Model Predictions

for the

C-SOS Oil Shale Process

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Acknowledgements

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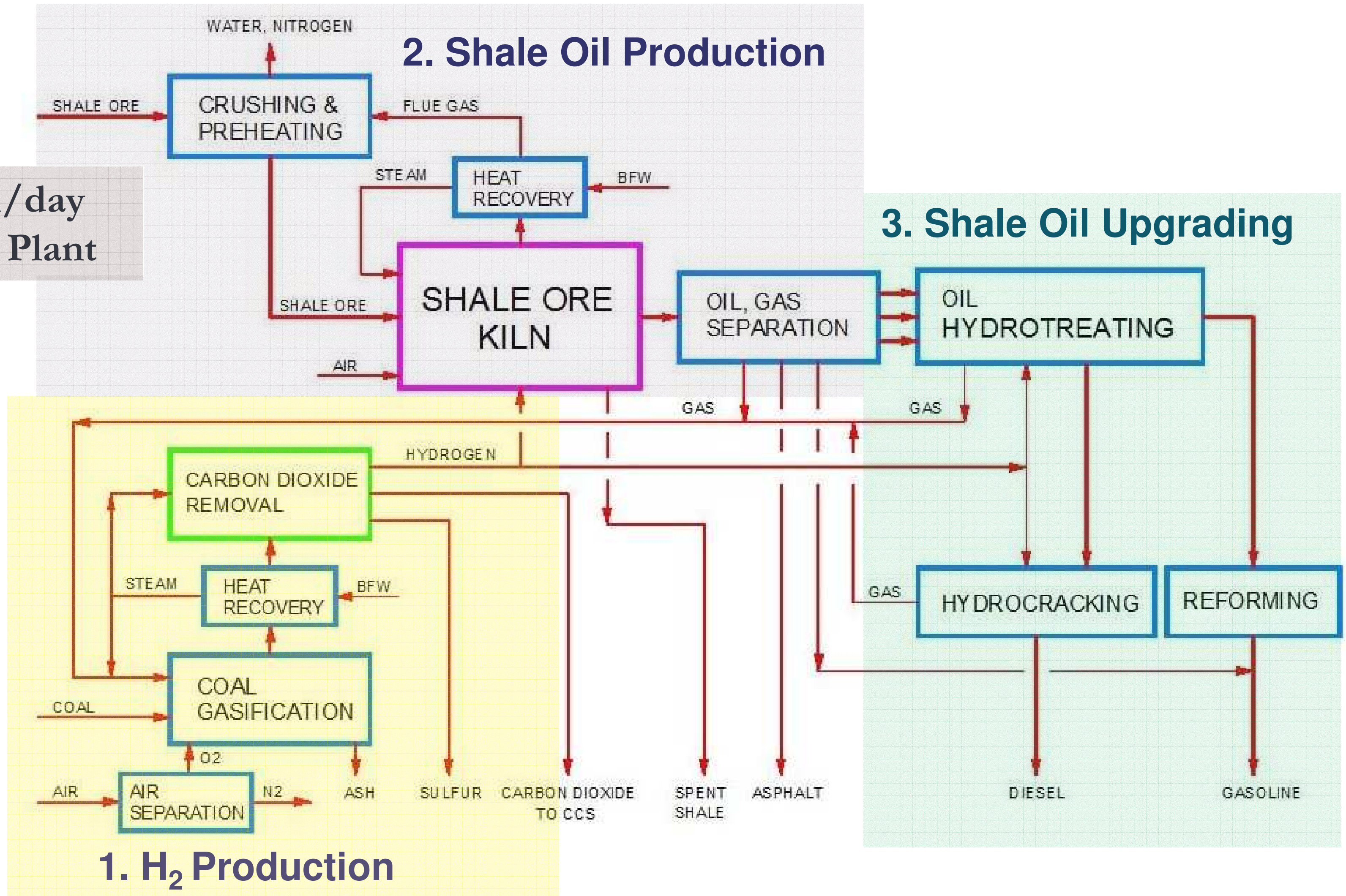
  - Phase II Contract
  - Chandra M. Nautiyal, Project Officer
- BLM/OSEC (Dan Elcan) / Sage Geotech (Gary Aho) – 150 tons of oil shale
- CR Colleagues {other paper – The Clean, Shale Oil Surface (C-SOS) Pilot Plant Process}
  - Dr. Craig Eatough
  - Mr. Steven Eatough
  - Mr. Kent Hatfield

