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UNDERSTANDING THE PRESSURE CYCLING IN-SITU COMBUSTION PROCESS (PC-ISC) IN THE MORGAN FIELD: POTENTIAL APPLICATIONS TO POST-CHOPS RESERVOIRS

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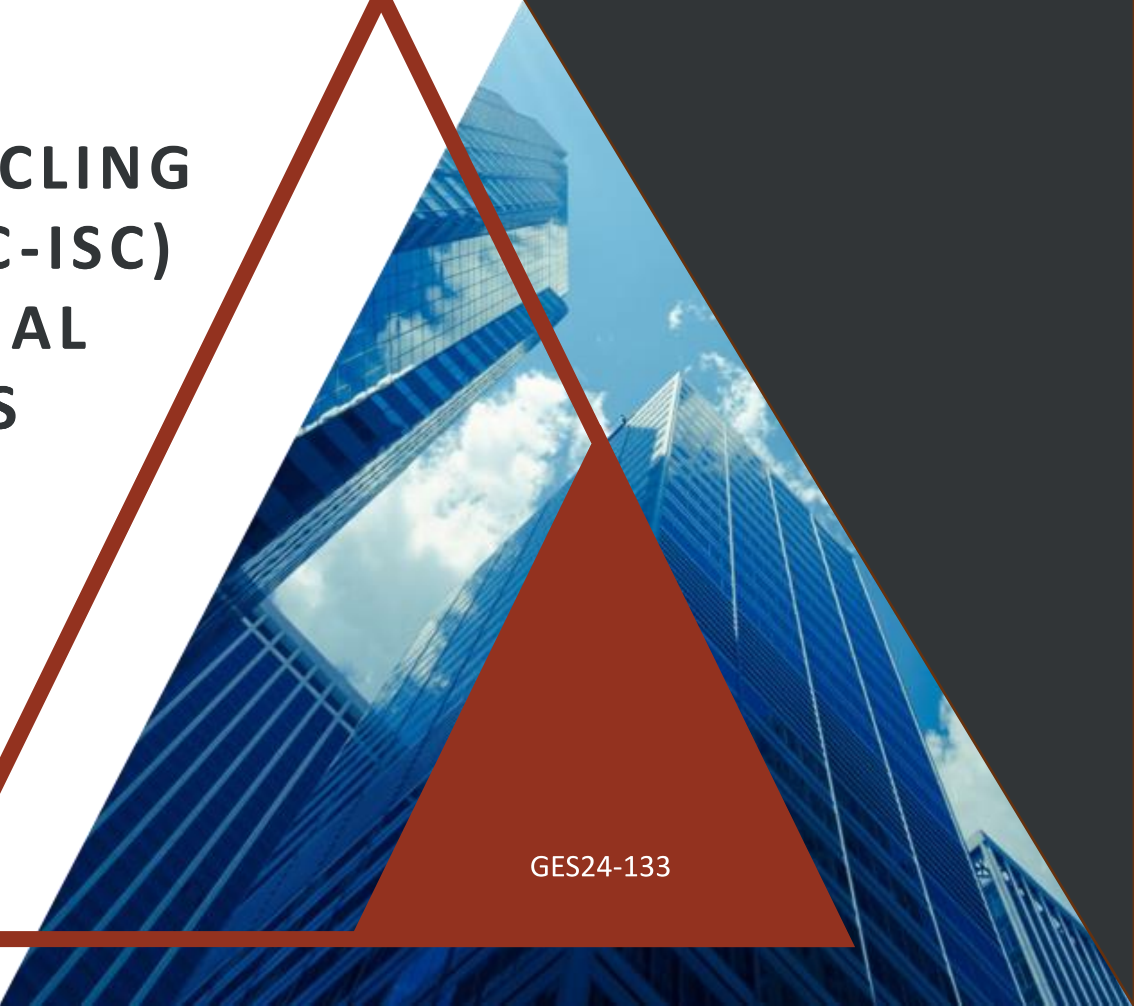


GES24-133

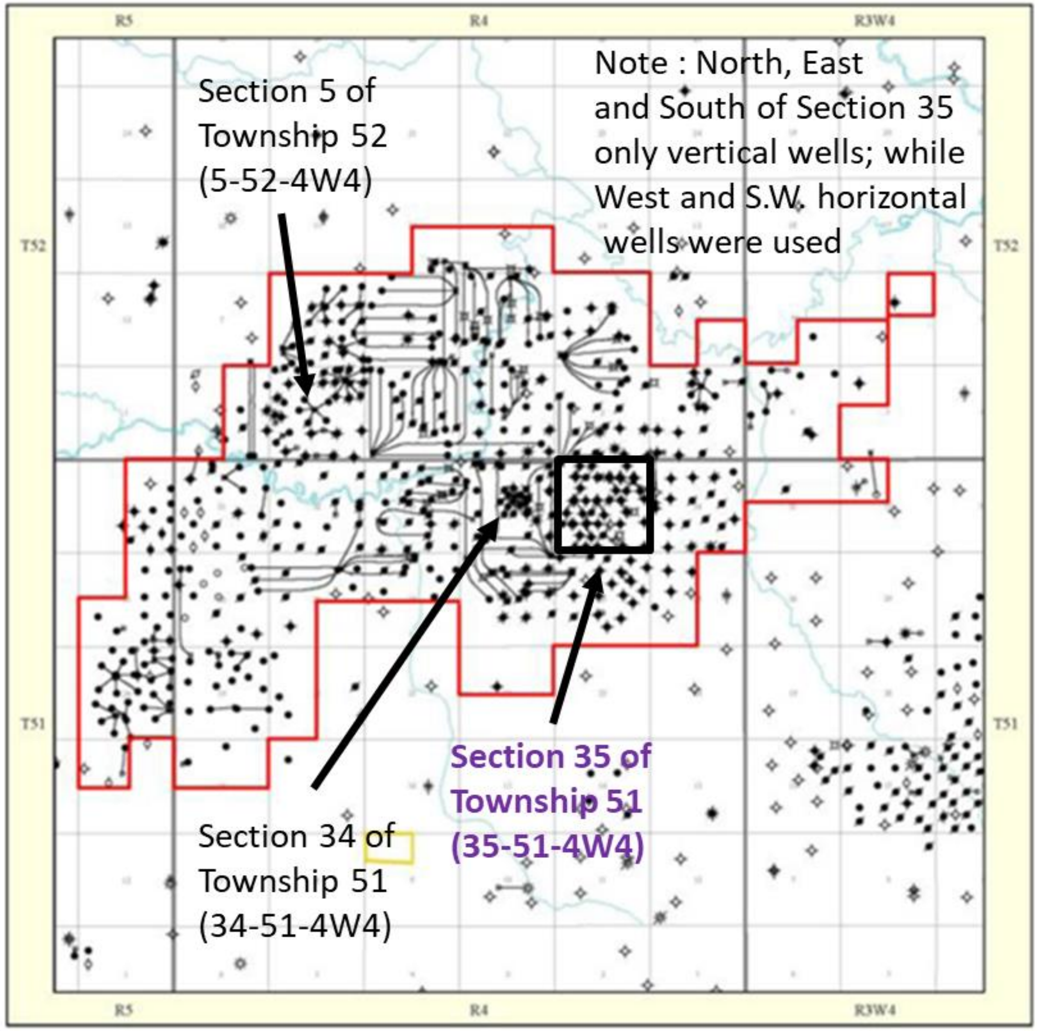
OUTLINE

- Morgan Field
- Development of Section 35
- Pressure Cycling ISC Operations
- Key Performance Observations
- Summary
- Recommendations & Future Work

MORGAN FIELD

- ❖ Location
  - NE Alberta
  - T51-52R3-5W4 → over 20 sections
- ❖ Reservoir
  - Lloydminster Formation
  - Thin sands: ~ 10 m average thickness
    - Relatively clean: permeability ~ 2 Darcies
  - Heavy oil → gravity 11-12 °API
    - Mobile: 6,800 mPa·s at 21°C (live)

Morgan Wells



Section 5 of Township 52 (5-52-4W4)

Note : North, East and South of Section 35 only vertical wells; while West and S.W. horizontal wells were used

