVONIAN
CARBONATE
ROCKS 312

ATHABASCA 712

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St. Paul, MN 55101 Made in USA

OIL SAND DEPOSITS CONTAINING BITUMEN

DEPOSIT RESERVOIR

1. ATHABASCA

2. COLD LAKE

3. PEACE RIVER

4. WABASCA

SANDSTONE

5. GROSMONT

CARBONATE

3M

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transparency
mounting frame

3M

TIMING AND COST OF BITUMEN DEVELOPMENT

Drilling Patterns

5 spot

7 spot

9 spot

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LOCATIONS OF AOSTRA FIELD PILOTS

no.

BITUMEN IN-SITU PILOTS

LOCATION
 MIDLAND
 ALBERTA
 CANADIAN

OPERATOR
 MIDCO
 SHELL
 SINOIL

METHOD
 COMBUSTION
 TEAM
 TEAM THEN
 COMBUSTION
 TEAM

SIZE
 NINE SPOTS
 HORIZONTAL WITH
 FOUR SPOTS
 SEVEN SPOTS
 ONE SPOT

HEAVY OIL PILOTS

LOCATION
 VIKING
 KANSAS
 SUNRISE

OPERATOR
 PETRO CANADA
 ALBERTA ENERGY

METHOD
 STEAM
 COMBUSTION
 COMBUSTION

SIZE
 TWO SPOTS
 ONE SPOT

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 assembly

3M

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mounting frame

AOSTRA INPUT TO PILOTS

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<u>Heavy Oil</u>			
Kinsella - Petro-Canada	Dec. 31/81	9.5	6.5
Suffield - AEC	Dec. 31/85	5.0	2.1
Pumping Study - Pengalta	June 30/82	0.1	.02
TOTAL		14.6	8.6

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Slide 9

AOSTRA DATA BASE MANAGEMENT SYSTEM

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- **PROVIDES DATA INPUT FOR MATHEMATICAL SIMULATIONS, ETC.**

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Slide # 45

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CONSULTIVE PARTICIPANTS (C.P.)

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VG - 2

NEAR-SURFACE ATHABASCA DEPOSITS

MINING OVERBURDEN REMOVAL

CONCERNS

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VG - 3

NEAR-SURFACE ATHABASCA DEPOSITS

BITUMEN EXTRACTION AOSTRA'S MAJOR OBJECTIVES

- **REDUCE SIZE OF, OR, ELIMINATE
TAILINGS PONDS.**
- **INCREASE AMOUNT OF WATER
AVAILABLE FOR RECYCLE.**
- **REDUCE BITUMEN LOSSES TO
TAILINGS.**
- **IMPROVE BITUMEN RECOVERY
FROM LOW GRADE OIL SANDS —
WITH HIGH CLAY CONTENT.**

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VG - 4

NEAR-SURFACE ATHABASCA DEPOSITS

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- 5. AMOUNT OF RECYCLED WATER RESTRICTED.**

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- 2. CLAY PRODUCT SHOULD BE WELL CONSOLIDATED.**
- 1. RECYCLED WATER SHOULD HAVE
< 3 — 5% SOLIDS.**

RETORTING - DRY DISTILLATION

CHARACTERISTICS OF RETORTING

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- 2. LURGI-RUHRGAS PROCESS — LURGI MINERALÖL-TECHNIK**
 - TECHNIQUE COMMERCIALIZED ON OTHER FEEDS
 - MORE EQUIPMENT REQUIRED
 - RESULTS OF PILOT TESTS BEING EVALUATED.

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VG - 8

RAW BITUMEN TO USEABLE PETROLEUM PRODUCTS

AOSTRA'S MAJOR OBJECTIVES

- **INCREASE LIQUID YIELD.**
- **IMPROVE ENERGY EFFICIENCY.**
- **REDUCE ENVIRONMENTAL IMPACT.**
- **PROCESSES THAT ARE ECONOMIC OVER BROAD RANGE OF CAPACITIES.**
- **MANUFACTURE OF PETROCHEMICALS FROM BITUMEN AND HEAVY OILS.**

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transparency
mounting frame

VG - 12

RAW BITUMEN TO USEABLE PETROLEUM PRODUCTS

CONVERSION TO PETROCHEMICALS

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- PERFORMANCE AND PRODUCT YIELDS DETERMINED.
- COMPARATIVE EVALUATION MADE WITH CONVENTIONAL PROCESSES.
- OPPORTUNITIES FOR FURTHER RESEARCH BEING DEVELOPED.

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VG - 13

RAW BITUMEN TO USEABLE PETROLEUM PRODUCTS

HEAVY OIL UPGRADING PROGRAM

- SEVERAL PROCESSES — NEW AND/OR IMPROVED,
OFFERED TO REPLACE COKING TECHNOLOGY
AND
- TO SATISFY ONE OR MORE OF AOSTRA'S
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- GOAL — TO CONSTRUCT AND OPERATE
DEMONSTRATION PLANT FOR SELECTED
PROCESSES

AB-7

Appendix II

PEACE RIVER IN-SITU PROJECT
FACTS AND FIGURES

SYNTHETIC OILS
SHELL CANADA RESOURCES LIMITED

PEACE RIVER IN-SITU PROJECTPRIMARY OBJECTIVE

ESTABLISH THE BASE DATA TO EVALUATE THE TECHNICAL AND ECONOMIC FEASIBILITY OF A FULL-SCALE STEAM DRIVE PROJECT FOR BITUMEN RECOVERY AT PEACE RIVER.

REQUIRED PARAMETERS ARE:

- BITUMEN RECOVERY EFFICIENCY.
- BITUMEN/STEAM RATIO.
- CHANGES WITH TIME:
 - . PRODUCTION RATES.
 - . WELL EFFLUENT CONSTITUENTS.
 - . BITUMEN PROPERTIES.
 - . EMULSION CHARACTERISTICS.
 - . FLUID TEMPERATURES.
 - . MECHANICAL REQUIREMENTS FOR OPERATING IN A HOT CORROSIVE ENVIRONMENT.

SECONDARY OBJECTIVES

1. MORE DETAILED UNDERSTANDING OF RESERVOIR MECHANISMS USING:
 - NUMERICAL SIMULATION
 - OBSERVED TEMPERATURE PROFILES
 - PRODUCTION RATES, PRESSURES
 - VAPOUR SATURATION DISTRIBUTION
 - CORRELATIONS WITH EARLIER PHYSICAL MODEL PREDICTIONS

2. MECHANICAL REQ'T FOR OPERATING STEAM WELLS AND OTHER EQUIPMENT AT HIGH TEMPERATURES:
 - CORROSION
 - WELL DESIGN
 - IPR OF HOT WELL INFLOW
 - WELL BORE IMPAIRMENT

3. REQ'T FOR SURFACE FACILITIES OPERATIONS:
 - PERFORMANCE OF HOT PRESSURIZED 3 Ø SEPARATORS-
 - EFFICIENCY OF INDUCED GAS FLOTATION CELL
 - ELECTRICAL DEHYDRATOR/DESALTER EFFICIENCY
 - OPERATION OF VERTICAL, HELICAL STEAM GENERATORS WITH BITUMEN FUEL.
 - FEASIBILITY OF RECYCLING PRODUCED WATER
 - EMULSION TREATING

4. OTHER:
 - CORRELATION OF SURFACE AND BOTTOM MEASUREMENTS.
 - THERMAL ALTERATION OF PRODUCED FLUIDS.
 - USE OF TRACERS IN RESERVOIR ANALYSIS
 - ENVIRONMENTAL IMPACT.

PRIOR FIELD TESTS/LABORATORY RESEARCH

FROM 1963 THROUGH 1974 FOUR SMALL SCALE, SHORT DURATION FIELD PILOT PROJECTS WERE CARRIED OUT BY SHELL IN PEACE RIVER. THESE PILOTS WERE DESIGNED TO, AND DID, GIVE BASIC DATA AND KNOWLEDGE WITH RESPECT TO ALTERNATE RECOVERY MECHANISMS. THESE DATA WERE INDICATIONS ONLY AND WERE, OF COURSE, SUBJECT TO SIGNIFICANT INTERPRETATION. THE INTERPRETATION WAS THAT A STEAM DRIVE MECHANISM OFFERED THE GREATEST CHANCE OF ECONOMIC SUCCESS. THIS DECISION WAS MADE IN LIGHT OF THE ACCUMULATED KNOWLEDGE OF STEAM INJECTION PROCESSES THAT HAD BEEN ACQUIRED FROM COMPARISONS OF THESE AND OTHER FIELD PILOTS WITH SCALED LABORATORY MODELS AND WITH ANALYTICAL MODELS.