Objectives

- Contract Objective – Demonstrate and characterize the C-SOS oil shale pilot plant
- Modeling Analysis Objective – Develop and apply an oil shale process model for the kiln and the aft-end collection system

C-SOS General Flow Diagram

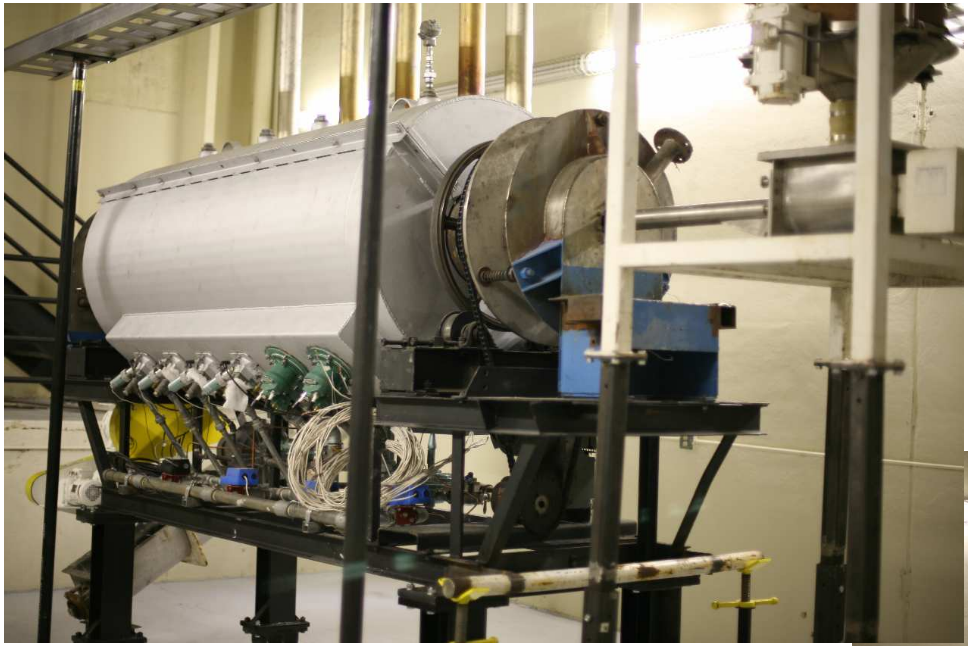
5 ton/day
Pilot Plant

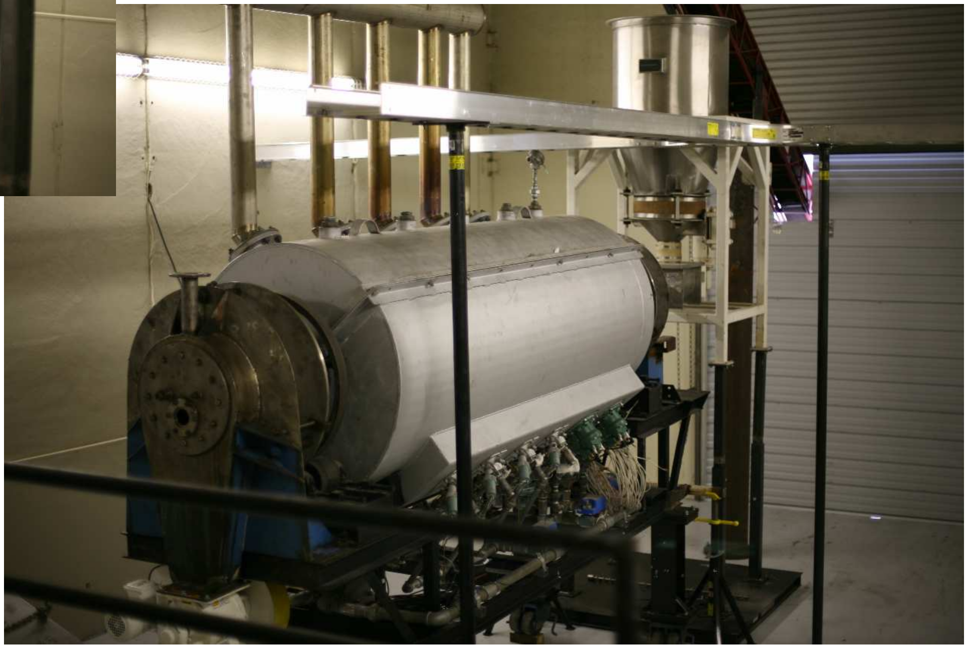


Two Element Model

- Front-end: Kiln
- Aft-end: Recovery & Separation

Front-End: Kiln

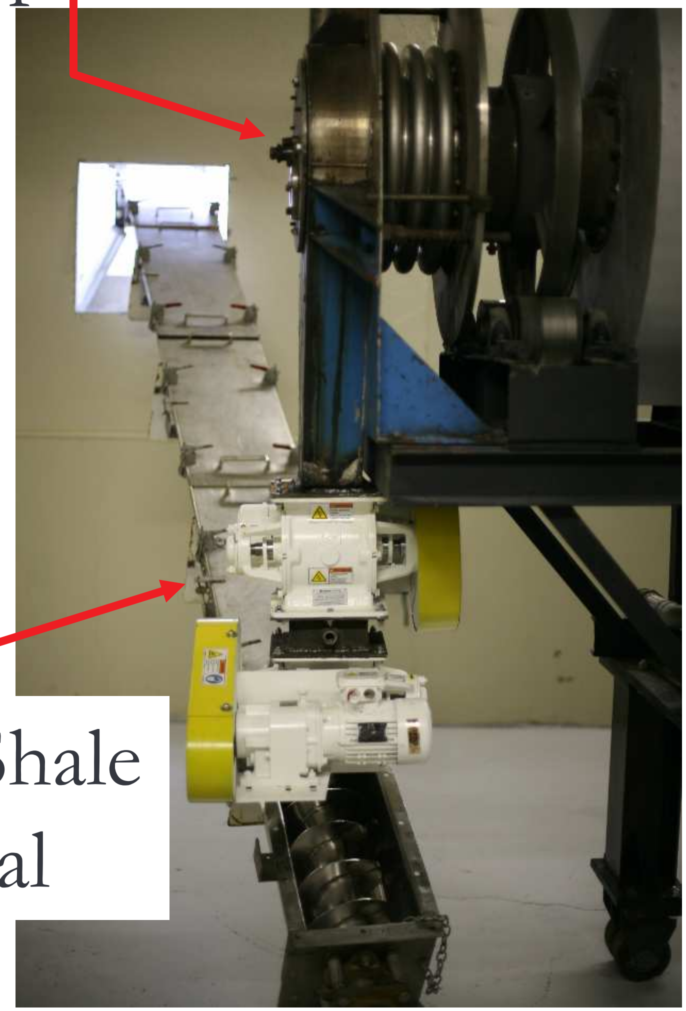




Front-End: Kiln (continued)

