Katz (Strawn) Field CO2 Project

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Outline

- Field Overview
- Reservoir Data
- CO2 Project – Design and Implementation
- Facilities – Compression / Pipeline
Katz (Strawn) Field

King, Knox, Stonewall, Haskell Counties, Texas

80 miles north of Abilene, TX
Pennsylvanian reef reservoirs
Modified from Galloway, et al. (1983)
Katz Type Log

1st Strawn (4,800’ Sand)
- Average Porosity – 16%
- Average Permeability – 53 md

2nd Strawn (4,900’ Sand)
- Average Porosity – 17%
- Average Permeability – 124 md

Dirty 3rd Strawn (5,100’ Sand)
- Average Porosity – 16%
- Average Permeability – 3.2 md

Clean 3rd Strawn (5,100’ Sand)
- Average Porosity – 16%
- Average Permeability – 55 md

25 Square Miles of 3D data
Specialty Processing
Relative Acoustic Impedance
# Katz Field History

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 1951</td>
<td>Katz Field discovered by Katz Oil Co, H.D. Dozier No. 1 (current well name, ERU No.59).</td>
</tr>
<tr>
<td>Mar. 1951</td>
<td>Katz (5100) Field discovered by T.D. Humphrey, Mattie Davis No. 1 (located on the Orsborn Unit).</td>
</tr>
<tr>
<td>Jul. 1983</td>
<td>Katz (Day) Field discovered by Getty Oil Co, Roy Day No. 4 (current well name, SWRU No.35).</td>
</tr>
<tr>
<td>Oct. 1984</td>
<td>Orsborn Unit waterflood began into the Katz and Katz (5100) Fields (Conoco, operator).</td>
</tr>
<tr>
<td>Nov. 1989</td>
<td>SWRU unitized in the Katz, Katz (Day), Katz (5100) Fields (BP Exploration, operator).</td>
</tr>
<tr>
<td>May 2006</td>
<td>Kinder Morgan Production Co. became operator of ERU, CBLU, and SWRU.</td>
</tr>
<tr>
<td>Nov 2009</td>
<td>Consolidated 3 fields into the Katz (Strawn) Field.</td>
</tr>
</tbody>
</table>
Katz Total Production
(Katz + Katz (Day) + Katz (5100)) Fields

Combined ERU, CBLU, SWRU

Cum oil = 59.98 MM STB
P + S = 32.5% OOIP

Nov 1989 CBLU and SWRU WF
Oct 1987 ERU WF
The Katz (Day) Field is not located in this well, but would be found at this relative depth in portion of reservoir where it exists.

Historically Katz was comprised of 3 fields.
Sid Katz
H. T. Lorentzen “C”
Well No. 11,
Stonewall County, TX

Orientation of the 3 sands to the 3 fields
Sid Katz
H. T. Lorentzen “C”
Well No. 11,
Stonewall County, TX

Katz (Strawn) Field

Consolidation into 1 field was approved by TRRC
November 4, 2009
## Reservoir Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lithology</strong></td>
<td>Strawn Sandstone</td>
</tr>
<tr>
<td><strong>Producing Interval</strong></td>
<td>4800’ – 5400’</td>
</tr>
<tr>
<td><strong>Reservoir Dip</strong></td>
<td>3 degrees (to SW)</td>
</tr>
<tr>
<td><strong>Net Pay</strong></td>
<td>45’ * 3 sands = 135’</td>
</tr>
<tr>
<td><strong>Porosity</strong></td>
<td>12 – 22%</td>
</tr>
<tr>
<td><strong>Perm</strong></td>
<td>2 – 3700 mD</td>
</tr>
<tr>
<td><strong>Initial Water Saturation</strong></td>
<td>28%</td>
</tr>
<tr>
<td><strong>1st and 2nd Sand WOC</strong></td>
<td>TZ begins -3503’ thru -3438’</td>
</tr>
<tr>
<td><strong>3rd Sand WOC</strong></td>
<td>-3660’</td>
</tr>
<tr>
<td><strong>Water Salinity</strong></td>
<td>120,000 ppm Cl, TDS = 185,000 ppm</td>
</tr>
<tr>
<td><strong>Reservoir Temperature</strong></td>
<td>116 deg F (orig. 119 deg F)</td>
</tr>
<tr>
<td><strong>Reservoir Pressure</strong></td>
<td>1600 psig (orig. 2200 psig)</td>
</tr>
</tbody>
</table>
Katz Field
Structure Map
First Sand Formation Top
CI = 10 feet
1st Sand - HCFT
2nd Sand - HCFT
3rd Sand - HCFT
## Key Reservoir Engineering Data