THROUGHOUT THE ABOVE PERIOD, A CONCURRENT LABORATORY PROGRAM WAS CONDUCTED TO SUPPLEMENT AND FURTHER DEFINE AND UNDERSTAND RESULTS FROM THE FIELD TESTS. WITH THE BASIC DATA DERIVED FROM THE FIELD TESTS AS A STARTING BASIS, AN EXTENSIVE LABORATORY PROGRAM OF SCALED PHYSICAL MODEL EXPERIMENTS WAS UNDERTAKEN TO DEFINE THE MINIMUM SIZED PILOT TO YIELD RESULTS WHICH WOULD BE COMPARABLE TO A "COMMERCIAL" DEVELOPMENT PATTERN. ALSO, TO EXPLORE THE EFFECTS OF OPERATIONAL POLICIES ON THE BASIC PERFORMANCE AND ON THE EXTRA POLATION OF PILOT PERFORMANCE TO "COMMERCIAL" DEVELOPMENT. SOME OF THE AREAS INVESTIGATED WERE:

1. WELL SPACING
2. TYPE OF WELL PATTERN
3. NUMBER OF PATTERNS
4. WELL COMPLETION INTERVALS, ETC.
5. INJECTION/PRODUCTION SCHEDULES.

THIS LABORATORY PROGRAM RESULTED IN THE PRESSURE PULSE STEAM DRIVE AS DESCRIBED IN A PAPER BY DILLABOUGH AND PRATS, IE: CONVENTIONAL STEAM DRIVE FOLLOWED BY ONE OR TWO PRESSURE PULSES. AN ULTIMATE RECOVERY IN THE ORDER OF 50% OF THE ORIGINAL OIL IN PLACE WAS INDICATED FROM THESE INVESTIGATIONS.

A LABORATORY RESEARCH PROGRAM WILL CONTINUE THROUGHOUT THE LIFE OF THE PILOT TO INVESTIGATE AND CLARIFY FIELD PERFORMANCE.

FIGURE 1OIL SANDS DEPOSITS IN ALBERTA*

PEACE RIVER	90 BILLION BBLs.	1800 FT.
ATHABASCA	630 BILLION BBLs.	0-2000 FT.
WABASCA	50 BILLION BBLs.	800 FT.
COLD LAKE	150 BILLION BBLs.	1400 FT.

* CRUDE BITUMEN IN PLACE

OIL SANDS DEPOSITS IN ALTA.

FIGURE 1

FIGURE 2IN-SITU PILOT OVERALL LOCATION MAP

- A. PILOT SITE IS 20 AIR MILES EAST/NORTHEAST OF THE TOWN OF PEACE RIVER (POPULATION 5000).
- WELL PATTERN COVERS 50 ACRES.
 - PLANT OCCUPIES 15 ACRES.
- B. SOURCE WATER STATION AT OUTLET OF CADOTTE LAKE IS ABOUT 16 AIR MILES EAST OF THE PILOT.
- 27,500 B/D (800 GPM) AT 450 PSIG BY MEANS OF 3, 100 HP MULTI-STAGE PUMPS IN SERIES.
 - DESIGNED FOR UNATTENDED OPERATION.
 - SOURCE WATER PIPELINE, 16 MILES, 8" DIAMETER, INTERNALLY/EXTERNALLY COATED, ZAP-LOC DESIGN, 8 FOOT COVER.
- C. GAS SUPPLY TO PROJECT
- 4.2MM SCFD SWEET GAS FROM A SMALL GAS RESERVOIR (GAS CAP ABOVE BULLHEAD).
 - 2 WELLS WITH 4 MILES OF 6" DIAMETER SUPPLY LINE TO PLANT.
 - USED FOR FUEL, BLANKET GAS AND GAS LIFT.
 - OWNERSHIP EQUALLY SHARED BY RESOURCES AND EXPLORER; GAS SOLD TO PROJECT.
- D. WATER DISPOSAL SYSTEM
- 2 WELLS WITH 2 MILES OF 6" DIAMETER, COATED PIPELINE USED TO DISPOSE OF PRODUCED AND PLANT WASTE WATER TO THE MISSISSIPPIAN DEBOLT FORMATION (2200 FT), UNDERLYING THE TAR SAND (BULLHEAD) FORMATION.
 - CAPACITY OF 22,500 B/D (15,500 B/D PRODUCED WATER) AT 650 PSIG WELLHEAD PRESSURE.

E. POWER SUPPLY

- 14 MILE, 25 KV POLE LINE SUPPLYING 3000 KW TO PLANT WITH 16 MILE POLE LINE EXTENSIONS TO CADOTTE LAKE PUMP STATION.

F. NATIVE COMMUNITIES (MÉTIS)

- CADOTTE LAKE COMMUNITY OF 190 IS 2 MILES EAST OF SOURCE WATER STATION.
- LITTLE BUFFALO COMMUNITY OF 150 IS 12 MILES EAST OF CADOTTE LAKE.
- TOTAL LABOUR FORCE OF 55.
- 34 NATIVES UTILIZED DURING CONSTRUCTION.
- 6 NATIVES SPONSORED IN A DRILLING ROUSTABOUT TRAINING PROGRAM IN EDMONTON.
- 3 NATIVES TRAINED FOR 12 MONTHS AT SHELL'S FIELD PRODUCTION FACILITIES IN ALBERTA AND WILL JOIN THE PILOT OPERATING STAFF IN AUGUST 1979.
- ACREAGE FOR COMMUNITY GRAZING PASTURE HAS BEEN CLEARED BY PROVINCIAL GOVERNMENT IMMEDIATELY SOUTH OF PILOT GAS WELLS.

FIGURE 3RESERVOIR

THE 90 FOOT THICK OIL DEPOSIT IS IN THE BULLHEAD FORMATION WHICH OCCURS AT 1800 FEET FROM THE SURFACE. THE RELATIVELY THIN (9 FOOT) "WATER" ZONE AT THE BOTTOM OF THIS RESERVOIR WILL HELP PROMOTE INJECTION FLUIDS TO ENTER AND MOVE PREFERENTIALLY ALONG THE BOTTOM OF THE RESERVOIR. THE RECOVERY PROCESS CONSISTING OF CONVENTIONAL STEAM DRIVE, FOLLOWED BY PRESSURIZATION AND BLOWDOWN IS EXPECTED TO ACHIEVE RECOVERY OF UP TO 50% OF THE CRUDE BITUMEN IN PLACE.

FIGURE 3PEACE RIVER IN-SITU PILOTAVERAGE RESERVOIR DATA

<u>DEFINITION</u>	<u>VALUE</u>
TOTAL ZONE THICKNESS	27 M (90 FT.)
POROSITY (WGT. AVERAGE), %	28.4
BITUMEN SATURATION (WGT. AVERAGE), % PORE VOLUME	77
ORIGINAL FORMATION PRESSURE REFERENCED TO +175 FT. SUB-SEA	3660 KPA (530 PSIG)
ORIGINAL FORMATION TEMPERATURE	17°C (62°F)
BITUMEN GRAVITY, SP.GR. @ 15°C/15°C	1.0071 (9° API)
PERMEABILITY (ABSOLUTE TO BRINE), MD	440

AVERAGE STRESSED PETROPHYSICAL PARAMETERS

<u>ZONE</u>	<u>POROSITY, % BV</u>	<u>TAR SATURATION, % PV</u>	<u>BRINE PERMEABILITY, MD</u>	<u>THICKNESS, M (FT)</u>
OIL ZONE	27.4)	88)	120)	23 (74)
	28.9)	79)	212)	
	28.1) 28.4	74) 79	320)	
	30.0)	72)	1,227)	
BASAL "WATER" ZONE	)	)	) 1,440	2 (7)
	27.4)	54) 54	1,650)	3 (9)

FIELD

A. WELLS - FIGURE 4

THERE IS A COMBINATION OF STRAIGHT AND DEVIATED WELLS. THIS CONFIGURATION HAS PROVIDED SOME EXPERIENCE ON THE RELATIVE DIFFICULTY AND COST OF DIRECTIONAL DRILLING COMPARED TO STRAIGHT HOLES; OPERATING EXPERIENCE SHOULD GIVE A BASIS FOR ESTIMATING THE RELATIVE DIFFICULTY AND COST FROM AN OPERATIONS POINT-OF-VIEW. THESE DATA WILL BE USED IN DERIVING AN OPTIMUM "COMMERCIAL" PROJECT DESIGN.