Hopper

Oil Vapor/Gas Outlet

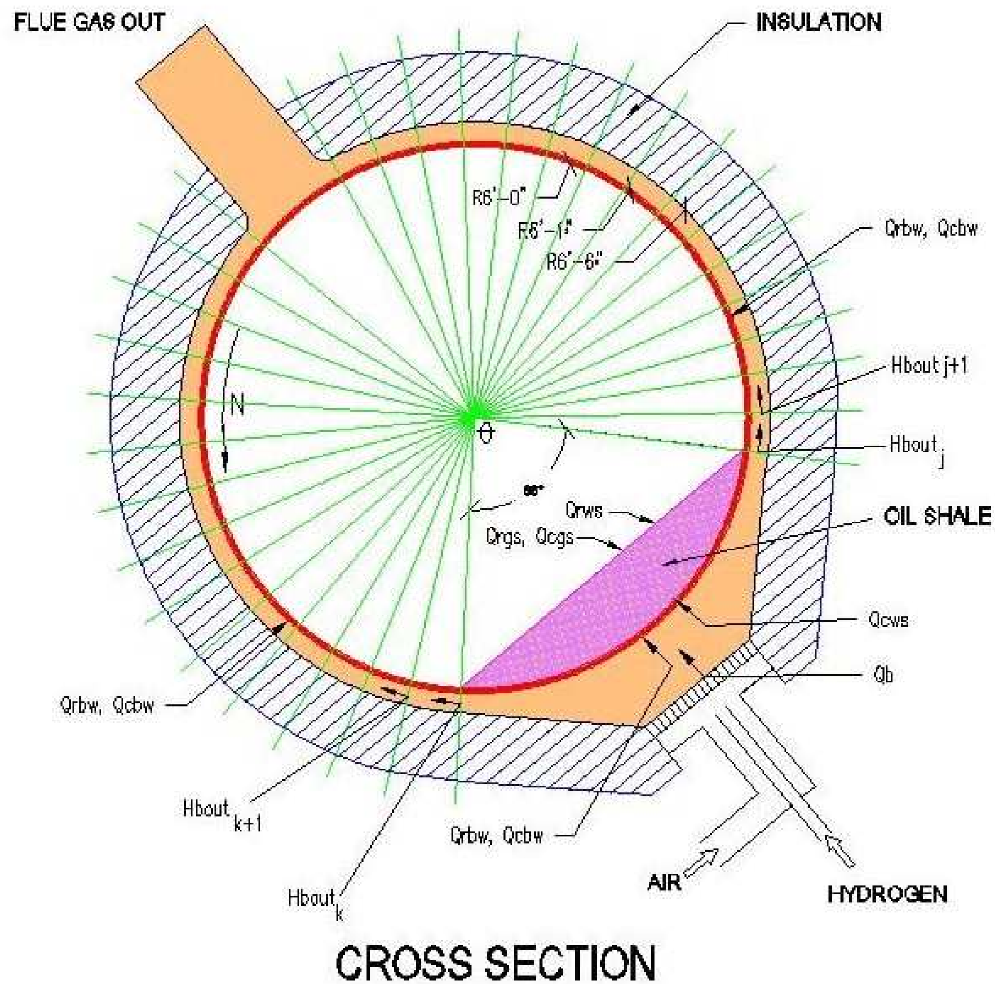


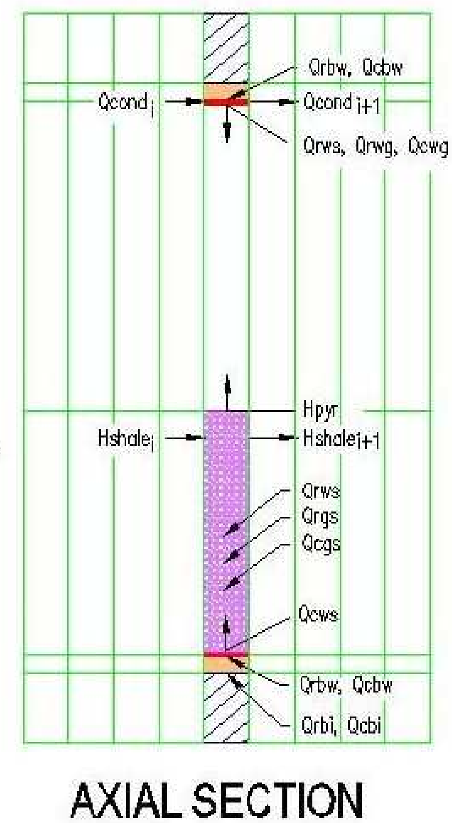
Spent Shale Removal

Aft-end: Shale Oil Recovery and Separation Unit

Source of Shale
White River Mine Stockpile

Kiln Model Configuration





Kiln Model Parameters

SHALE PROPERTIES

- Particle size
- Moisture content
- Density (v. porosity, particle size)
- Heat capacity (v. temperature)
- Thermal conductivity (v. porosity, temp.)
- Heat of pyrolysis
- Oil yield / mass shale
- Oil heat capacity (v. temperature)
- Gas yield / mass shale
- Gas heat capacity (v. temperature)
- Pyrolysis reaction rate (v. temperature)
- Oil cracking rate (v. temperature)

KILN THROUGHPUT

- Inside diameter
- Length
- Fill fraction or fill angle
- Angle of repose
- Slope
- Rotation Rate
- Shale bulk density

SHALE SURFACE HEAT TRANSFER

- Bulk density
- Bulk heat capacity
- Bulk thermal conductivity
- Mean particle dia.
- Kiln interface gas film thickness

Pilot Plant Reference Case
Model Inputs

SHALE

- 4.2 ton/day
- Western Shale (Miknis & Robertson*)
- 27.5 gal/ton
- 1.62% water
- Gas 4.6%

KILN

Inside dia.	0.83 (ft)
Length	7.00 (ft)
Volume	4.0 (ft^3)
Rotation Rate	20.00 (rpm)
Slope	1.0°
Angle of repose	40.0°

* Data taken from tables in: F.P. Miknis, R.E. Robertson, "Characterization of DOE Reference Oil Shales", DE88005703, September 1987