<table>
<thead>
<tr>
<th></th>
<th>Core</th>
<th>φ-k Transform</th>
<th>Dykstra-Parsons</th>
<th>Relative Perm End Points</th>
<th>Wettability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>Average</td>
<td></td>
<td>0.82</td>
<td>0.248</td>
<td>0.753</td>
</tr>
<tr>
<td>1st</td>
<td>53 md</td>
<td>47.7 md</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>124 md</td>
<td>263.2 md</td>
<td>0.67</td>
<td>0.278</td>
<td>0.641</td>
</tr>
<tr>
<td>Dirty 3rd</td>
<td>3 md</td>
<td>3 md</td>
<td>0.70</td>
<td>0.39</td>
<td>0.639</td>
</tr>
<tr>
<td>Clean 3rd</td>
<td>55 md</td>
<td>50 md</td>
<td>0.64</td>
<td>0.347</td>
<td>0.694</td>
</tr>
</tbody>
</table>

### Graphs

#### 1st Sand

- **Relative Permeability Curves**
- **Water Saturation (% PV)**
- **k_\text{rw} Data**
- **Lake k_\text{rw} Match**
- **B-C k_\text{rw} Match**

#### 2nd Sand

- **Relative Permeability Curves**
- **Water Saturation (% PV)**
- **k_\text{rw} Data**
- **Lake k_\text{rw} Match**
- **B-C k_\text{rw} Match**
Capillary Pressure

Air-Brine Capillary Pressure

PWL = 72ft

TZ Height = 67 ft

y = -83.333x + 2957.5

y = -0.1451x + 16.601

Used to characterize 2nd Sand TZ

Height above 100% FWL (ft)

Water Saturation (%)
PVT Data

- Discovery Pressure – 2200 psia
- API Gravity – 38.6°
- Oil Viscosity – 2.151 cP
- Current GOR - < 100 scf/bbl
  - Original Solution GOR – 250 scf/bbl
- Current Bubblepoint – 138 psia
  - Original Bubblepoint – 1130 psia
- Oil Formation Volume Factor – 1.183 rvb/stb
PVT Data (cont)

- Oil Fingerprint Analysis
  - All three sands have same source
    - Biomarkers indicate Late Paleozoic
      - Barnett Shale
    - Marine Depositional Environment
      - Marine algal-bacterial organic matter
      - Low terrigenous organic material
Original vs. Current Oil Recombination

Katz Recombined Oil Comparison

Indication that light ends have been produced

MW = 218

MW = 222

Hydrocarbon Component

C1 C2 C3 iC4 nC4 iC5 nC5 C6 C7

Mole %

Original Recombined Oil Composition
Current Recombined Oil Composition
Recombined Hydrocarbon Components

Katz Recombined Hydrocarbon Components

Indicates potential paraffin and asphaltene problems
CO2 Project Hurdles

- No allocated production/injection data
- Limited and missing well test data
- Old neglected wellbores
- No physical core samples
- No CO2 Pipeline
  - Long PL for smaller target
- Multiple Zones
- Brazos River
- Outdated / limited log data
CO2 PVT

- MMP – 1746 psia @ 100% CO2
  - 1751 psia @ 90% CO2 – 10% Produced Gas
  - 2104 psia @ 75% CO2 – 25% Produced Gas
- CO2 FVF – 1.83 mcf/rvb
- CO2-Water Solubility – 83 scf/bbl
Katz Slim-tube Tests

Katz Slim-tube Tests
MMP 1,746 psi at 120 °F, 100% CO2
MMP 1,751 psi at 120 °F, 10% Gas and 90% CO2
MMP 2,104 psi at 120 °F, 25% Gas and 75% CO2

Effect of gas contamination on MMP
Analytical Model

- Generates Ideal WAG Ratio and Slug Sizes, Total Recovery, Production Forecast
  - Good for limited datasets
  - Quick
- Requires Water-Oil Rel Perm Curves and Basic PVT Properties
Analytical Model

Fractional Flow Curves

Analytical Model

1. Fractional Flow Curves

OB': Initial Saturation
Cont. H₂O
Cont. CO₂
Vcw
Max Oil Bank WAG

OB
J

Water Fractional Flow (%)

Water Saturation (%)
Dim Rec Curves w/ Katz Overlay for SS Reservoirs

*Oil Recovery (% OOIP)* vs. *Total HCPVi*

- **Field A** (dotted line)
- **Field B** (square markers)
- **Field C, Phases 1&2** (triangle markers)
- **Field C, Phase 3** (circle markers)
- **Field D** (cross markers)
- **Katz** (solid green line)

Legend:
- **Katz**
Project Forecast

- 150.8 MMSTBO CO2 Target
- Economic Recovery – 15.8%
- Purchase CO2 Vol. – 220 BCF
- Net – 9 Mcf/bbl
- Gross – 19 Mcf/bbl
- Total Recovery – 23.8 MMSTBO

- Dimensionless Curve Construction
  - Combination of Reservoir Simulation, Analogies, Analytical Models, and Engineering Experience
Katz CO2 Project Forecast
Combined 3 Sands - HCFT
3 Sands – HCFT (w/ patterns)
CO2 Project Design