SEVEN, 7 SPOT PATTERNS, 7 ACRES EACH.

PRODUCTION:	24	(2 DIRECTIONAL)
		<ul style="list-style-type: none">• 4 PERFORATED CONVENTIONAL STEEL LINER• 4 OPEN HOLE ALLOY LINER• 16 OPEN HOLE GRAVEL-PACK ALLOY LINER
INJECTION:	7	(6 DIRECTIONAL, MAXIMUM ANGLE 24°)
		<ul style="list-style-type: none">• PERFORATED COMPLETION
OBSERVATION:	12	<ul style="list-style-type: none">• 5 DUAL TEMPERATURE AND PRESSURE• 5 SINGLE TEMPERATURE)• 2 SINGLE PRESSURE OBS 8-800 FT EAST OF SITE USED IN 73/74 TEST AND R-3-19, 2 MILES WEST (R-3-19 NOT SUPPORTED BY AO STRA)
FUEL GAS:	2	
POTABLE WATER:	2	(ALSO SERVES AS STANDBY SYSTEM TO CADOTTE LAKE)
WATER DISPOSAL:	<u>2</u>	
TOTAL	49	

B. FIELD PIPINGPLOT PLAN - FIGURE 5

CONTROL OF PRODUCTION/INJECTION IS CENTRALIZED AT PLANT IN ORDER TO PROVIDE FLEXIBILITY (IE: DILUENT CAN BE ADDED ANYWHERE FROM PLANT INLET TO BOTTOM OF PRODUCING WELLS, WELLS CAN BE BEAM PUMPED OR GAS LIFT) AND TO PROVIDE MULTIPLE WELL TESTING (4 CONCURRENT).

ARRANGEMENT - FIGURE 6

THE FIELD GATHERING SYSTEM CONSISTS OF ONE CENTRAL SATELLITE STATION THROUGH WHICH THE OUTER SATELLITES FUNNEL ALL OUTGOING AND INCOMING FLUIDS.

FROM:

A. <u>PLANT TO SATELLITE NO. 1:</u>	11 LINES ABOVE GROUND IN INSULATED UTILIDOR.
B. <u>SATELLITE NO. 1 TO EACH OF:</u>	
• 7 INJECTOR WELLS:	2 LINES ABOVE GROUND
• 6 INNER PATTERN PRODUCTION WELLS:	2 MULTI-PURPOSE UNDER-GROUND LINES
• OTHER 3 SATELLITES:	5 MAIN SERVICE UNDER-GROUND LINES
C. <u>EACH OUTER SATELLITE TO RESPECTIVE PRODUCTION WELLS:</u>	2 MULTI-PURPOSE UNDER-GROUND LINES

APPROXIMATELY 8 MILES OF UNDERGROUND (4 FT COVER) LINES, WITH MAIN PRODUCTION/INJECTION LINES ENCASED IN CULVERTS FOR HEAT EXPANSION.

LEGEND

- SATELLITES
BATTERY
INJECTION WELLS -
 BOTTOM HOLE LOC.
INJECTION WELLS -
 SURFACE HOLE LOC.
PROD. WELLS -
 BOTTOM HOLE LOC.
PROD. WELLS -
 SURFACE HOLE LOC.
OBSERVATION WELLS

T - TEMPERATURE
 D - DUAL TEMP. & PRESS.
 P - PRESSURE
 30 WELL NUMBER

PEACE RIVER IN-SITU
 PILOT PROJECT
 FIELD PATTERN

FIGURE 4

FIGURE 5

PEACE RIVER IN-SITU PILOT PROJECT
INJECTION/PRODUCTION PIPELINE ARRANGEMENT

TOTAL = 10 MILES

FIGURE 6

PLANTFIGURE 7

CONSISTS OF WATER TREATMENT/STEAM GENERATION, TAR DEHYDRATION, DILUENT RECOVERY AND WATER DISPOSAL FACILITIES. IT INCLUDES THE OFFICE, LABORATORY, AND PLANT/FIELD COMPUTER CONTROL COMPLEX.

A. SOURCE WATER TREATMENT - FIGURE 8

800 GPM AT 100 PSIG PASS THROUGH SAND/ANTHRACITE FILTERS AND CARTRIDGE FILTERS AND THEN 600 GPM ARE SOFTENED BY 2 STAGE SODIUM ZEOLITE RESIN BEDS TO ACHIEVE A ZERO HARDNESS (LESS THAN 1 PPM) FOR BOILER FEED WATER. 200 GPM UNSOFTENED WATER IS FOR PLANT USE.

B. STEAM GENERATION - FIGURE 9

FOUR IDENTICAL BABCOCK & WILCOX M.E. VERTICAL COIL BOILERS ARE THE FIRST TO BE INSTALLED IN NORTH AMERICA (BUT PREVIOUSLY USED BY SHELL GROUP IN MARAVEN, VENEZUELA). THREE WILL SUPPLY UP TO 210,000 LB/HR. 2350 PSIG SATURATED STEAM FOR RESERVOIR INJECTION AND ONE WILL BE USED AT 550 PSIG FOR PROJECT UTILITY STEAM. THESE BOILERS WERE SELECTED BECAUSE THEY ARE ABLE TO UTILIZE LOW QUALITY BOILER FEED WATER, HAVE FAST START-UP CHARACTERISTICS, REQUIRE LESS SPACE AND CAN FIRE PRODUCED FUEL GAS, DILUENT OR TAR (2° API).

THE FLUE GAS FROM THE BOILERS WILL FLOW THROUGH A COMMON 280 FT HIGH STACK. MAXIMUM DISCHARGE OF SULPHUR WILL BE UP TO 14 LT/D (MAXIMUM 0.2 PPM SO_2 AT GROUND LEVEL).

C. TAR DEHYDRATION - FIGURE 10

FACILITIES INCLUDE PROVISIONS FOR SIMULTANEOUS:

1. INNER AND OUTER WELL PATTERN FLOW MEASUREMENTS VIA TWO FREE WATER KNOCKOUT VESSELS.
2. FOUR INDEPENDENT WELL FLOW MEASUREMENTS VIA FOUR TEST SEPARATORS.

C. TAR DEHYDRATION (CONTINUED) - FIGURE 10

TAR (WITH DILUENT) IS COMMINGLED AND GOES VIA ONE ELECTRIC DEHYDRATOR TO THE DILUENT RECOVERY UNIT (DRU).

PRODUCED SOUR GAS (1 MMSCF/D) IS USED FOR BLANKET GAS, GAS LIFT OR BURNED IN STEAM GENERATORS.

PRODUCED SOUR WATER (15,500 B/D) IS ROUTED TO WATER DISPOSAL SYSTEM.

D. DILUENT RECOVERY UNIT - FIGURE 11

THE MIXED PRODUCED TAR IS HEATED IN A SWEET-GAS-FIRED HEATER AND IS FRACTIONATED IN THE RECOVERY COLUMN INTO 3 LIQUIDS:

- DILUENT (30° API), 1900 B/D RECYCLED TO FIELD
- GAS OIL (15° API), ROUTED TO TANK FARM
- PITCH (2° API), ROUTED TO TANK FARM

THE DILUENT RECOVERY UNIT IS DESIGNED TO HANDLE A NET PRODUCTION OF 3500 B/D OF RAW TAR, ABOUT 55% OF WHICH IS EXPECTED TO BE AVAILABLE FOR SALE.

E. WATER DISPOSAL SYSTEM - FIGURE 12

PLANT WASTE WATER (7,000 B/D) AND RESERVOIR PRODUCED WATER (15,500 B/D) WILL BE PROCESSED VIA A GAS-ENTRAINED OIL FLOTATION CELL, FILTERED AND THEN INJECTED AT 900 PSIG INTO THE DEBOLT FORMATION (2200 FT.).

F. TANK FARM - FIGURE 13

TAR	-	65 M BBLS
GAS OIL	-	35 M BBLS
DILUTE TAR	-	10 M BBLS
PRODUCED WATER	-	10 M BBLS
DILUENT	-	5 M BBLS
SLOP	-	5 M BBLS

THESE INCLUDE A TANK - TRUCK LOADING/UNLOADING FACILITY.