Reference Case Inputs (continued)

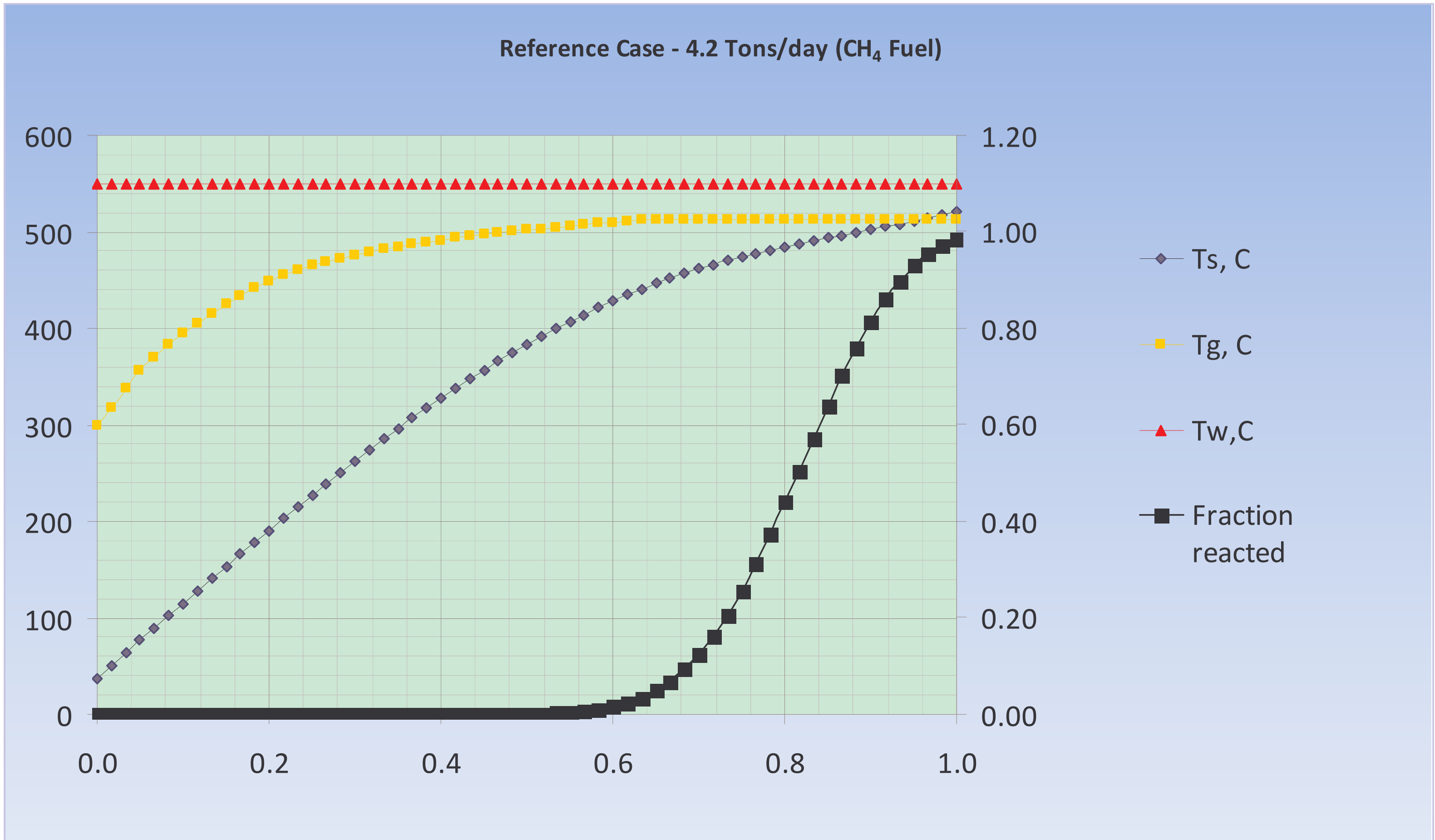
OIL

	Boiling Point (F)	Mw	Wgt %
NBP1	251	145	0.436
NBP2	433	175	0.452
NBP3	487	196	0.458
NBP4	543	219	0.472
NBP5	597	247	0.476
NBP6	656	278	0.485
NBP7	708	312	0.490
NBP8	733	329	0.490
NBP9	758	339	0.498
NBP10	788	360	0.499
NBP11	818	382	0.506
NBP12	849	407	0.514
NBP13	880	432	0.523
NBP14	915	464	0.518
NBP15	949	498	0.521
NBP16	983	535	0.521
NBP17	1020	734	2.218