- 57 WAG Injectors
- 74 Producers
- 84 New Drills
- 47 Workovers
- 76 P&A’s
- 4 Water Curtains
- 5 Observation Wells
- 3 Disposal Wells
CO2 Project Design

- Injection Rates
  - 18% HCPV/yr
- Injection Pressure
  - Fracture Gradient of 0.72 psi/ft
  - CO2
    - Surface – 1650 psig
    - BH - 3375 psia
  - Water
    - Surface 1400 psig
    - BH – 3380 psig
Katz Injection Wells

• Down hole isolation assembly used on CO₂ WAG injectors:
  – Control CO₂ injection side when high GOR seen at producer.
  – One method of zonal conformance:
    * cheaper than some polymer jobs or expandable liner systems.
  – Can function individual zone sleeves from surface via slick line, no rig necessary.
  – Can limit individual zone rate based on orifice size.
# Downhole Isolation Assembly

<table>
<thead>
<tr>
<th>Installation</th>
<th>Description</th>
<th>OD</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Proposed Packer Installation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 7/8&quot; EUE 9RD Tubing String With Poly Liner</td>
<td>2.875</td>
<td>1.901</td>
<td></td>
</tr>
<tr>
<td>5 1/2&quot; Box X 2 3/8&quot; Pin On-Off Tool With Profile</td>
<td>4.50</td>
<td>1.875</td>
<td></td>
</tr>
<tr>
<td>Approx depth 4,750'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 1/2&quot; Box X 2 3/8&quot; Double Grip Mechanical Set Right Hand 1/4&quot; Turn Release 1/4&quot; Right Hand Turn To Release</td>
<td>4.750</td>
<td>1.901</td>
<td></td>
</tr>
<tr>
<td>2 7/8&quot; EUE 9RD Tubing String With Poly Liner Perforations</td>
<td>2.875</td>
<td>1.901</td>
<td></td>
</tr>
<tr>
<td>2 7/8&quot; X 1.812&quot; Segregation Valve With Isolation Sleeve in Place to Allow Setting Of Isolation Packers</td>
<td>3.668</td>
<td>1.812</td>
<td></td>
</tr>
<tr>
<td>Approx depth 4,850'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 1/2&quot; Box X 2 3/8&quot; Double Element Hydro 1V Hydraulic Set Packer Packer Shear Release</td>
<td>4.750</td>
<td>1.901</td>
<td></td>
</tr>
<tr>
<td>2 7/8&quot; EUE 9RD Tubing String With Poly Liner Perforations</td>
<td>2.875</td>
<td>1.901</td>
<td></td>
</tr>
<tr>
<td>2 7/8&quot; X 1.612&quot; Segregation Valve With Isolation Sleeve in Place to Allow Setting Of Isolation Packers</td>
<td>3.668</td>
<td>1.612</td>
<td></td>
</tr>
<tr>
<td>Approx Depth 5,050'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 1/2&quot; Box X 2 3/8&quot; Double Element Hydro 1V Hydraulic Set Packer Packer Shear Release</td>
<td>4.750</td>
<td>1.901</td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
<td>2 7/8&quot; X 1.50&quot; Segregation Valve With Isolation Sleeve in Place to Allow Setting Of Isolation Packers</td>
<td>3.668</td>
<td>1.500</td>
<td></td>
</tr>
<tr>
<td>2 7/8&quot; EUE 9RD Tubing String With Poly Liner Bull Plug</td>
<td>2.875</td>
<td>1.901</td>
<td></td>
</tr>
</tbody>
</table>
Segregation valve Assembly
Producing Wells – ESP’s

- 1100 – 1500 psig intake pressure
  - ~3000’ FL
  - CO2 in dense phase
  - No Gas Separator
  - Mixed Flow Stages
- All equipped w/ VSD’s and BH Sensors
- Continuous and Batch Corrosion Treatments
  - Mitigate predicted low pH reservoir fluids
    - pH ~ 3.5
    - High Cl
- ~ 400 psig Wellhead Pressure
  - Can produce at high GOR’s without freezing
  - Reduces need for inlet compression
Compression Overview

• Two Stage Compression – Gas Fired
  – Stage 1
    • Suction – 300 psia
    • Discharge – 700 to 800 psia
      – 10º Approach Chiller
        » Drop out any liquids
  – Stage 2
    • Suction – 700 psia
    • Discharge – 2200 psia
      – 10º Approach Chiller
  – Cooling Tower
    – 1800 psia supply to the field at 95ºF
• No Hydrocarbon Recovery
Katz SWIF and Production Satellites

Green = New or Addition
Orange = Relocated or Change
Eastern Shelf Pipeline

10” 91-mile Carbon Steel PL
1700 psig delivery pressure
Capacity  65 MMCF / Day
Thank You

• Questions?