PLANT PLOT PLAN

FIGURE 7

SOURCE WATER TREATMENT

FIGURE 8

STEAM GENERATION

FIGURE 9

DILUENT RECOVERY

FIGURE 11

WATER DISPOSAL

FIGURE 12

FIGURE 13

PROJECT DATA GATHERING NETWORKFIGURE 14

A TOTAL OF 12 OBSERVATION WELLS HAVE BEEN PROVIDED TO MONITOR THE PERFORMANCE WITHIN THE PILOT AREA AND TO MEASURE THE EFFECT ON THE SURROUNDING RESERVOIR. THE PARAMETERS MEASURED ARE TEMPERATURES AND PRESSURES AND ELECTRICAL LOGGING SURVEYS CAN BE CONDUCTED. THE PRODUCTION AND INJECTION WELLS ARE EQUIPPED WITH DOWNHOLE PRESSURE AND TEMPERATURE MONITORING DEVICES. THE INFORMATION FROM EACH WELL AND SATELLITE IS GATHERED FOR SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA). 550 POINTS TOTAL WILL BE LINKED TO THE CAO CENTRAL COMPUTER IN CALGARY.

THE PLANT PROCESS CONTROL IS ELECTRONIC HONEYWELL TDC 2000 MICRO-PROCESSOR CONTROL SYSTEM. IT HAS IN-PLANT DISPLAY/RECORDING/CONTROLLING FEATURES AND WILL BE CONNECTED TO THE CAO CENTRAL COMPUTER IN CALGARY.

THE PUMP STATION CONTROL IS ACHIEVED BY A SELF-CONTAINED MINI-COMPUTER CIRCUITRY WITH STATUS RELAYED TO THE PLANT CONTROL ROOM VIA UHF RADIO SIGNALS.

6/78

FIGURE 14

PROJECT STATUS

THE OVERALL CONSTRUCTION OF THE PROJECT IS COMPLETE AND THE OPERATING PHASE COMMENCED ON OCTOBER 31, 1979.

THE PROJECT IS CURRENTLY IN THE STEAM SOAK/STIMULATION PHASE OF THE PRODUCTION WELLS. FIFTEEN WELLS HAVE UNDERGONE HOT WATER/STEAM INJECTION AND ARE CURRENTLY BEING PRODUCED. HOT WATER/STEAM IS CURRENTLY BEING INJECTED IN THE REMAINING NINE WELLS.

STEAM DRIVE FROM THE INJECTION WELLS IS EXPECTED TO COMMENCE IN JANUARY 1981.

SOME PROBLEMS WERE EXPERIENCED WITH THE DISPOSAL WELLS; HOWEVER, CONTINGENCY PLANS WERE SUCCESSFUL IN IMPROVING THEIR PERFORMANCE.

OVERALL PILOT OPERATIONS ARE PROCEEDING ACCORDING TO THE PROGNOSIS, WITH RELATIVELY MINOR DEVIATIONS FOR CONTINGENCIES.

FURTHER LABORATORY TESTING WILL BE DONE TO CONFIRM THAT SPECIFICATION ASPHALT CAN BE MANUFACTURED FROM THE PRODUCED BITUMEN. IF THE SPECIFICATIONS CANNOT BE MET, THE PRODUCT NOT USED AS PLANT FUEL WILL BE TRUCKED TO MARKET AS HEAVY OIL.

PK/MJS
80-11-18

PEACE RIVER IN-SITU PROJECT OPERATIONS PROGNOSIS

1. COLD PRODUCTIVITY TESTS
 - SHORT TERM TEST
2. STEAM SOAK ALL PRODUCTION WELLS
 - 6-9-9 SEQUENCE
3. STEAM DRIVE
 - PROMOTE HEAT COMMUNICATION
4. BACK PRESSURE PRODUCTION WELLS
 - AFTER HEAT BREAKTHROUGH
5. CONTROLLED PRESSURE STEAM DRIVE
 - UNTIL STEAM BREAKTHROUGH
6. ONE OR MORE PRESSURE CYCLES
 - PRESSURE BUILD UP
 - BLOWDOWN
7. FINAL STAGE
 - GRAVITY DRAINAGE-NO STEAM
 - HEAT SCAVENGING
 - STRIPPER OPERATIONS

EXPECTED PILOT LIFE APPROXIMATELY 9 YEARS

JANUARY 1, 1980

PRODUCTION DEPARTMENT IN-SITU TAR SANDS PEACE RIVER PILOT PROJECT

IN-SITU TAR SANDS
DIVISION MANAGER

SENIOR STENOGRAPHER

GEOLOGICAL/
GENERAL
ENGINEERING

STAFF PET. ENG. 1

PRODUCTION/
RESERVOIR
ENGINEERING

SR. STAFF ENG. 1
STAFF RES. ENG. 2
ENG. MECH. 1
ENG. PET. 1
ENG. TECH. 2

COST CONTROL/
SCHEDULING
COST REPORTING

ANALYST 1
SR. CLERK 1

PROJECT
ENGINEERING

STAFF ENG. 1
STENOGRAPHER 1
CHEM. ENG. 1
MECH. ENG. 1
ENG. MECH. 1
ENG. TECH. 1

OPERATIONS STAFF

PROJECT
COORDINATOR

TECHNICAL
SERVICES

TECHNICAL SERVICES
COORDINATOR
PROD. ENG.
ENG. TECH. II CHEM.
ENG. TECH. II SCADA
ENG. TECH. II FAC.

OPERATIONS
/CRAFTS

TEAM COORDINATOR

ADMINISTRATIVE

STENO/RECEPTIONIST

AOSTRA
REPRESENTATIVE

D.H. SMITH

ENGINEERING
SPECIALISTS

AS REQUIRED

PURCHASING
AND
EXPEDITING

AS REQUIRED

WELL SERVICES

WELL SERVICES
COORDINATOR

STEAM PLANT
COORDINATOR

PLANNING/
TRAINING
COORDINATOR

CRAFT TEAM

INSTRUMENT
ACQUISITION

DATA

POWER
SYSTEM

ROTATING
EQUIPMENT

* OPERATING TEAMS

PLANT
FIELD/
OFF-
ICES

CRAFTS
LAB
WHSE

CLERK

TRASH

-1-2

CALGARY

20

PEACE RIVER

40

TOTAL

60

AB-349

PEACE RIVER IN SITU PROJECT OPERATING STAFF

4TH QTR. 1979
1980
1981

TOTAL STAFF-40

FULL SCALE PLANT MINIMUM TIMING PROJECTION

AB-8

U.S. TAR SAND OIL RECOVERY PROJECTS

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ABSTRACT

The increasing U. S. energy demands, decreasing conventional crude oil reserves, and decontrol of crude oil prices have resulted in significant numbers of projects in U. S. tar sands. Data are reported for 62 projects involving both in situ and mining and plant extraction technologies. The data include operator name, project location, project status (completed, current, or planned), project type (commercial, pilot, or research), reservoir and oil characteristics, and estimated product costs. The cost estimates per unit of produced oil provide encouragement for the commercialization of the U. S. tar sand resource.

INTRODUCTION

As the demand for energy in the United States increases and the reserves of conventional petroleum decrease, the interest in development of less conventional energy sources is increasing dramatically. This interest, plus the recent decontrol of crude oil prices, has resulted in widespread activities aimed at commercialization of the U. S. tar sand resource.

Although the U. S. currently has little commercial oil production from tar sand, considerable hope exists that in situ steam and combustion technologies, proven successful for heavy oils in California, as well as various mining and plant extraction processes, will lead to significant production from tar sand. Continued research and the field testing in 62 reported oil recovery projects (a majority, but not all field projects in U. S. tar sands) is providing the base of knowledge and experience for the economic exploitation of this energy resource. In many cases, the reported projects are in deposits or fields with less than 15.9 million m³ of oil-in-place; in all cases, the proposed or applied technologies are considered to be feasible for production rates of 1.59 thousand m³ of oil per day or less. Five projects in reservoirs containing oils with less than 10 Pa-s viscosity are included because the unique oil recovery methods are expected to be applicable to tar sands.

Cost data from several of the field projects indicate costs per cubic meter of produced oil in the \$100 to \$125 range. These data, primarily capital investments and operating costs, are still incomplete but do provide encouragement for commercial development.

The status of the reported projects include time (completed, current or planned) and type (commercial, pilot or research). Planned pilot and planned commercial status are nearly synonymous because nearly all commercial projects are preceded by successful pilots.

