Optimisation of Steam Assisted Gravity Drainage [SAGD] for improved recovery from unconsolidated heavy oil reservoirs

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Presentation at:
4th European Sand Management Forum, 10th & 11th March 2010

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- Reservoir Management
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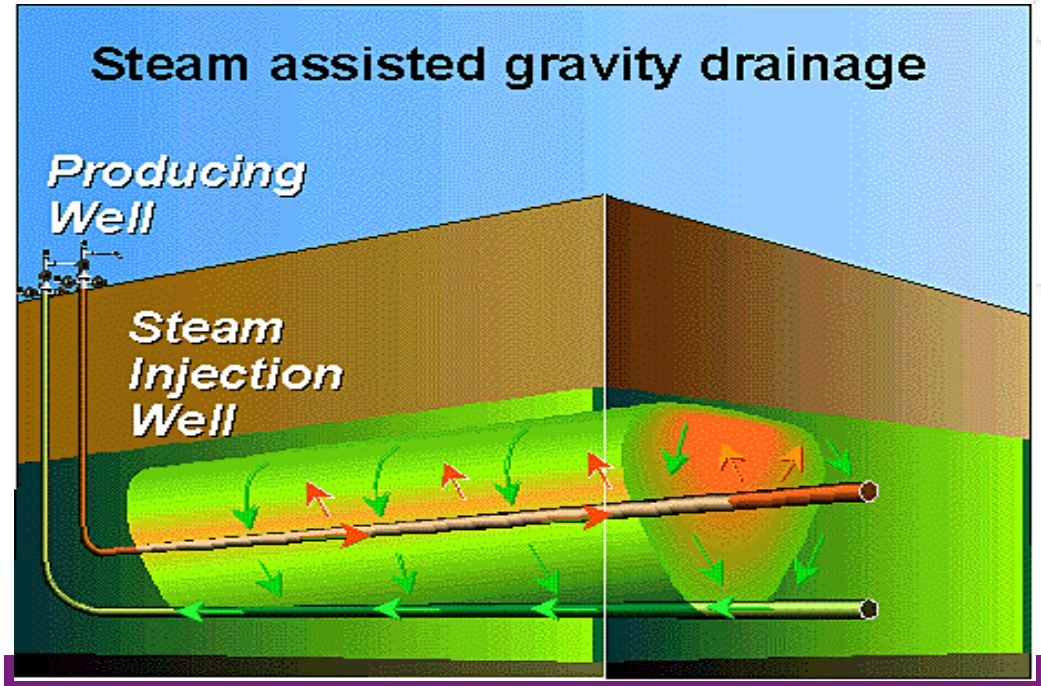
Background

- Reserves- conventional 1.3 & Heavy 5.5TB
- Heavy oil – 0.93SG & >200 cp viscosity
- Less mobility
- Appropriate recovery mechanics
- Enhanced Oil Recovery
  - Thermal
  - Cold
- Steam Assisted Gravity Drainage (SAGD)

What is SAGD?

- Two parallel & vertically aligned horizontal wells
- Upper-Injector & Lower-Producer
- Potential recovery factor >= 60%
- Steam-Reduces Viscosity
- High mobility