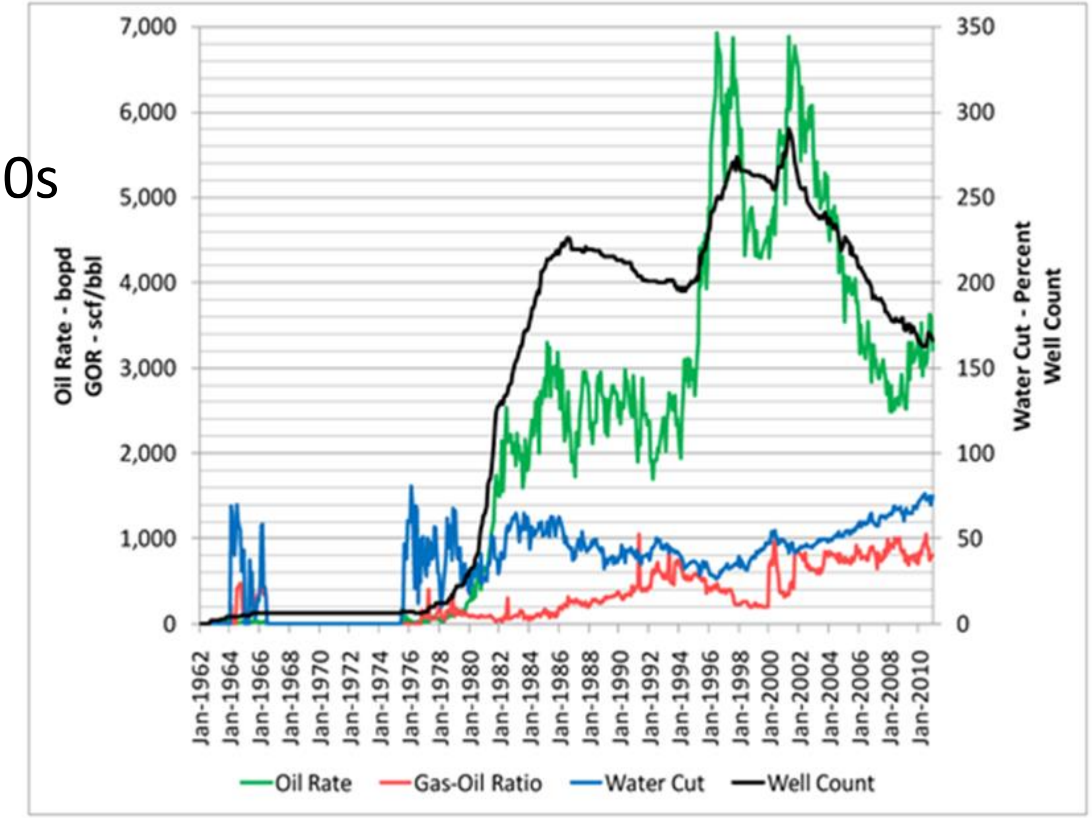
Section 35 of Township 51 (35-51-4W4)

Section 34 of Township 51 (34-51-4W4)

MORGAN FIELD

- ❖ Exploitation
  - Multiple operators
  - Majority of development → early to mid ’80s
  - Cumulative recovery ~ 5-6% (to 2010)
- ❖ Recovery Schemes
  - Mainly primary production
  - Technology improvements in ‘90s
    - PC pumps and horizontal wells
  - EOR pilots in ‘80s
    - CSS, ISC, others → limited success
    - Exception: **Section 35-51-4W4**
  - Combined Thermal Drive pilot
    - Stimulation in phases: steam, steam-air; then ISC

Morgan Fluid Production

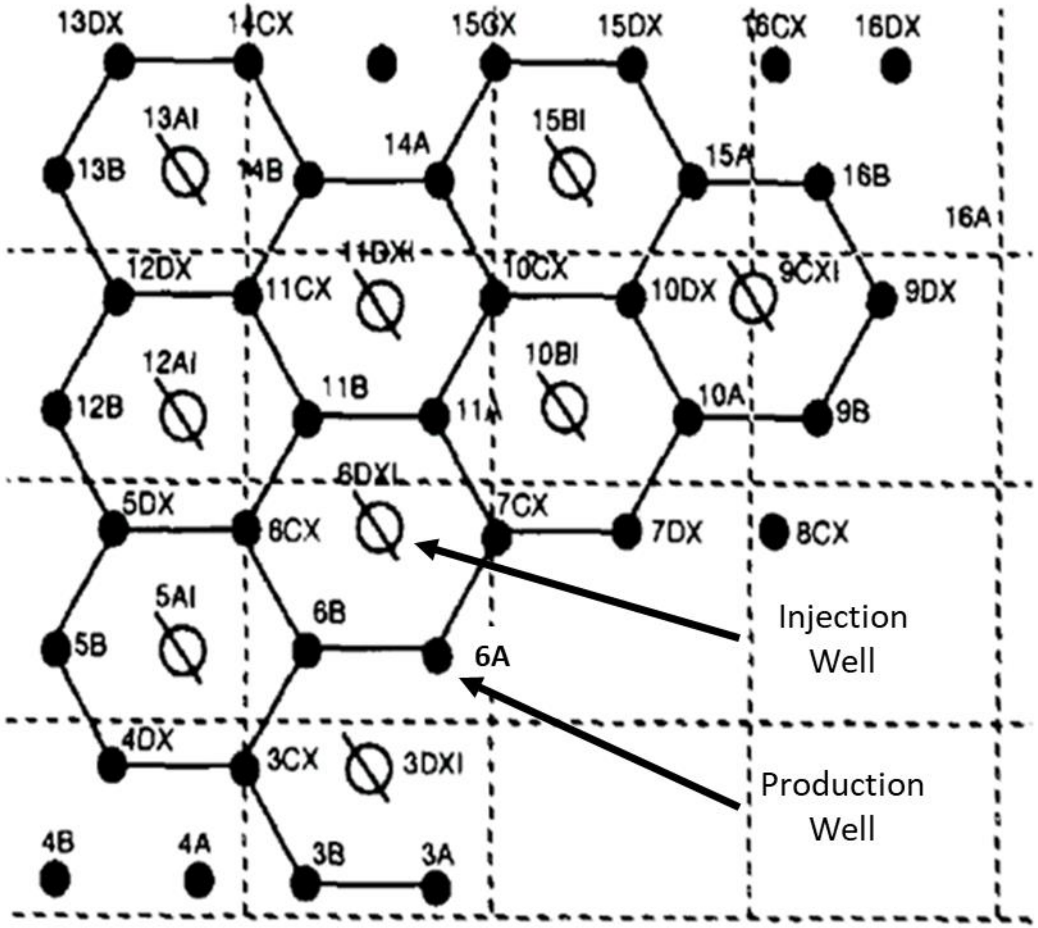


Source: Gutierrez et al., 2011 (SPE-150593)

SECTION 35 DEVELOPMENT

- Initial Production
  - Brief primary production period: 1980-81
  - Small number of wells, low production rates
- Thermal Operations
  - Inverted 7-spot patterns → 30 acres/pattern
    - 45 wells on 10-acre spacing (vert/dev)
  - **First phase → cyclic stimulation of wells**
    - Initially steam injection, later steam/air
  - Total of 9 cycles: 1981-85
    - Cycle 1 → only CSS
    - Cycles 2-6 → some wells CSS, some CSAS
    - Cycles 7-9 → only CSAS

Thermal Well Patterns



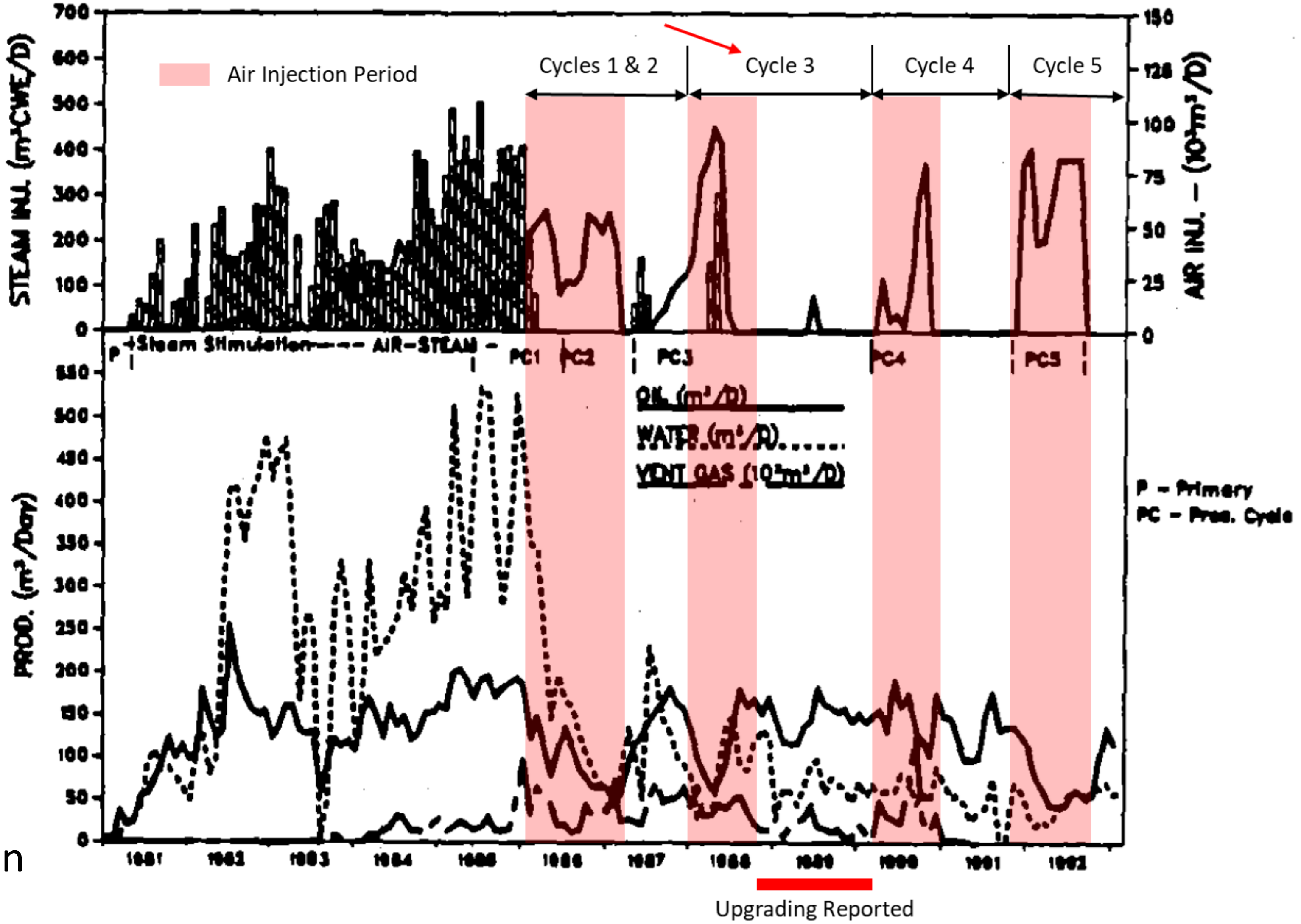
Source: Marjerrison & Fassihi, 1994 (SPE-27793)