TAR SAND DEFINITION

Tar sand is defined here as any consolidated or unconsolidated rock (other than coal, oil shale, or gilsonite) that contains a hydrocarbonaceous material with a gas-free viscosity greater than 10 Pa-s at reservoir temperature. Additional terms synonymous with tar sand are bituminous sandstone, oil-impregnated rock, oil sand, and rock asphalt. Tar sand deposits are distinguishable from heavy oil deposits by differences in viscosity between the contained bitumen or oil. The tar sand bitumen viscosity is so great that commercial production is impossible by ordinary primary methods. On the other hand, heavy oil viscosity is sufficiently low to permit production but probably not at economic

rates. The United Nations Institute for Training and Research (UNITAR), the Interstate Oil Compact Commission (IOCC), and the American Petroleum Institute (API) have all recommended adoption of similar tar sand definitions.

U. S. TAR SAND RESOURCE

About 550 tar sand occurrences are known to exist in 22 of the United States (Figure 1)(Ball Assoc., 1965). Information on the majority of these deposits is very limited and therefore the resource estimate refers to only five states. The estimated resource in California, Kentucky, New Mexico, Texas, and Utah is 4 to 6 billion m^3 of oil-in-place in 43 evaluated deposits (Marchant, 1980). There are eleven known deposits that contain a resource of 15.9 million m^3 or more, leaving 500+ occurrences in the small deposit category. An estimated 15 per cent of the U. S. tar sand resource is at shallow enough depths to allow surface or strip mining. At present, development has been occurring in the large deposits, primarily in California, Texas, and Utah. Several states, including California (Hallmark, 1979), Kentucky (McGrain, 1976), Missouri (Wells, 1979), and Utah (Campbell & Ritzma, 1979), have published results of recent tar sand resource assessments. A number of the smaller deposits is now being investigated by private investors; the majority of the large deposits are either under lease to major companies or are presently included in unleaseable Federal acreage.

The tar-sand deposits involved in the reported projects possess a wide range of reservoir characteristics. Porosities are generally about 30 percent, but range from 17.5 to 35 percent. Permeabilities are also generally high, but range from 0.012 to 5.92 μm^2 . Oil saturations range up to 82 percent of pore space. Water saturations are reported as high as 65% in California reservoirs and generally less than 5% in the major Utah deposits. Reported oil gravities and viscosities range from 0.96 Mg/m^3 to about 1.12 Mg/m^3 and from 10 to over 2,000 Pa-s, respectively. Depths of overburden range to 975 m.

OIL RECOVERY PROJECTS

Figure 2 and Tables 1 and 2 identify 62 known field projects related to U.S. tar sands. Included are 40 in situ projects and 22 mining and plant extraction projects in 10 states. Two-thirds of the projects are in California and Utah and about one-fourth are in Kentucky and Texas.

In Situ Processes

The primary technical deterrent to production of oil from tar sand by in situ processes is the high oil viscosity and resultant immobility. In most (35 of 40) reported in situ oil-recovery projects, the viscosity reduction is accomplished by thermal processes using either steam or combustion. The several current commercial in situ projects in California are in reservoirs containing oils with viscosities of 10 Pa-s to 25 Pa-s, which are relatively low values for tar sands.

Steam - Most of the 25 steam projects utilize a steamdrive preceded by or in conjunction with cyclic steam injection. Several projects in California are classified as unconventional because they are, or will be, applied to reservoirs at depths greater than 760 m. Unique steam applications include co-injection with sodium hydroxide and carbon dioxide (SCOT), the HOPCO process, coal-fired fluidized-bed combustors for steam generation, and a downhole steam generator. The Cornell Heavy Oil Process Inc. (HOPCO) utilizes a 1.5 m diameter (ID) cased well terminating in a 7.62 m diameter cavern near the bottom of the reservoir from which horizontal production wells are drilled. The production wells also serve as steam injection wells during a reservoir preheating phase. After preheating, vertical wells drilled from the surface serve as steam-injection wells and the horizontal wells serve as producing wells. The downhole steam generator reported here was developed by the Sandia (New Mexico) National Laboratory under contract to the U. S. Department of Energy. Similar downhole steam generators are being developed by private industries. The current pilot is testing operations utilizing both air and oxygen. The downhole generator has two primary advantages over conventional steam generators: 1) it reduces heat losses in surface and well piping; and 2) it avoids air pollution and enhances steam effectiveness by injecting exhaust gases into the reservoir with the steam. The Conoco and Enpex projects in the Saner Ranch field in Texas include planned use of coal-fired fluidized-bed combustors to generate steam. The Conoco project includes a patented "Fracture Assisted Steam Technology (FAST)". At the Kirkwood project in Wyoming's Burnt Hollow deposit, the addition of sodium hydroxide will enhance the steam drive process. Reading & Bates and Rio Verde plan to accomplish the same enhancement in their Kentucky project by addition of carbon dioxide. The Signal Oil and Gas Co. tests in Utah's Sunnyside deposit were conducted in horizontal wells drilled into a quarry face. The Cornell Heavy Oil Process (HOPCO), Inc., and Department of Energy-Sandia National Laboratory projects are included because these technologies are expected to be applicable to tar sand oils.

Combustion - The majority of the ten in situ combustion projects utilize variations of the forward combustion process. The only reverse combustion applications were by Phillips Petroleum Co. in a completed pilot project in Missouri (Trantham, 1966) and by the U. S. Department of Energy's Laramie Energy Technology Center (LETC) in Utah. The LETC series of experiments has included reverse combustion (Land, 1977); combination reverse and forward combustion (Johnson, 1981); steamdrive (Johnson, 1981); and (scheduled for 1982) combination reverse combustion and steamdrive.

Other - The Illinois Institute of Technology Research Institute, under contract to the U. S. Department of Energy, is currently conducting a small scale field experiment in Utah to test the feasibility of in situ heating of tar sands with radio frequency (RF) electrical waves. As the RF heating is accomplished, production of the mobilized oil to a collection chamber occurs by gravity drainage. The Calvin Billings Co. has planned to produce heavy oil from the Bellevue field in Louisiana by application of the Frasch sulfur mining technology, which will involve solution of the heavy oil by a hot solvent. This project is also included because the process, which does not involve removal of rock from the reservoir,

should be applicable to tar sand. Tertiary Recovery Ltd. will enhance their wet combustion process in Texas by explosive fracturing ("Astrofrac") of the reservoir prior to ignition. In their completed combustion pilot in Kentucky, Gulf Oil Co. employed a propped induced fracture. The processes to be employed in four other projects, one each in Missouri and Texas and two in Utah, are not identified at this time.

Mining and Plant Extraction Processes

The commercial potential of tar sand by mining is a function of the ratio of overburden thickness to tar-sand thickness. Experience in the Canadian tar sands (the only current significant commercial tar sand surface mining operations) indicates that this ratio should not exceed one. It is estimated that only 15% of the U. S. resource has a ratio of one or less. Conventional underground mining is not considered feasible for tar sands, but various combinations of mining and in situ processes are being tested. The mining and plant extraction processes utilized in the reported projects involve three primary oil-extraction processes: solvent, water with various additives, and thermal retorting. Each project, although it can be included in one of these broad process categories, is unique, with the process details tailored to the operator's preferences and patents and the resource characteristics. The mining phases of the reported projects are all similar conventional strip-mining operations.

Solvent - Nine of the 22 reported mining and plant extraction projects utilize solvent processes for extraction of the oil from the tar sand. Most of these are unique patented or proprietary processes. The Western Tar Sands, Inc., project in Utah's Raven Ridge deposit utilizes an anhydrous solvent process enhanced by ultrasonics. The Aarian Development, Inc., project in Utah will enhance the solvent process by addition of inert gas.

Water - The eight reported water base oil extraction processes all involve additives to enhance the oil-from-rock separation. The additives include caustic, surfactant, solvents, and various diluents. Only the Great National Corp. project in Utah's Sunnyside deposit will use a cold water process; all others involve hot water. The Great National project will use a two stage process: (1). concentration of the oil content by a U.S. Bureau of Mines ambient temperature floatation process, which includes soda ash and phosphate dispersants and a fuel oil collector; (2). final separation of the oil from the concentrate by either a fluidized bed reactor or an anhydrous solvent. The EOR Petroleum Co. project in Labette County, Kansas, will employ a combination mining-in situ technique developed by Tetra Systems, Inc., and referred to as the "flip-flop" process. In the "flip-flop" process, the top of the oil reservoir is accessed by a mine shaft and tunnels; a heated surfactant solution is pumped to the exposed top of the reservoir and enters (aided by gravity) the reservoir, thus displacing the oil upward; the displaced oil is "skimmed" off the top of the reservoir and pumped to the surface.

