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Society of Petroleum Engineers
Distinguished Lecturer Program
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Remediating Cusiana & Cupiagua
(Fracturing Between a Rock and a Hard Place)
(In Memory of Robert ‘Bob’ Hannah 1930 – 2007)

Martin Rylance
BP Exploration
Cusiana & Cupiagua “The Patients”
Cusiana “Anatomy of a Giant Oil Field”

Discovered: 1987
Hyd’ Type: Oil (34 - 43 API)
Hyd’ Column: +/- 1,400 ft
Recovery: Gas / Water Inj
Well Stock: 37 Producers
: 13 G-Injectors
: 4 W-Injectors
Depth: 14-16,000 ft
STOIIP: 1,564 MM.bbls
Cupiagua “Anatomy of a Giant Gas Field”

- Discovered: 1988
- Hyd’ Type: RGC (39-43 API)
- Hyd’ Column: +/- 6,000 ft
- Recovery: Gas Cycling
- Well Stock: 29 Producers
  - 11 G-Injectors
- Depth: 14-20,000 ft
- STOIIP: 1,180 MM.bbls
- Yield: 280 stb/mm.scf
Cusiana & Cupiagua “The Symptoms”

Typical PBU Results Cus/Cup

Skin = + (20 – 120)
Perm = 1 – 500 md
kh = 2,000 – 10,000 md-ft

Extremely High Skins (Formation Damage & Perforations)
Increasing Skin (Cusiana) with an increasing GOR & WC
Increasing Skin (Cupiagua) with pore-pressure depletion
Decreasing kh (Cus & Cup) with pore-pressure depletion
Cusiana & Cupiagua “The Symptoms”

- Oil Rate (mbopd)
- GOR (mscf/stb)
- Actual Oil Decline Rate (mbopd)
- Expected Decline Rate (mbopd)
- GOR Variation (mscf/stb)

Elapsed Time (Days)

- 31-Jan-1992
- 30-Apr-1992
- 29-Jul-1992
- 27-Oct-1992
- 25-Jan-1993
Cusiana & Cupiagüa “The Symptoms”
Cusiana & Cupiagua “The Illness”

Almost Linear Relationship
One Porosity Unit Equal to
Order of Magnitude of Perm

Cus & Cup Mirador
PBU N. Slope Alaska
Cusiana & Cupiagua “The Complications”

SDLA Stress State

$\sigma_v = \begin{array}{c} 0.95 - 1.00 \text{ psi/ft} \\ \sigma_h = \begin{array}{c} 0.70 - 0.80 \text{ psi/ft} \\ \sigma_H = \begin{array}{c} 1.20 - 1.60 \text{ psi/ft} \end{array} \end{array}$

Severe Faulting
Stress Rotation
Vertical Rotation
Frontal Rotation
Cusiana & Cupiagua “The Complications”

Arenite Fm. 97.0 - 98.0 % Quartz
Young’ Mod 8.00 - 12.0 MM.psi
Poisss’ Ratio 0.15 - 0.25
UCS 25.0 - 35.0 m.psi
Tensile 7.00 - 10.0 m.psi
Permeability 0.10 - 500 md
Porosity 4.00 - 8.00 %
Cusiana & Cupiagagua "The Complications"

- Perm Reduction ca. 90%
- Gas Breakout Problem
- Water Production Problem
- Cond. Dew-Point Problem
- Phase Trapping Common
Cusiana & Cupiagua “The Medicine”

1. Minimize the Solids Pumped into the Formation.

2. Optimize the Deviation, Azimuth & Perforations.

3. Maximize Integrity & Surface Treating Pressure.

Cusiana & Cupiagua “Cleanliness”

PRESSURE LIMIT

Surface Pressure (psi)
Pumping Rate (bpm)

PICKLE WITH CT 3 MTHS LATER
Cusiana & Cupiagua “Cleanliness”

Slide No. 16

Graph showing oil production rate (m.bopd) and cumulative oil (mm.bbls) from 01-Jan-1997 to 01-Jan-2002.
Cusiana & Cupiagua “Orientation”

- Deviation & Azimuth.
- Gun (SPF/PHS/Pen)
- Liner-/Hole-Size/CMT.

FRACTURE LINK-UP
Cusiana & Cupiagua “Integrity”

- Cusiana Approach
  Maximise WHTP
  Managed Liner SF
  Utilise Friction Loss

- Cupiagua Approach
  HWOU Deployed FS
  RU Directly on Tree
  Deploy Thru 7” MB
  MWHTP 18,000 psi
Cusiana & Cupiagua “Stacked Fracs”

• Cusiana Approach
  Sand-Back Sand-Plugs
  Millable Composites
  (Underbalance Driver)

• Cupiagua Approach
  All Zones Perf & Flow
  Isolate Upper w/ PKR
  Isolate Lower w/ Sand
  PKR Re-Set after Frac
Cupiagua “The Recovery”

- **GOR (m.scf/bbl)**
- **Cum. Oil (mm.bbls)**
- **Oil Rate (mbopd)**
- **Gas Rate (mm.scf/d)**

*Elapsed Time:*
- 01-Jan-1999
- 31-Dec-2000
- 31-Dec-2002
- 30-Dec-2004
- 30-Dec-2006

*Graph shows changes in oil production rate over time.*
Cusiana & Cupiagua “The Patient”

- **Cupiagua Production (bopd)**
- **Cusiana Production (bopd)**

Daily Production (mbopd)

- May-91
- May-92
- May-93
- May-94
- May-95
- May-96
- May-97
- May-98
- May-99
- May-00
- May-01
- May-02
- May-03
- May-04
- May-05
- May-06
- May-07
- May-08
Cusiana & Cupiagua “The Summary”

FRACTURING PROGRAMME

• Over 170 Fracs performed between 1995 – 2008
• Over 25 mm.lbs of 12/18, 16/20 & 20/40 placed
• Largest Fracs/Highest Pressures in S. America
• Over 180 km of Frac-String run through-tubing

CUSIANA & CUPIAGUA RESERVOIRS

• Current Cumulative Recovery 1,100 MM.bbls
• Cusiana & Cupiagua Wells (100 – 200 mm.scf/d)
• Cusiana & Cupiagua > 5 Tcf Gas Reserves
Remediating Cusiana & Cupiagua
(Fracturing Between a Rock and a Hard Place)

QUESTIONS ?