SECTION 35 DEVELOPMENT

- Thermal Operations
  - **Second phase → air injection into patterns (i.e., PC-ISC)**
    - Central injector, surrounded by producers
    - Two stages
      i. Air injection at injectors, producers shut in
      ii. Air injection stopped, producers re-activated
  - Total of 5 cycles: 1986-92
    - Cycles 1-2 → transition from continuous to periodic air injection
      - Initially low air injection rates, producers open
      - Producers shut in as gas slugging and sand influx became problematic
      - Then air injection rates increased until pressure reached a target level ~ 7.0-7.5 MPa
    - **Cycles 3-5 → separation of air injection and oil production stages**

THERMAL PILOT PERFORMANCE

- ❖ Cyclic Stimulation
  - Addition of air to steam
    - Stimulated oil production, slowing increase in SOR
- ❖ PC-ISC
  - Injection/production
    - Very long periods for both > 7 months
  - Ignition/re-ignition
    - Very long process for ignition in cycle 1 and re-ignition in subsequent cycles
    - Standard ignition procedure (via SS) only in 4 W patterns



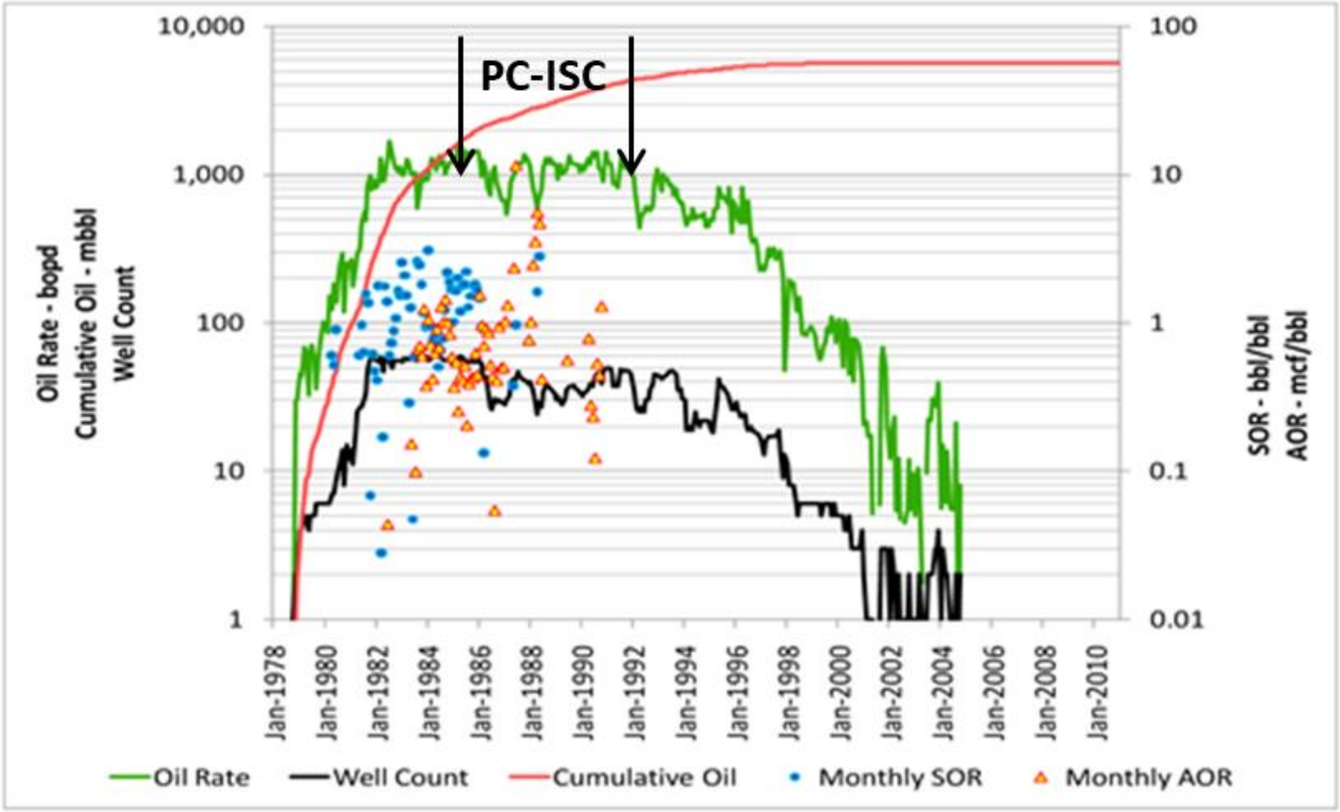
Section 35 Injection & Production History

Source: Marjerrison & Fassihi, 1994 (SPE-27793)

PC-ISC PERFORMANCE

- Oil Production
  - During PC-ISC pilot period
    - Sustained plateau in production rates
  - Following PC-ISC pilot period
    - Persistent rate of production at significant levels for nearly 10 years after PC-ISC operations ended
- Recovery Factor
  - During entire exploitation period
    - Comparatively high
      ~ 22-23% across Section 35

Section 35 Production History

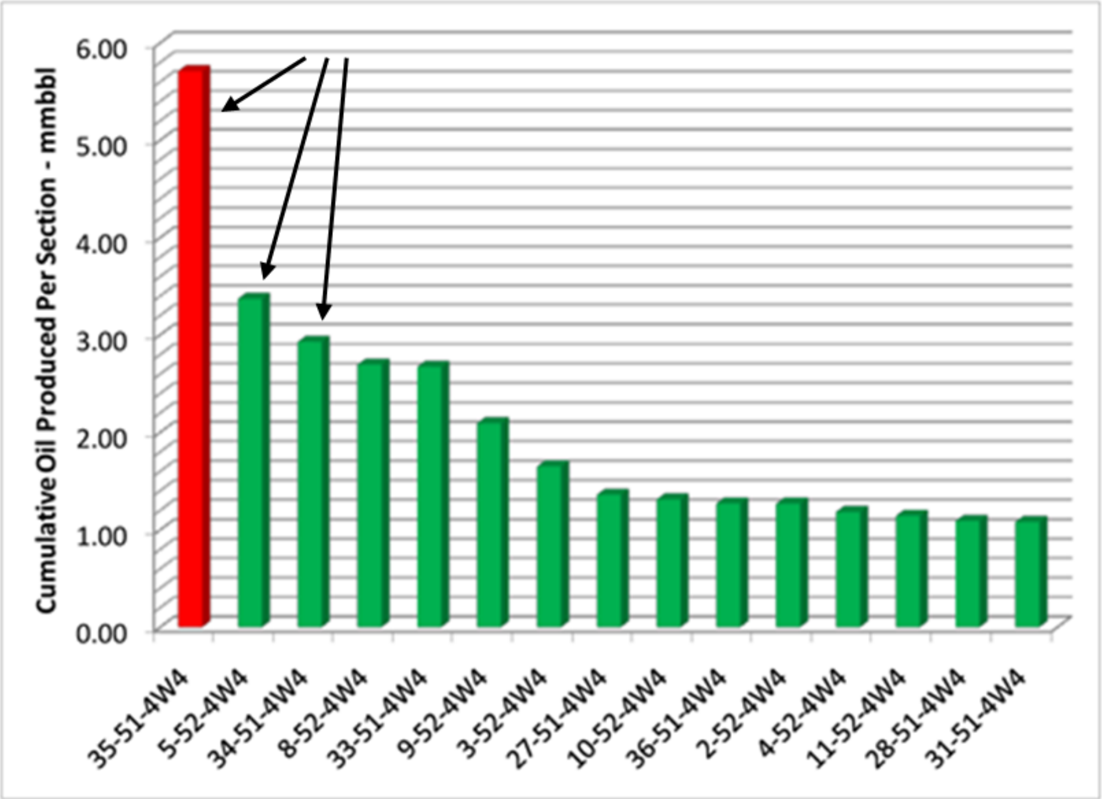


Source: Gutierrez et al., 2011 (SPE-150593)