Thermal retort - The Getty Oil Co. pilot project in the McKittrick area of California will test two oil-extraction technologies simultaneously: a Dravo solvent process and a Lurgi retort. The oil to be mined for

this project has a viscosity of less than 10 Pa-s but the project is included here because both tested processes are expected to be applicable to tar sand oils. The planned Great Basin Hydrocarbons project at Green River, Utah, will retort oil from nearby deposits utilizing waste heat from a planned coal-gasification plant.

Upgrading

Tar sand oils exceed 10 Pa-s in viscosity (some known cases exceeding 2,000 Pa-s) at reservoir temperatures and, in some cases, contain high concentrations of sulfur and heavy metals. These characteristics dictate some form of upgrading of the produced crude oils before refining. In some areas, the upgrading may be accomplished by merely diluting the produced tar sand oil with more conventional crude oils produced in the same area. Only 10 of the 62 projects are reported to include currently or plan to include some form of upgrading as follows: upgrading by the oil recovery process; upgrading by addition of diluents, and an upgrading plant.

Diluent - Four of the reported projects upgrade the produced oil by addition of a diluent, either a lighter crude oil or a distillate. Santa Fe Energy Company dilutes (one part diluent to 2 parts crude oil) the 1.04 Mg/m³ crude oil produced from their Oxnard, California, project with a 0.88 to 0.83 Mg/m³ distillate to obtain a 0.97 Mg/m³ mixture. Continental Oil Company (Conoco) mixes 0.85 Mg/m³ crude oil with the 1.06 Mg/m³ oil in the well bores to obtain a 0.97 Mg/m³ mix. W. C. Kirkwood Oil & Gas Company will dilute the 1.01 Mg/m³ produced oil to 0.99 Mg/m³ in the pilot in the Burnt Hollow, Wyoming deposit. Kirkwood expects to utilize a coking process for upgrading future commercial production and Conoco also expects that future commercial production will require upgrading by some process other than dilution.

Upgrading plant - The Chaparrosa Oil Company plans to employ either a hydrocracking or a coking process to upgrade the 1.04 Mg/m³ oil produced from their Southwest Texas project.

Upgrading by an oil-recovery process - The Rio Verde Energy Company expects the high temperatures generated in their Kentucky in situ, wet combustion project to upgrade the oil from 1.00 Mg/m³ and 100 Pa-s viscosity to 0.97 Mg/m³ and 2 Pa-s. Tertiary Recovery, Ltd., expects similar results from their in situ, wet combustion pilot in Texas. The fluidized bed separation phase of the Great National Corp. project in the Sunnyside, Utah, deposit is expected to upgrade the 1.00 Mg/m³ oil to a 0.92 Mg/m³ synthetic crude oil. The solvent-with-inert-gas separation process planned for the Aarian Development, Inc., Sunnyside, Utah, project is also expected to produce an upgraded synthetic crude oil.

COSTS

The economics involved in determining the cost of producing oil from U. S. tar sand deposits are dependent on a number of factors, including

recovery method, geographic location, depth and thickness of sand, proximity to pipeline or refinery, and labor market. The cost data listed in Table 3 are general cost data received from companies operating the projects.

The data in Table 3 reflect, in most cases, direct capital investment, engineering costs, drilling costs, fluid injection costs, and annual operating costs. The cost per cubic meter for the U. S. DOE-SNL Wilmington project does not include the cost of producing wells. Getty Oil Company's cost per cubic meter of \$116 for the Cat Canyon Project includes only operating cost. Costs related to royalty interest, all taxes, lease costs, transportation, and exploration are not included in the cost-per-cubic meter rate shown. In some cases, the cost-per-cubic meter data were calculated by the authors from data supplied by the operator. The reader should be aware that the total project cost divided by the estimated recovery will not always result in the cost-per-cubic meter shown.

Most of the reported projects are primarily pilot projects but some have the status of commercial projects. The success of these pilot projects is essential for future technology. Results of these tests will help dictate the final design and equipment selection of future commercial operations.

Cost data shown in Table 3 list projects from a number of states and for different recovery methods. The cost per cubic meter varies from a low of \$46.40 per cubic meter for the Cornell-HOPCO project in the Kern River Field, California, to a high of \$274.40 per cubic meter for the Tertiary Recovery Ltd. project in Texas. It is again stressed that many of these cost-per-cubic meter prices are estimates and others are based on a pilot test. Two of the projects have a very high per cubic meter cost estimate of over \$250, but these values could be lowered as the projects increase in magnitude and better process control is achieved. The majority of the per-cubic meter costs are in the \$100 to \$125 price range; if upgrading and other costs are about \$31 per cubic meter, this would put the net price at \$138 to \$157 per cubic meter. If the prices shown are, or become, firm prices, they are well within the range of a commercial tar sand operation.

SUMMARY

The 62 projects reported here represent a recent significant increase in activity related to the U. S. tar sand resource. These reported projects, summarized in Table 4, are a majority, not all, of those planned or underway.

TABLE 4. Status of Reported Projects

<u>Status</u>	<u>In Situ</u>	<u>Mining and Plant Extraction</u>	<u>Totals</u>
Current Commercial	7	0	7
Current Pilot	7	2	9
Planned Commercial	5	6	11
Planned Pilot	13	10	23
Completed Pilot	6	4	10
Current Research	<u>2</u>	<u>0</u>	<u>2</u>
Totals	40	22	62

That most of the U. S. tar sand resource is too deep for economic development by mining is reflected in the ratio of planned and current in situ to mining and plant extraction projects - nearly 2 to 1. The reported in situ projects utilize, primarily, proven enhanced oil recovery technologies as applied to the related "heavy crude oil" resource. In most cases, the reported mining and plant extraction projects also utilize various elements of proven technologies which are assembled into processes that are unique and unproven.

The incomplete reported cost data, and the number of projects reported as "planned or current commercial" provide encouragement that the commercial feasibility of the U. S. tar sand resource will be proven.

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Figure 1. Tar sand occurrences in the U.S.

Figure 2. U.S. tar sand projects

U.S. Tar Sand Field Projects - In Situ

STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES	
				Gravity Mg/m ³	Viscosity Pa-s
<u>CALIFORNIA</u>					
Cat Canyon F. ^{1/}	Conoco	cu. comm.	steam drive	1.00	1.6-10
Cat Canyon F.	Getty	cu. pilot	steam drive	1.01	28
Cat Canyon F.	Husky	pl. pilot	steam drive	1.00-1.01	4-20
E. Cat Canyon F.	Texaco	cu. comm.	steam drive	1.00	13.3-15.5
Cymric F.	Gulf	pl. comm.	steam drive	0.99	28
Kern Front F.	Chevron	cu. comm.	steam drive	0.98	23
Kern River F.	Cornell	pl. comm.	HOPCO	0.97	00.8
Marport Area	Ogle	cu. pilot	steam drive	1.04-1.06	1,000
McKittrick	Union	cu. comm.	steam drive	0.99	10
Midway-Sunset F.	Arco	cu. comm.	steam drive	0.99	24.5
Midway-Sunset F.	Shell	cu. comm.	steam drive	0.99	17
Midway-Sunset F.	Union	cu. comm.	steam drive	0.99	10
Oxnard F.	Exeter	pl. comm.	steam drive	1.03	500
Oxnard F.	Husky	pl. pilot	cyclic steam	1.00-1.04	500
Oxnard F.	Santa Fe	cu. pilot	steam drive	1.04	1,000
Paris Valley F.	Husky	co. pilot	wet comb.	0.99-1.01	50-400
Wilmington F.	DOE-SNL	cu. pilot	DIISG	0.97	0.7
<u>KENTUCKY</u>					
Butler C.	Rio Verde & Reading & Bates	pl. pilot	steam with CO ₂	TBD	100
Edmonson C.	Gulf ^{2/}	co. pilot	comb. with frac.	1.00	150
Edmonson C.	Rio Verde	pl. comm.	wet comb.	1.00	100
Edmonson C.	Westken	pl. pilot	steam drive & comb.	0.97-0.00	>15
<u>LOUISIANA</u>					
Bellevue F.	Cal. Billings	pl. comm.	"Frasch mining"	0.94	0.7
<u>MISSOURI</u>					
Vernon C.	Houston NG ^{3/}	pl. pilot	-	TBD	10
Vernon C.	Phillips ^{3/}	co. pilot	rev. comb.	1.06	500