Gas

	Boiling Point (F)	Mw	Wgt %
H2O	212	18.015	6.62
H2	-423	2.016	0.0729
C0	-313	28.01	0.1657
CH4	-259	16.042	0.2355
CO2	-70	44.01	2.8232
C2H4	-155	28.053	0.0499
C2H6	-128	30.069	0.1477
H2S	-77	34.081	0.2335
C3H6	-54	42.08	0.0669
C3H8	-44	44.096	0.1038
C4H10	31	58.12	0.6287

Kiln Model Predictions (4.2 tons/day)



Kiln Model - Summary

Kiln Inputs

Stream	1	Raw Shale to Kiln	
Temperature (F)	77		
Pressure (psia)	12.6		
		Inputed Rates	
Compound		lbm/min	
CH4		5.836	

Stream	17	Steam Purge for Kiln	
Temperature (F)	1000		
Pressure (psia)	12.6		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol/hr
H_2O	18	0.2918	0.97269

Stream	6	Combustion Fuel (CH_4) to Kiln	
Temperature (F)	77		
Pressure (psia)	12.85		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol/hr
CH4	16	0.1566	0.58718

Stream	18	Kiln Valve Purge Steam	
Temperature (F)	1000		
Pressure (psia)	12.6		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol/hr
H_2O	18	0.0050	0.01667

Stream	7	Combustion Air to Kiln	
Temperature (F)	77		
Pressure (psia)	12.6		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol/hr
Air	28.964	2.693	5.57855

Stream	19	Rotary Valve Purge Steam	
Temperature (F)	1000		
Pressure (psia)	12.6		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol/hr
H_2O	18	0.0050	0.01667

Kiln Ouputs

Stream	20	Flue Gas Out	
Temperature (F)	1022		
Pressure (psia)	12.6		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol / hr
Flue Gas	27.630	2.850	6.18802

Stream	22	Spent Shale Out	
Temperature (F)	970		
Pressure (psia)	12.6		
		Inputed Rates	
Compound		lbm/min	
Spent Shale		4.889	

Stream	25	Oil Vapors & Gas + Steam	
Temperature (F)	1000		
Pressure (psia)	12.6		
	Mw	Inputed Rates	
Compound		lbm/min	lb-mol/hr
Oil Vapors & Gas		1.2388	1.91292

Predicted Material & Energy Balances – Reference Case

Materials (lbs/day)				Enthalpy (BTUx10^5/hr)			
IN		OUT		IN		OUT	
Dry Oil Shale	10080	Spent shale	8424	Dry Oil Shale	9.12	Spent Shale	1.09
		Water	156	Kiln Fuel (CH_4)	2.02	Process Water	0.02
		Gasoil	274	Electricity	0.1	Oil Product	6.59
		Heavy diesel cut	446	Steam	0.22	Flue gas	0.42
		Diesel cut	250			Flare gas	1.13
		Gasoline cut	40			Burner & Heat Losses (10%)	2.02
		Light gasoline cut	12				
		Flare gas	478				
Total	10080		10080		11.46		11.27

Observations

- 2 component model describes C-SOS pilot plant in detail
  - Kiln parameters
  - Extent of oil release
  - Effects of key variables
  - Properties of 57 process streams
  - Production of residual, diesel, and gasoline cuts
  - Material balance
  - Energy balance

Preliminary Observations

- Computation for the Reference Case
  - 10% shale ore goes to oil products
  - 5% of shale ore goes to useful gas product
  - Net Energy Production[1] ≈ 60%
  - Energy Recovery[2] = 72%
- Computations for Base Case (First Pilot Plant test)
  - In process
  - Comparison with pilot plant test data

1 Energy in oil / total energy in the process (w/o mining, transportation and crushing)
2 Energy in oil / energy in the raw shale

Plans – Second Year – Phase II

- Pilot plant Tests
  - Effect of key variables
  - Oil split and quality
  - Long duration test
- Oil fractions upgrading
  - Hydro treating
  - Hydro cracking
- Comparison with Model Predictions
- Demonstration/Commercial Scale
  - Preliminary Design
  - Cost

Thank You

Robert Jackson

Doug Smoot

Ambar Ochoa

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