PC-ISC PERFORMANCE

- Characteristics
  - High oil production rates → 5-20 m^3/d/well
  - Unusually low AOR → 350-450 sm^3/m^3
  - Periods of significant in situ upgrading
    12 °API → 22 °API
  - Relatively high oil recovery factor despite large ISC well spacing
  - No damage to production wells
- Key Features
  - Unconventional ISC process
    - Reservoir pre-heating from CSS, CSAS
    - Circumstantial evidence of local ISC fronts and local high-permeability channels

Morgan Production by Section



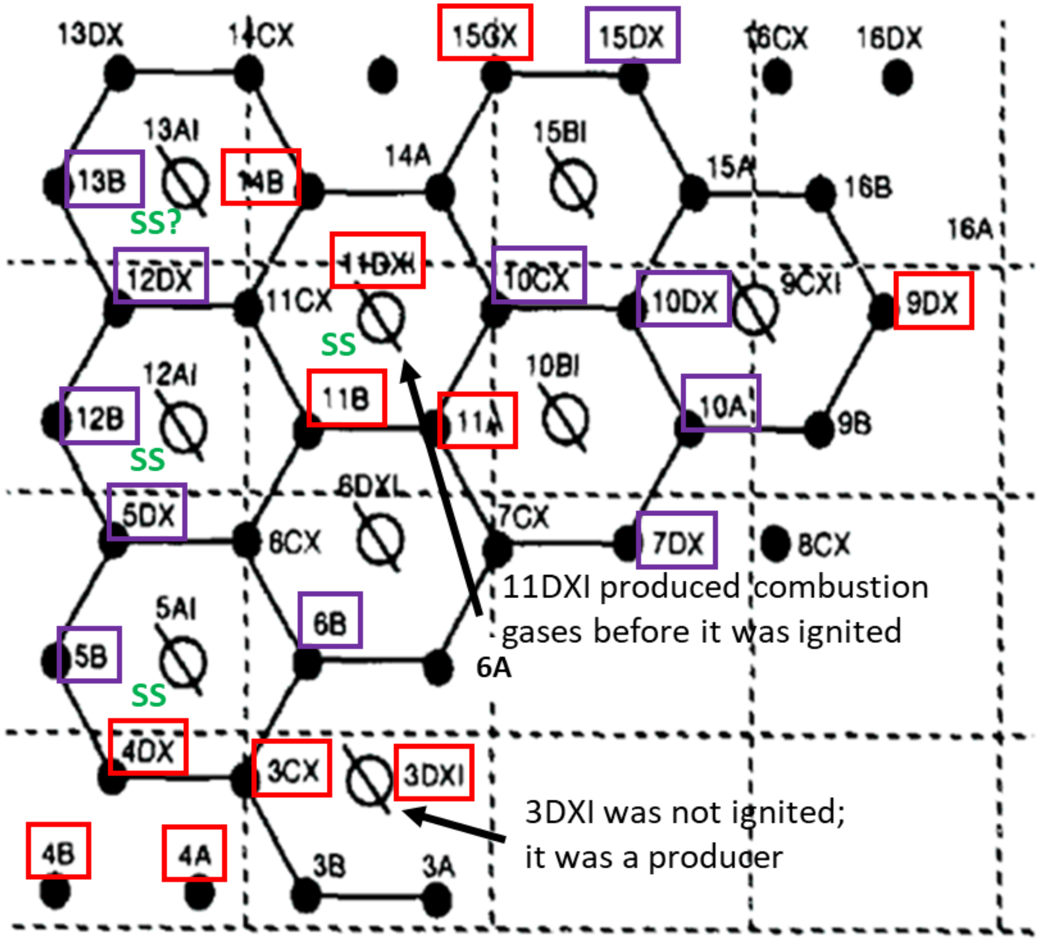
Source: Gutierrez et al., 2011 (SPE-150593)

KEY PERFORMANCE OBSERVATIONS

- ❖ Burn Quality
  - Wide range across section
    - Inferred from H/C ratios in produced gas

      Indicates variable conditions at ISC fronts

      → HTO and/or LTO regimes
  - Relatively low consumption of O_2 in HTO reactions
    - HTO/LTO → 60/40
- ❖ Produced Gas Composition
  - Atypical for ISC
    - Relatively low CO_2 concentrations
    - Relatively high CH_4 concentrations



11DXI produced combustion gases before it was ignited

3DXI was not ignited; it was a producer

🟥 Wells associated with mainly HTO regime

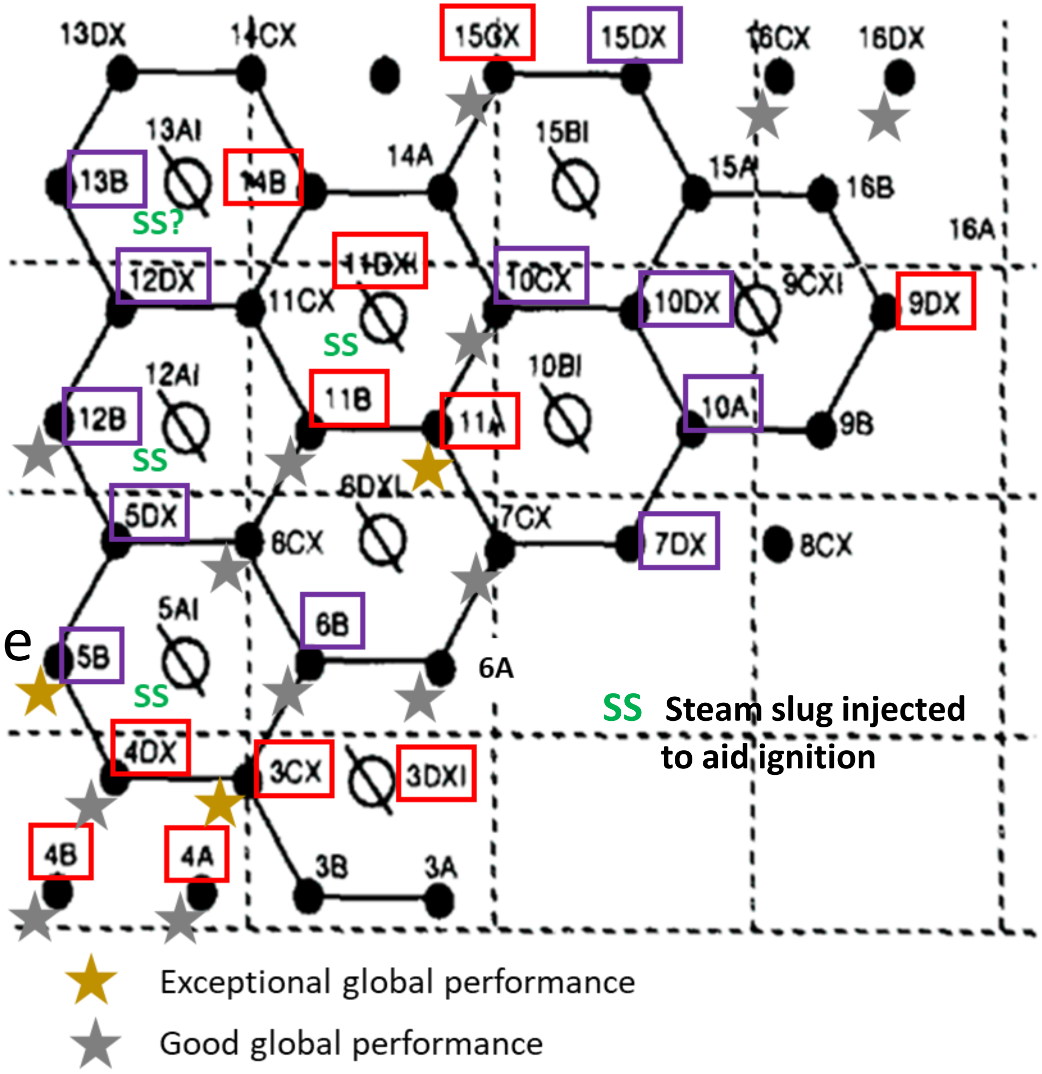
🟪 Wells associated with combined HTO and LTO regimes; unmarked wells associated with mainly LTO regime