Table 1a. (Continued)

STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES	
				Gravity Mg/m ³	Viscosity Pa.s
<u>TEXAS</u>					
Bandera Tank F.	Tertiary Rec.	pl. pilot	combustion 5/ steam drive	1.01	20
Saner Ranch F.	Conoco	cu. pilot	steam drive	1.01	2,000
Saner Ranch F.	Enpex	pl. pilot	steam drive	1.06-1.08	2,000
SW Texas	Chaparossa	pl. pilot	steam drive	1.04	>10
SW Texas	Mobil	co. pilot	combustion	1.04	>10
SW Texas	Nucorp	cu. pilot	steam drive	1.09-1.12	300
SW Texas	Unidentified	pl. pilot	steam	-	-
SW Texas	Unidentified	pl. pilot	thermal	1.06	-
<u>UTAH</u>					
NW Asphalt Ridge D.	DOE-ITRI	cu. res.	RF heating	0.97	1,000
NW Asphalt Ridge D.	DOE-LETC	cu. res.	comb. & steam drive	0.97	1,000
Sunnyside D.	Shell ⁴ / ₄	co. pilot	steam soak	1.01	100
Sunnyside D.	Signal	co. pilot	steam soak	1.00-1.01	100
Tar Sand Triangle D.	Altex	pl. pilot	-	-	-
Tar Sand Triangle D.	Unidentified	pl. pilot	-	-	-
Tar Sand Triangle D.	Unidentified	pl. pilot	combustion	0.99-1.01	113
<u>WYOMING</u>					
Burnt Hollow D.	Kirkwood	cu. pilot	steam drive	1.01	1,000

U.S. Tar Sand Field Projects - Mining & Plant Extraction

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STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES	
				Gravity Mg/m ³	Viscosity Pa·s
<u>ALABAMA</u>					
Colbert C.	Solv-Ex	pl. pilot	hot water & solvent	1.01	>10
<u>CALIFORNIA</u>					
Kern C.	Montex	pl. comm.	solvent	-	-
McKittrick D.	Getty	cu. pilot	Dravo & Lurgi ^{6/}	0.97-0.98	-
McKittrick D.	Unidentified	pl. pilot	-	-	-
<u>KANSAS</u>					
Labette C.	EOR Petroleum	pl. pilot	Tetra "flip-flop"	0.96	>10
<u>KENTUCKY</u>					
Edmonson C.	Green Coal & Texas Gas Tran.	pl. pilot	-	-	-
Logan C.	Tarco	pl. comm.	solvent	0.96	>10
<u>NEW MEXICO</u>					
Santa Rosa D.	Unidentified	pl. pilot	-	0.99	30
<u>UTAH</u>					
Asphalt Ridge D.	Aminoil	co. pilot	solvent	0.99-1.00	1,000
Asphalt Ridge D.	Asphalt Ridge Energy	pl. pilot	hot water & diluent	0.99-1.00	1,000
Asphalt Ridge D.	Enerecor	pl. pilot	hot water & caustic	0.99-1.00	1,000
Asphalt Ridge D.	Major Oil	co. pilot	hot water & diluent	0.99-1.00	1,000

Table 1b (Continued)

STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES	
				Gravity Mg/m ³	Viscosity Pa's
Asphalt Ridge D. Asphalt Ridge D. or P.R. Spring P.R. Spring D. Raven Ridge D.	Sohio Aarian C&A Companies Western Tar Sands	pl. pilot pl. pilot pl. comm. cu. pilot	solvent solvent & inert gas solvent anhydrous solvent & ultrasonics	0.99-1.00 1.00 1.00 -	1,000 1,000 1,000 1,000
Sunnyside D. Sunnyside D.	Green Basin Hydrocarbons Great National	pl. comm. pl. comm.	retort ambient water & thermal or anhydrous solvent	1.01 1.0	100 100
Sunnyside D. Whiterocks D. Whiterocks D. TBD	Standard of Indiana Al Hack Major Oil Natomas	pl. comm. co. pilot co. pilot pl. pilot	solvent hot water & diluent hot water & diluent solvent	1.01 - - -	100 - - -

1/ All abbreviations are defined in the appendix.

2/ Terwilliger, 1976.

3/ Trantham & Marx, 1966; Harvey & Arnold, 1974.

4/ Thurbert & Welbourn, 1977.

5/ Patented Fracture Assisted Steam Technology (FAST).

6/ Dravo solvent and Lurgi retort.

U.S. Tar Sand Field Projects - In Situ

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STATE LOCATION	GEOLOGIC FORMATION-AGE	WELL SHAPE	PATTERN SIZE hectares	DEPTH meters	THICKNESS meters	OIL-IN-PLACE $10^{-3} \frac{m^3}{m^3}$ or % porosity
<u>CALIFORNIA</u>						
Cat Canyon F.	-	5-spot	1.0	1097	11	35-60% (por)
Cat Canyon F.	Sisquoc (Plio)-Ter.	5-spot	2.3	762	21	0.197
Cat Canyon F.	Brooks (Plio)-Ter.	2 wells	-	945	68	0.286
E. Cat Canyon F.	Sisquoc (Plio)-Ter.	5-spot	4.0	796	26	75% (por)
Cymric F.	Tulare (Plio)-Ter.	5-spot	3.2	213	37	63% (por)
Kern Front. F.	Chunac (Plio)-Ter.	5-spot	1.9	794	40	49% (por)
Kern River F.	Kern River (Plio)-Ter.	-	-	213	18	0.215
Marport Area	Monterey (Mio.)-Ter.	5-spot	0.6	457	27	0.193
McKittrick F.	Tulare (Plei)-Ter.	5-spot	0.8	381	44	57% (por)
Midway-Sunset F.	Tulare (Plei)-Ter.	5-spot	0.5	293	13	42% (por)
Midway-Sunset F.	Reef Ridge (Mio)-Ter.	9-spot	2.0	305	92	65-80% (por)
Midway-Sunset F.	Reef Ridge (Mio)-Ter.	linear	-	305	137	64% (por)
Oxnard F.	Vaca (Plio)-Ter.	-	-	610	31	-
Oxnard F.	Vaca (Plio)-Ter.	3 wells	-	549	71	-
Oxnard F.	Vaca (Plio)-Ter.	5&7-spots	-	610	122	0.266
Paris Valley F.	Ansberry	-	-	256	15	-
Wilmington F.	Repetto (Plio)-Ter.	5-spot	2.0 (air)	671	4	0.154
<u>KENTUCKY</u>						
Butler C.	Golconda-Miss.	-	3.2 (O ₂)	183	-	40% (por)
Edmonson C.	Caseyville-Penn.	-	-	305	6	0.142
Edmonson C.	Golconda-Miss.	5-spot	2.0	91	13	0.116
Edmonson C.	Golconda-Miss.	7-spot	1.4	76	9	70% (por)
<u>LOUISIANA</u>						
Bellevue F.	Nacatoch-Cret.	20 wells	-	61	5	
<u>MISSOURI</u>						
Vernon C.	Warner-Penn.	linear	-	92	15	20-60% (por)
Vernon C.	-	-	-	15	4	

Table 2a (Continued)

STATE LOCATION	GEOLOGIC FORMATION-AGE	WELL SHAPE	PATTERN SIZE hectares	DEPTH meters	THICKNESS meters	OIL-IN-PLACE $10^{-3} \frac{m^3}{m^3}$ or % porosity
<u>TEXAS</u>						
Maverick C.	San Miguel-Cret.	5-spot	1.0	670	20	0.171
Saner Ranch F.	San Miguel-Cret.	5-spot	2.0	540	15	50% (por)
Saner Ranch F.	San Miguel-Cret.	5-spot	2.8	610	15	0.155
SW Texas	San Miguel-Cret.	-	-	274	26	-
SW Texas	San Miguel-Cret.	-	-	-	-	-
SW Texas	San Miguel-Cret.	5-spot	2.0	579	23	-
SW Texas	-	-	-	-	-	-
SW Texas	-	-	-	-	-	-
<u>UTAH</u>						
NW Asphalt Ridge D.	Mesaverde-Cret.	none	-	5	15	0.240
NW Asphalt Ridge D.	Mesaverde-Cret.	linear & 5-spot	-	-	-	-
Sunnyside D.	Wasatch-Ter.	1 well	0.4-0.2	183	3-15	0.240
Sunnyside D.	Wasatch-Ter.	4-spot	-	335	12	-
Tar Sand Triangle D.	White Rim-Perm.	3 wells ^{2/}	0.5	198	76	-
Tar Sand Triangle D.	White Rim-Perm.	-	-	-	-	-
Tar Sand Triangle D.	White Rim-Perm.	-	-	-	-	-
		5-spot	0.4	427	17	0.180
<u>WYOMING</u>						
Burnt Hollow D.	Minnelusa-Penn.	5-spot	1.0	274	15	0.120

^{1/} All 4, 5, 7, and 9 spot patterns are inverted, i.e., 1 injection well with 3, 4, 6, or 8 production wells.