SS Steam slug injected to aid ignition

Burn Quality in Section 35

KEY PERFORMANCE OBSERVATIONS

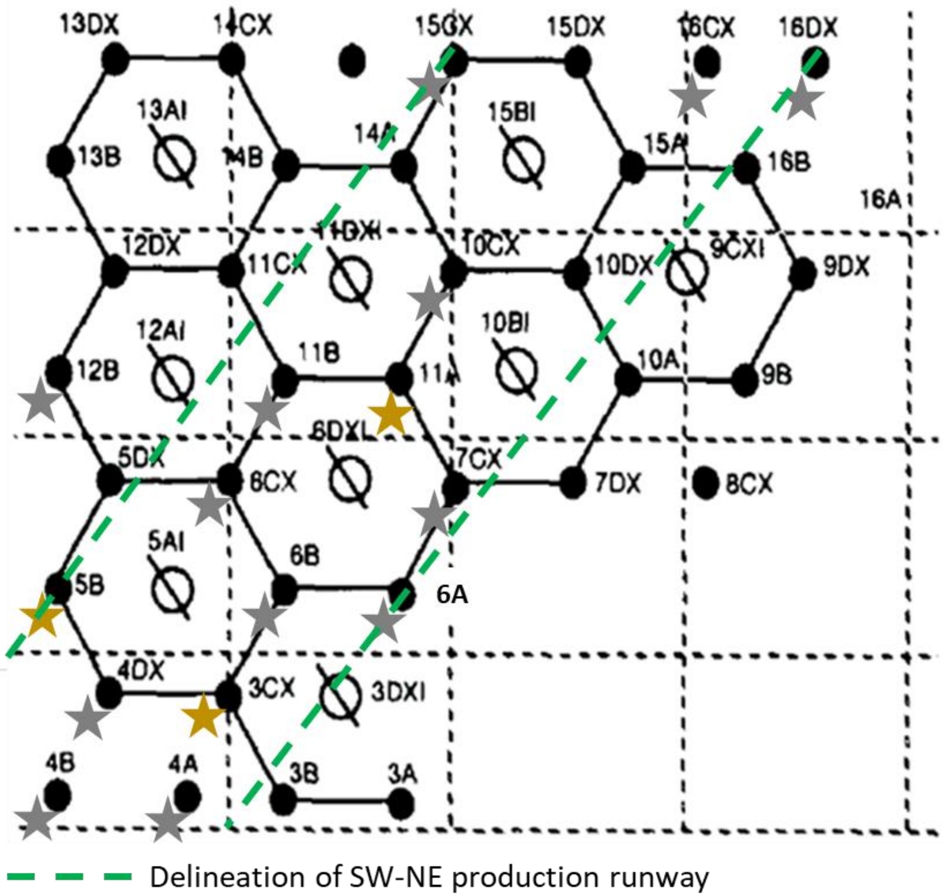
- Global Production Performance (GPP)
  - Although *GPP* varied across section, all wells reacted positively to ISC
  - No consistent trend between good global producers and good CSAS or CSS performance or presence of HTO regime
    - Ignition procedure was a more important factor in determining subsequent burn quality
    - Good PC-ISC producers were also good global producers
    - Some good global producers very far from nearest location of wells with HTO regime
      → NE producers



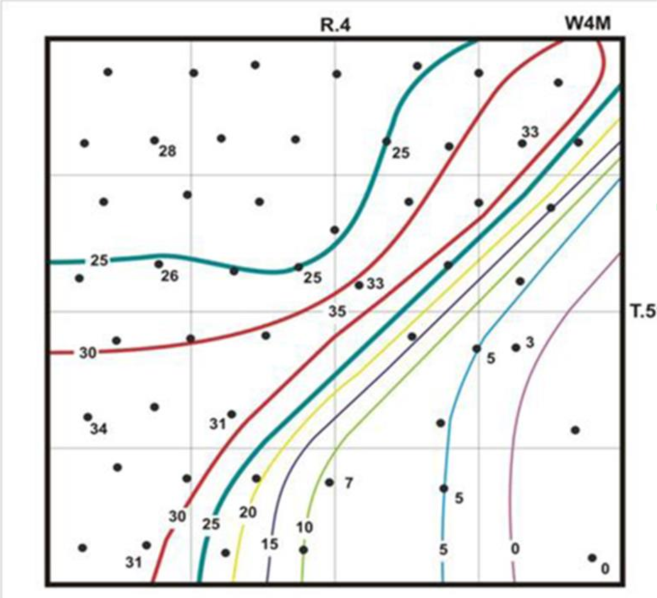
Global Production Performance in Section 35

KEY PERFORMANCE OBSERVATIONS

- ❖ Production Behaviour
  - Almost all good global producers located in a “runway”, with a SW-NE trend
    - Location of runway coincident with highest net pay
    - Likely also highest permeability trend



Runway in Section 35



Source: Gutierrez et al., 2011 (SPE-150593)

KEY PERFORMANCE OBSERVATIONS

- Sand Influx
  - Reports of persistent sand influx throughout period of thermal pilot operations
    - Poor documentation at the well level in publicly available reports
    - Primarily represented at the section level by the number of service jobs (i.e., a proxy) performed each month
  - Volume of produced sand across the section

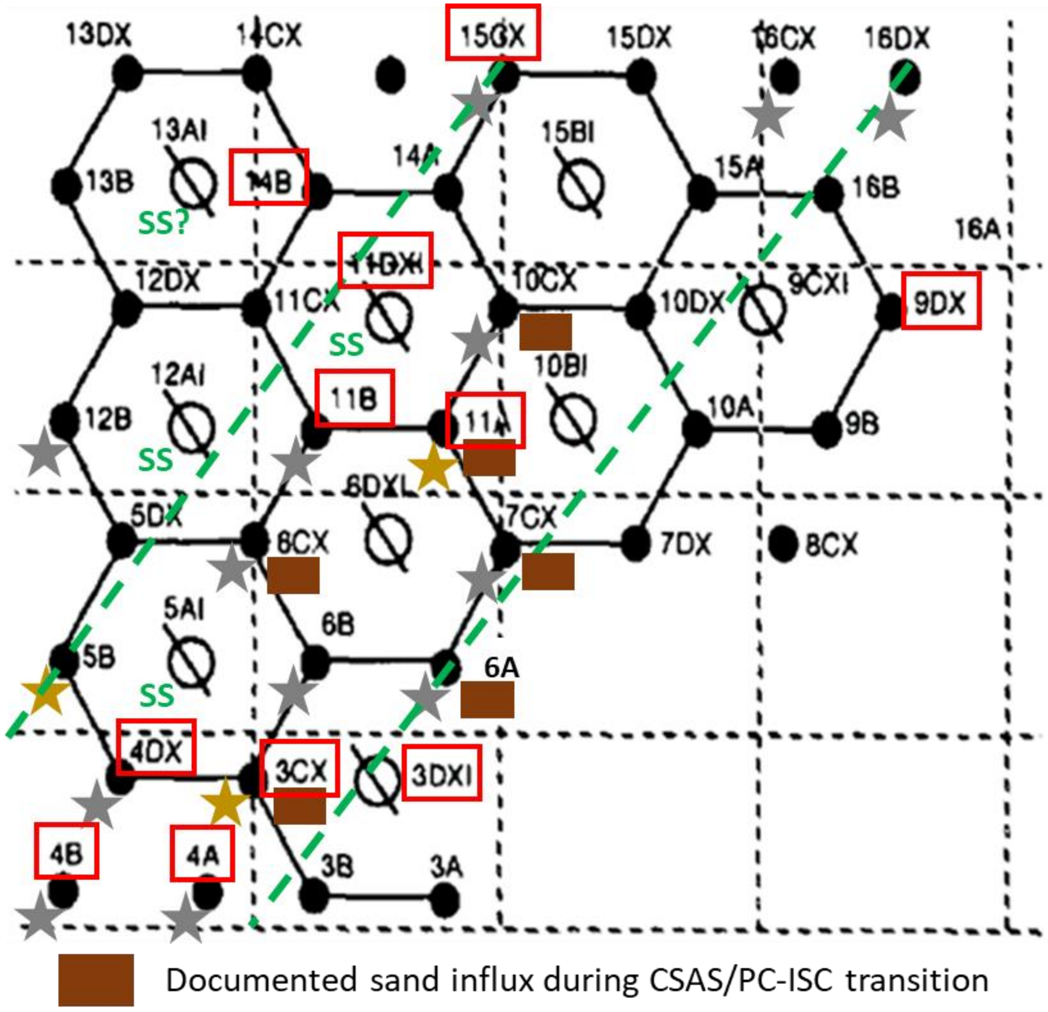
    ~ 1,000 m^3/year (anecdotal)

    - Average volume **per well** relatively small (compared with CHOPS)

      ~ 20 m^3/year

KEY PERFORMANCE OBSERVATIONS

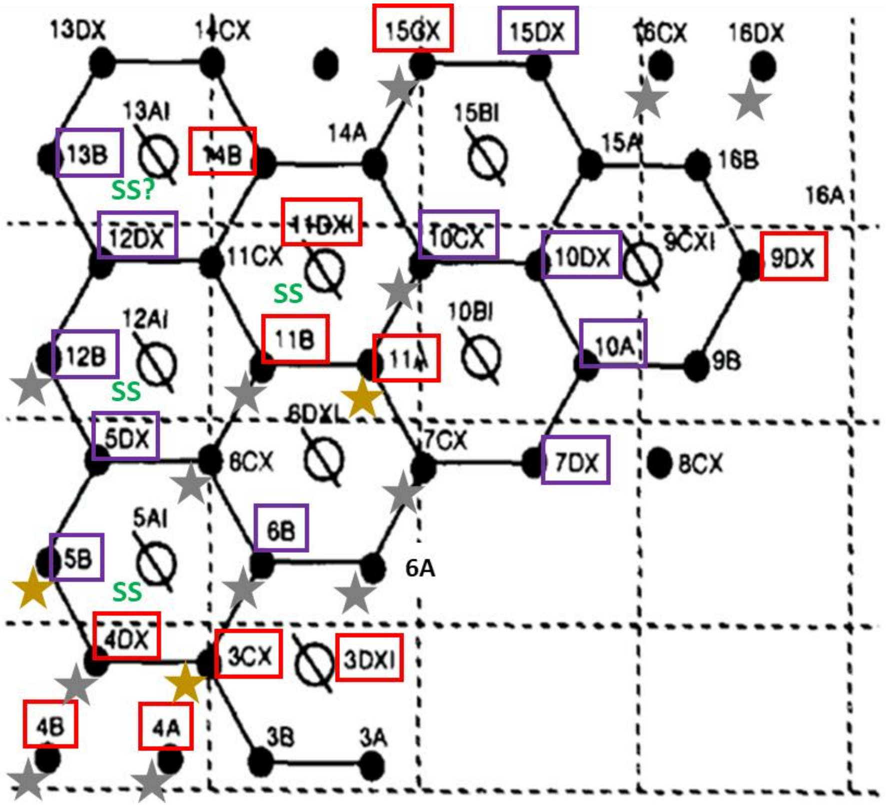
- Sand Influx
  - Increased levels of sand influx during transition from CSAS to Cycles 1-2 of PC-ISC
    - Well servicing frequency doubled initially during the transition compared with its average during CSS
    - Servicing frequency became elevated again during later cycles of PC-ISC
  - Indicates greater volumes of sand produced during these periods



Reported Sand Influx in Section 35

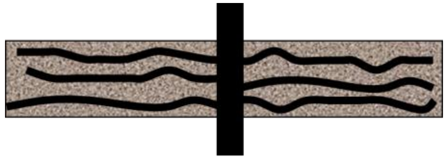
KEY PERFORMANCE OBSERVATIONS

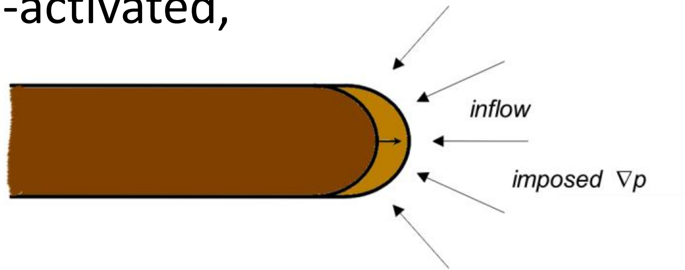
- Channelling
  - No continuous channel between two wells developed during CSS/CSAS operations
    - No steam breakthrough to offset wells during CSS
    - Limited reports of gas breakthrough during CSAS
  - Anomalous production behavior at some wells in NE patterns during Cycles 1-2 of PC-ISC
    - Despite lack of air injection in these patterns, they produced ~ 40% of the injected volume of gas
    - Good oil production from these patterns
    - Also high methane production



KEY PERFORMANCE OBSERVATIONS

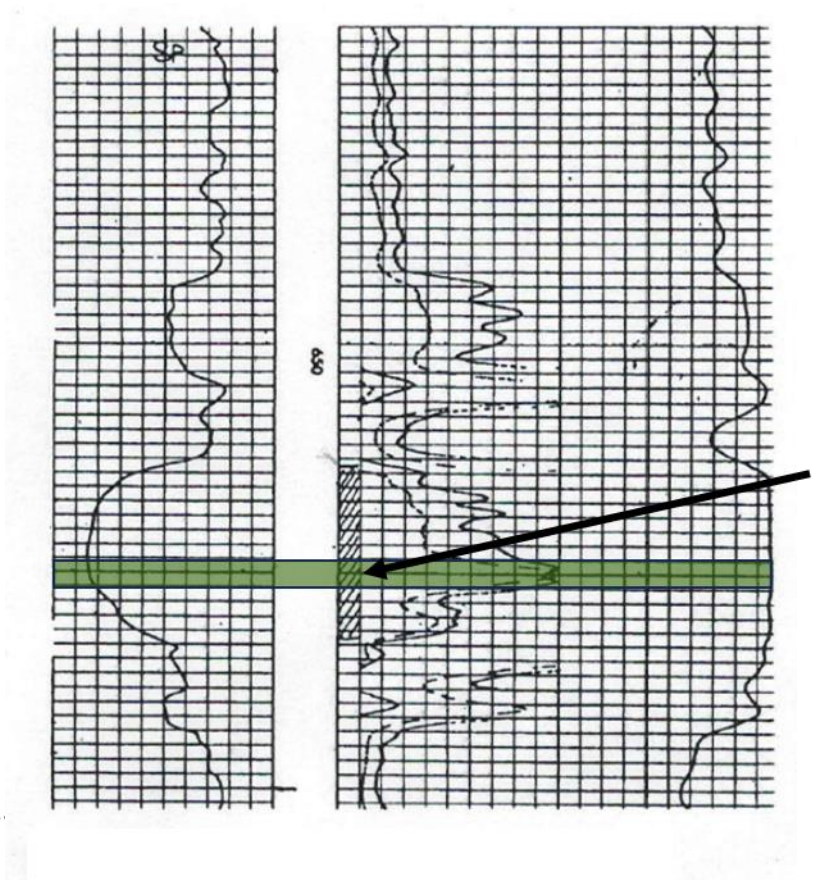
- High-Permeability Channels (HPC)
  - Network likely developed primarily during late stages of CSAS and Cycles 1-2 of PC-ISC
    - During CSS & CSAS, channels likely limited to near-well region, for all wells
      → subsequent PC-ISC producers and injectors
    - **During PC-ISC, channels emanated from producers toward pattern injectors**
      → likely highly directional, favouring SW-NE direction (i.e., along runway)
      - Channels may have become extended during later cycles of PC-ISC
  - Development mechanism
    - Large pressure gradients initiated at producers when they were re-activated, exceeding local threshold for sand matrix failure
      → generated growth of channels
    - Existence supported by results of previous simulation study
      - See Marjerrison & Fassihi, 1994 (SPE-27793)





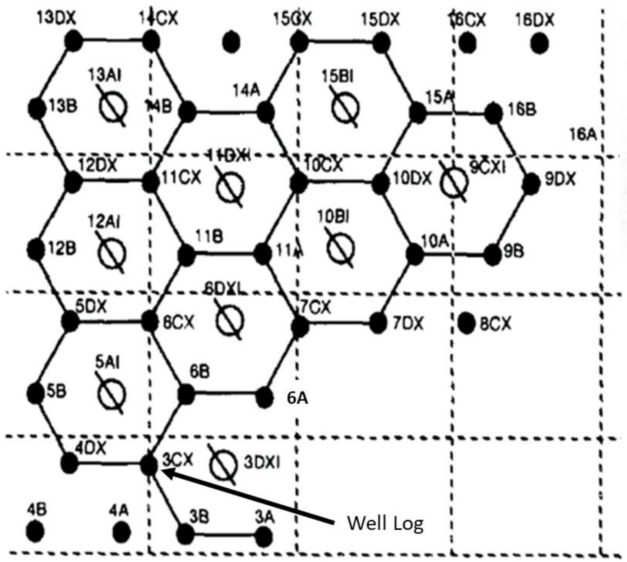
KEY PERFORMANCE OBSERVATIONS

- Channel Networks
  - Likely confined primarily to a layer in lower half of the pay
  - Preferred interval
    - Cleanest sand (GR) / highest oil saturation (IL)



Preferred Channel Interval

Well Log for 3CX



SUMMARY

- Morgan PC-ISC Pilot
  - Successful application of ISC in heavy oil
  - Very good performance metrics
    - Persistent high oil production rates, relatively high recovery factor
    - Unusually low AOR, periods of significant in situ upgrading
- Key Features
  - Unconventional ISC process
    - Reservoir pre-heating
    - Pressure cycling, consisting of alternative stages of air injection and oil production for long periods
      - Lead to formation of local ISC fronts
      - Important role played by local networks of high-perm channels