^{2/} Horizontal wells in quarry face.

U.S. Tar Sand Field Projects - Mining & Plant Extraction

STATE LOCATION	GEOLOGIC FORMATION-AGE	DEPTH meters	THICKNESS meters	$10^{-3} \frac{m^3}{m^3}$ or % porosity (por.) OIL-IN-PLACE or % weight (wt.)
<u>ALABAMA</u>				
Colbert C.	Hartselle-Miss.	0-20	11	170
<u>CALIFORNIA</u>				
Kern C.	-	-	-	-
McKittrick D.	Diatomaceous Earth (Mio) - Ter.	0-122	107-274	12% (wt)
McKittrick D.	Diatomaceous Earth (Mio) - Ter.	-	-	-
<u>KANSAS</u>				
Labette C.	Bartlesville-Penn.	30	4.4	>40% (por)
<u>KENTUCKY</u>				
Edmonson C.	-	-	-	-
Logan C.	Caseyville-Penn.	1-3	12	6% (wt)
<u>NEW MEXICO</u>				
Santa Rosa D.	Santa Rosa-Tri.	0-15	-	5% (wt)
<u>UTAH</u>				
Asphalt Ridge D.	Mesaverde-Cret.	-	-	-
Asphalt Ridge D.	Mesaverde-Cret.	-	-	-
Asphalt Ridge D.	Mesaverde-Cret.	-	-	-
Asphalt Ridge D.	Mesaverde-Cret.	-	-	-
Asphalt Ridge D.	Mesaverde-Cret.	0-91	-	0.129-0.258

Table 2b (Continued)

STATE LOCATION	GEOLOGIC FORMATION-AGE	DEPTH meters	THICKNESS meters	$10^{-3} \frac{m^3}{m^3}$ or % porosity (por.) or % weight (wt.)	OIL-IN-PLACE
UTAH (continued)					
Asphalt Ridge or P.R. Spring D. P.R. Spring D.	Green River & Wasatch-Ter.	-	-	-	-
Raven Ridge D.	Green River-Ter.	0-91	7.6	0.206	
Sunnyside D.	Wasatch-Ter.	-	-	-	
Sunnyside D.	Wasatch & Green River-Ter.	-	-	-	
Sunnyside D.	Wasatch & Green River-Ter.	0-61	122-152	>0.129	
Whiterocks D.	Navajo-Jur.	-	-	-	-
Whiterocks D.	Navajo-Jur.	-	-	-	-
TBD	-	-	-	-	-

Cost Data - Selected In Situ Projects^{1/}

STATE LOCATION	OPERATOR	RECOVERY METHOD	ESTIMATED RECOVERY 10 ³ m ³	TOTAL PROJECT COST \$10 ⁶	COST* \$/m ³
<u>CALIFORNIA</u>					
Cat Canyon F.	Conoco	steam drive	118	11	\$ 93.10 ^{3/}
Cat Canyon F.	Getty	steam drive	TBD	TBD	116.40 ^{3/}
Cat Canyon F.	Husky	steam drive	176	28	160.40
E. Cat Canyon	Texaco	steam drive	21	2.45	116.60
Cymric F.	Gulf	steam drive	143	TBD	TBD
Kern Front F.	Chevron	steam drive	2115	162.24	76.70
Kern River F.	Cornell	HOPCO	302	14	46.40
Marport Area	Ogle	steam drive	68	7.07	103.30 ^{4/}
Oxnard F.	Santa Fe	steam drive	TBD	350	113.20 ^{5/}
Wilmington F.	DOE-SNL	DIISG	TBD	TBD	113.20 ^{5/}
<u>KENTUCKY</u>					
Edmonson C.	Rio Verde	wet comb.	3800	TBD	129.40
<u>LOUISIANA</u>					
Bellevue F.	Cal Billings	Frasch	143 ^{2/}	TBD	TBD
<u>TEXAS</u>					
Bandera Tank F.	Tertiary Rec.	steam drive	64 ^{2/}	17.67	274.40
Saner Ranch F.	Conoco	steam drive	27	TBD	TBD
Saner Ranch F.	Enpex	steam drive	53	9.60	157.25
<u>UTAH</u>					
NW Asphalt Ridge D.	DOE-UTRI	RF heating	TBD	TBD	106.90
NW Asphalt Ridge D.	DOE-LFTC	comb. & steam	TBD	TBD	158.50
Tar Sand Triangle D.	Unidentified	combustion	TBD	13	TBD
<u>WYOMING</u>					
Burnt Hollow D.	Kirkwood	steam drive	26.1	7.80	257.90

* Some costs are operating costs; others include lease costs, etc.

Cost Data - Selected Mining & Plant Extraction Projects

STATE LOCATION	OPERATOR	RECOVERY METHOD	ESTIMATED RECOVERY 10 ³ m ³	TOTAL PROJECT COST ⁶ \$10	COST \$/m ³
<u>ALABAMA</u> Colbert C.	Solv-Ex	hot water & solvent	79 ^{2/}	TBD	\$164.80
<u>KANSAS</u> Labette C.	FOR	flip-flop	TBD	TBD	60.80
<u>KENTUCKY</u> Logan C.	Tarco	solvent	TBD	2 ^{6/}	TBD
<u>UTAH</u> Asphalt Ridge D. Asphalt Ridge or P.R. Spring D. Sunnyside D.	Enercor Aarian Great National	hot water solvent hot water	TBD 3,180 ^{2/} 11,000	TBD 28.30 401 ^{7/}	125.80 TBD 113.20- 132.10

1/ Cost data excludes royalty interest and leasing costs.

2/ m³ oil per day.

3/ Operating costs only.

4/ Asked-for-price guarantee from Synfuels Corp.

5/ Cost of production wells not included.

6/ Plant cost.

7/ Cost range from \$350,000,000 to \$401,000,000, payout in 6.4 years.

APPENDIXUNIT CONVERSIONS

<u>From</u>	<u>To</u>	<u>Multiply by</u>
hectare	acre	2.471
meter (m)	foot	3.281
cubic meter (m ³)	barrel	6.290
Pascal-second (Pa-s)	centipoise	1,000
dollars per cubic meter	dollars per barrel	0.159
μm ²	millidarcies	1.013 x 10 ³
Specific gravity	°API	°API = $\frac{141.5}{\text{specific gravity}}$ - 131.5

ABBREVIATIONS

C.	- county	Mio	- Miocene
co.	- completed	Miss.	- Mississippian
comb.	- Combustion	NG	- Natural Gas
comm.	- commercial	NW	- northwest
Cret.	- Cretaceous	Pa's	- Paschal seconds
cu.	- current	Penn.	- Pennsylvanian
D.	- deposit	Perm.	- Permian
Dev.	- development	Pet.	- Petroleum
DOE	- U.S. Department of Energy	pl.	- planned
DHSG	- downhole steam generator	Plei	- Pleistocene
E	- east	Plio	- Pliocene
F	- field	por.	- porosity
frac.	- fracture	Rec.	- Recovery
HOPCO	- Heavy Oil Process Company	res.	- research
IITRI	- Illinois Institute of Technology Research Institute	rev.	- reverse
Jur	- Jurassic	RF	- radio frequency waves
LETC	- Laramie (Wyoming Energy Technology Center)	SNL	- Sandia (New Mexico National Laboratory)
m	- meter	SW	- southwest
m ³	- cubic meter	TBD	- to be determined
Mg	- megagram	Ter.	- Tertiary
μg	- microgram	Tri.	- Triassic