SUMMARY

- Role of High-Perm Channel Networks
  - Facilitated production behaviour
    - Factor in generation of local ISC fronts
    - Transport of heated/upgraded oil ahead of burn front over long distances to producers
      → most pronounced for producers in NE patterns
    - Improved distribution of heat within reservoir
    - Effective "foamy oil" drive → expansion of gas bubbles in oil phase

- Further Analysis of PC-ISC
  - Deeper examination of the influence of high-perm channel networks on:
    - Generation and stability of local ISC fronts
    - Features of oil/gas transport from reservoir to producers
    - Generation and preservation of significant oil upgrading

RECOMMENDATIONS

- Design a PC-ISC Pilot
  - Methodology

    a) Semi-analytic studies based on physical principles of reservoir behavior
      - To constrain range of potential scenarios for characterization of various reservoir features (e.g., permeability variation), pre-heating procedures and PC-ISC operations in order to develop local ISC fronts

        → Assessment of reservoir response under different scenarios

    b) Numerical reservoir simulation studies
      - To develop a **quantitative** assessment and comparison of dynamic reservoir response to a set of scenarios generated by **a)** above
  - Aim → to assess applicability of PC-ISC to post-CHOPS reservoirs

ANALYSIS TO SUPPORT PILOT DESIGN

- Role of High-Perm Channel Networks
  - Influence on PC-ISC performance
- Pre-Heating Procedure
  - Focus on efficiency and generation of hot communications paths
- PC-ISC Operations
  - Identify sweet spots for air injection
  - Establish potential local ISC fronts
- Confinement
  - Identify impact of PC-ISC on distant offset wells
- Economics
  - Update 2011 analysis of Gutierrez et al. (SPE-150593)

Thanks for your attention.

Questions?

Project team members

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Reza Fassihi, Beyond Carbon, Houston
Dubert Gutierrez, AnBound Energy, Calgary
Ron Sawatzky, retired, Edmonton

BACK-UP SLIDES

Summary of factors/mechanisms explaining the observed spectacular results

❑Higher permeability interval located towards the bottom

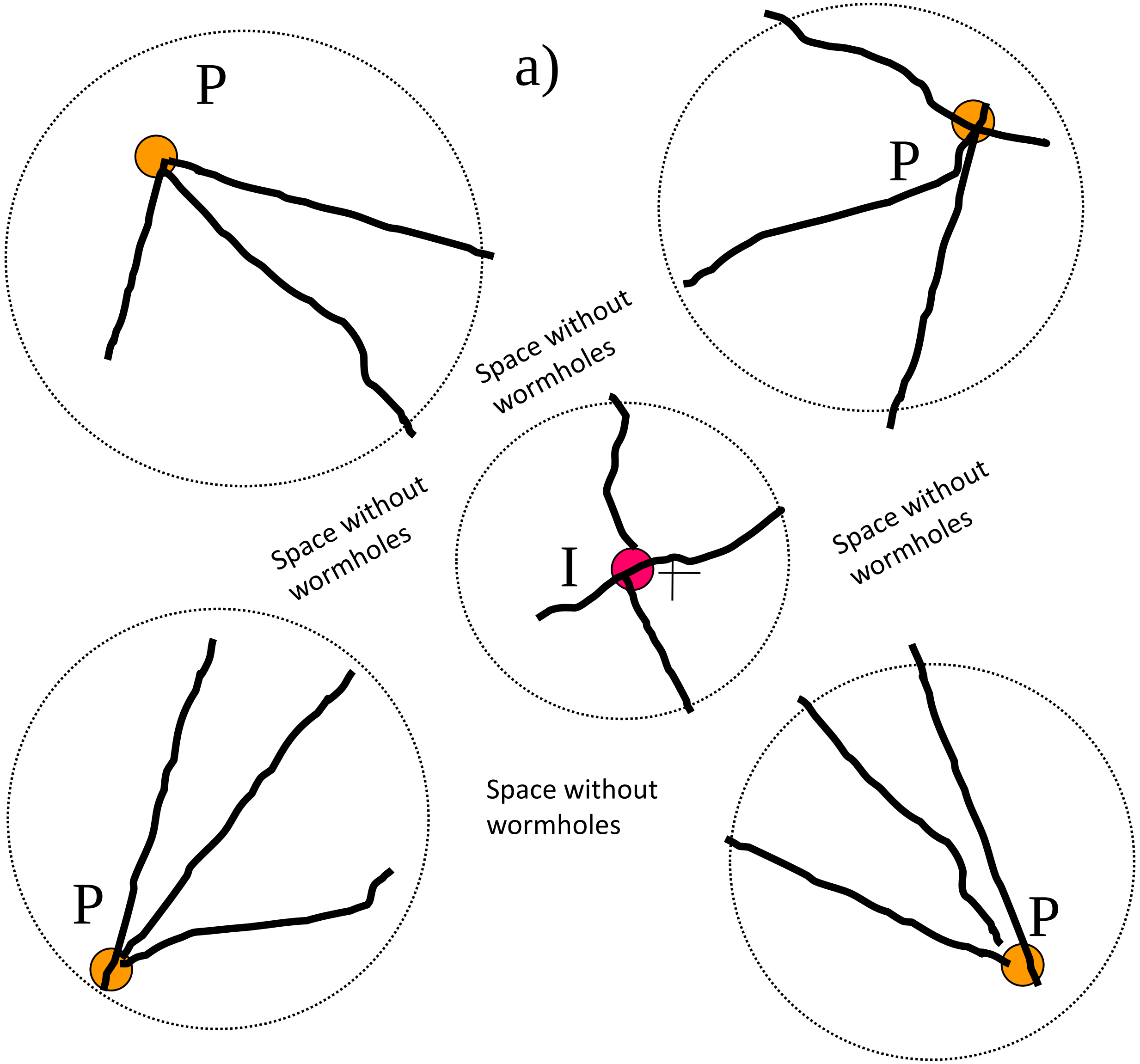
of formation **causing:**

❑Predominant generation of the wormholes (high permeability channels) at the bottom of the formation, **making possible:**

  - ❑Minimization of the heat losses in adjacent formations both for CSS/CSAS and PC-ISC
  - ❑Potential of the operation of a THAI-style oil displacement along and above the wormholes, during PC-ISC, **leading to:**

❑In-situ upgrading of the produced oil as related to short-distance operation of local ISC fronts via these wormholes

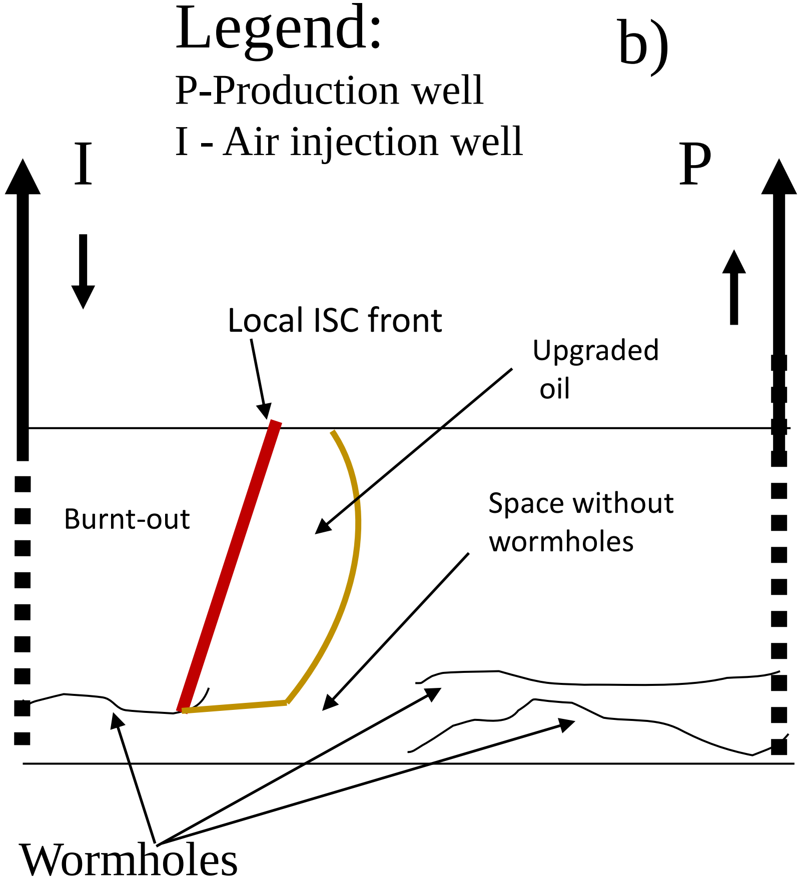
Plan view and cross section of the schematic wormholes in an inverted pattern with pressure cycling ISC (PC-ISC) application. Local channels network (LCN) around injection well and production wells are shown. LCN are located towards the bottom of the formation. Ultrasimplified



Legend:

P-Production well

I - Air injection well

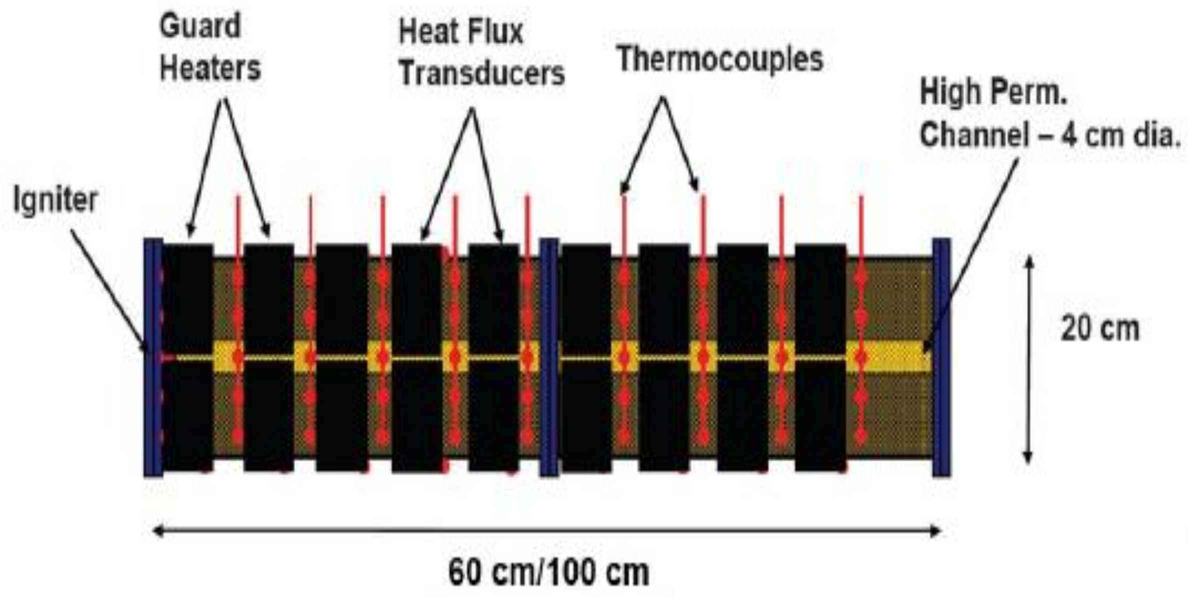


Note: The above schematic shows the location of the upgraded oil at the end of air injection stage of the PC-ISC cycle

Upgrading During THAI Process with a Single Wormhole

- Systematic laboratory investigations by ARC/AITF (2005-2006); 7 tests in a cylindrical model
- Quasi-adiabatic 20cm-diameter tube of 1m – length, operated horizontally

“Wormhole” on the axe of the tube (from inlet to outlet) that was filled with sand of extremely high permeability(50 times higher than that of the surrounding sand) *or even open cylindrical channel (a ceramic tube) with a diameter of 4cm; single test with open channel.*



Schematic of Experimental Model

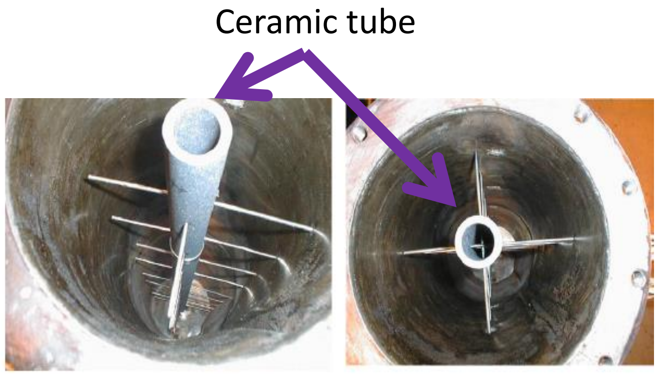
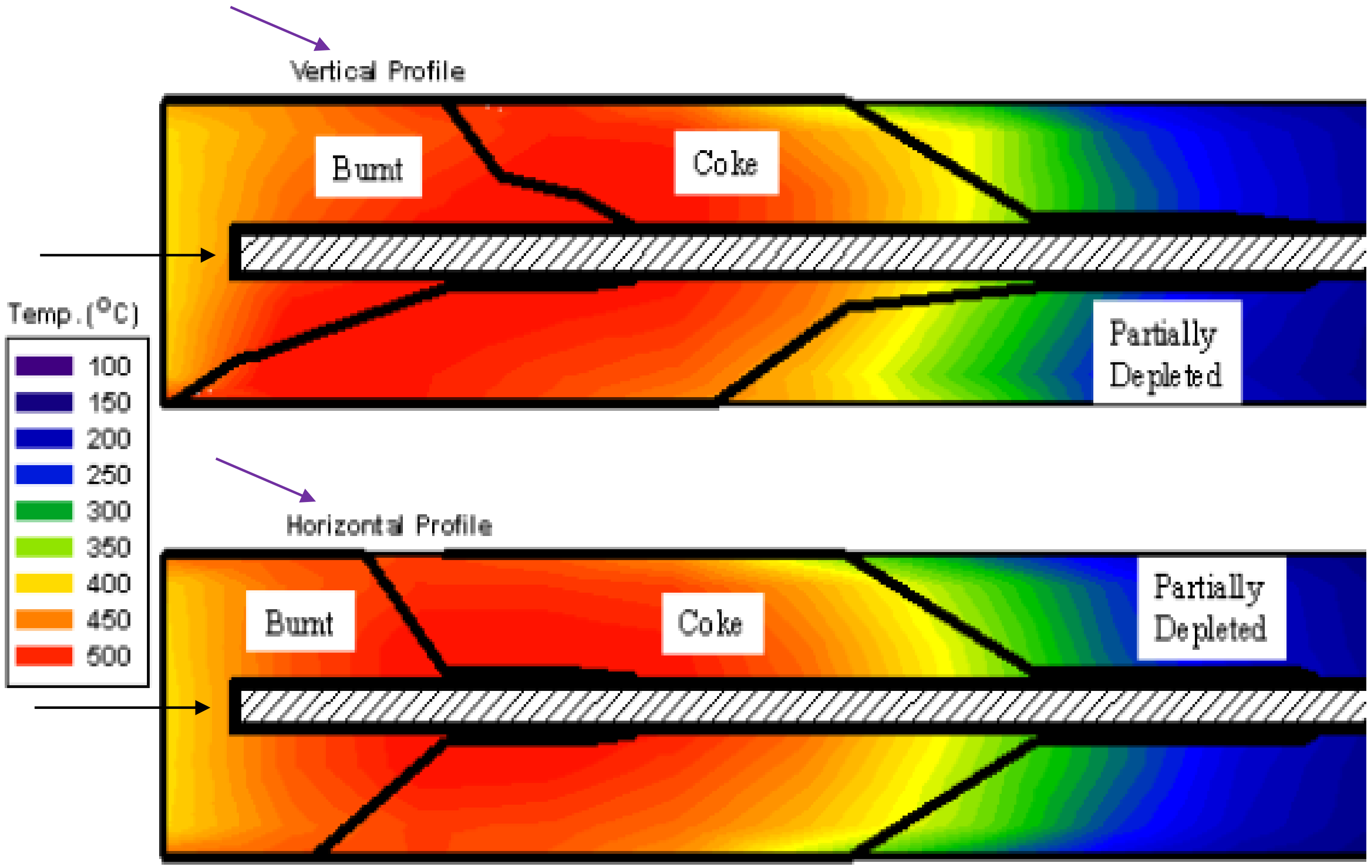


Figure 4 Photographs of Ceramic Tube in Experimental Set Up – Test 7

Chen & Coates, 2012

Propagation of the ISC front along a single “wormhole”



Note: The inlet was maintained at approx. 400 °C (strong pre-heating)

31hr run schematics of burnt out, coke and virgin zones

Chen & Coates, 2012

ISC after CHOPS – single channel, laboratory tests

- The results of the 7 tests were very encouraging, because:
- - Good lateral development of combustion around the single wormhole; no channeling of the ISC front
  - The test also confirmed the local blockage in the high permeability channel, on which the THAI process is based. In reality, it was a THAI test carried out in a non-ideal approach as the single “wormhole” was not located close to the bottom of the tube but mid-way vertically
  - Oxygen utilization was very high for such models with a very large-diameter “wormhole” from inlet to outlet
  - The tests performed in a predictable manner, all along the duration of the test
- **The results are very important in view of a potential field testing with the advantage of the current ISC knowledge; however, the Morgan project is more complex: it constitutes an attempt to evaluate the effect of multiple wormholes**
- Intensive preheating in the laboratory test was easily assured. However in the field is not so straightforward, as this has been made using CSS/CSAS operations.