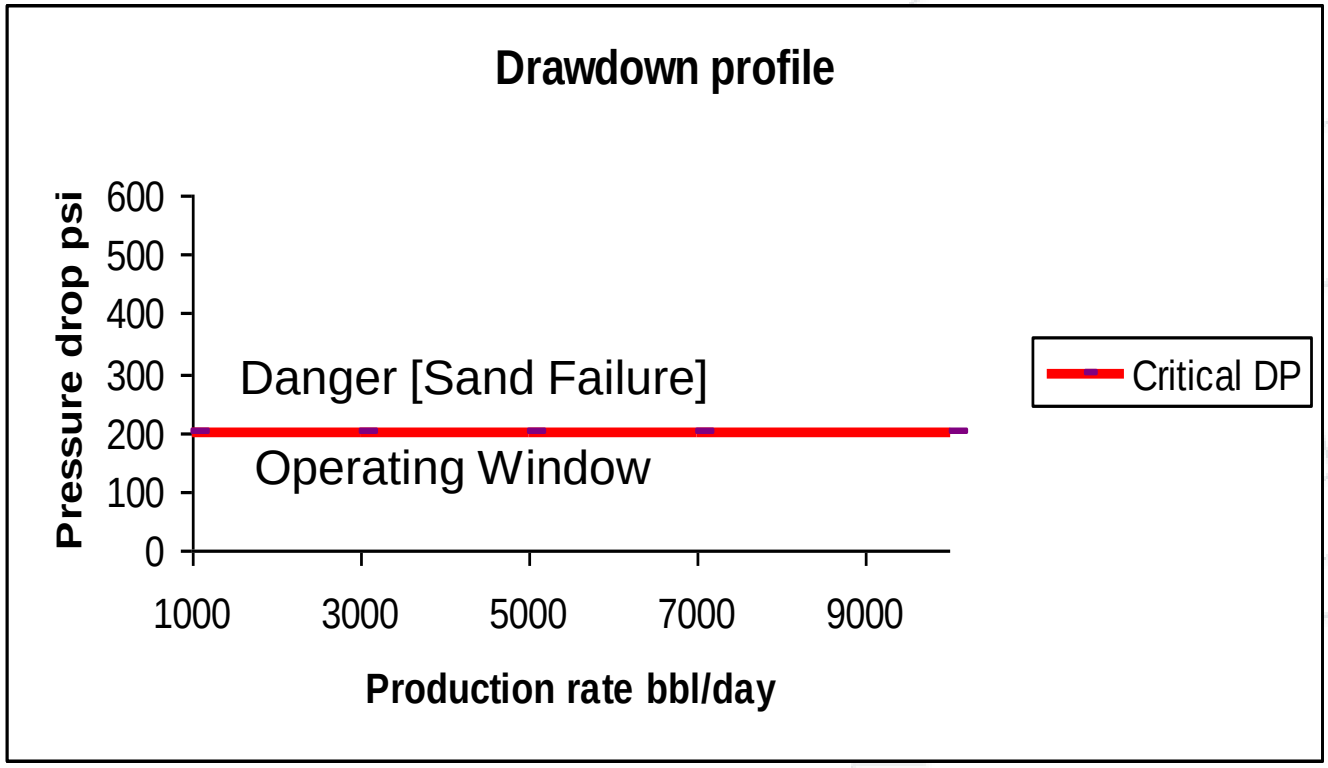


Reservoir Management

- High Productivity
  - Maximum Production
  - Minimum Drawdown
- Maintain integrity
- Mobility
- High Viscosity  High Drawdown
- Sand Management
  - Danger of Sand Failure

- What is the Critical Drawdown?

Critical Drawdown



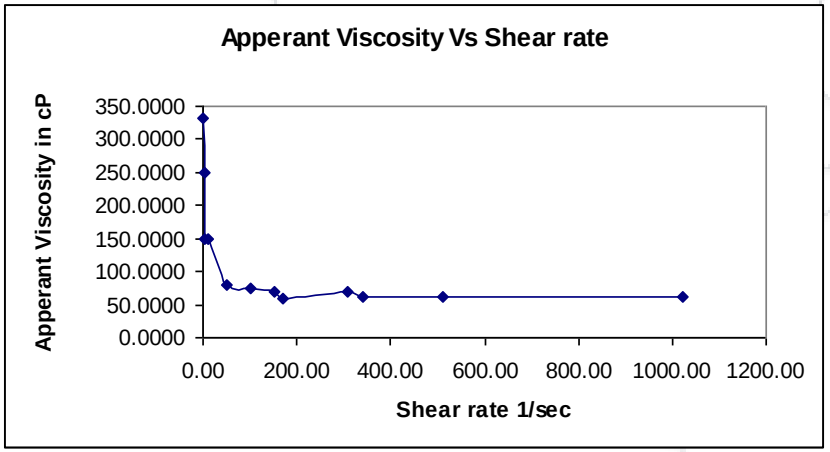
Mobility & Technical issues

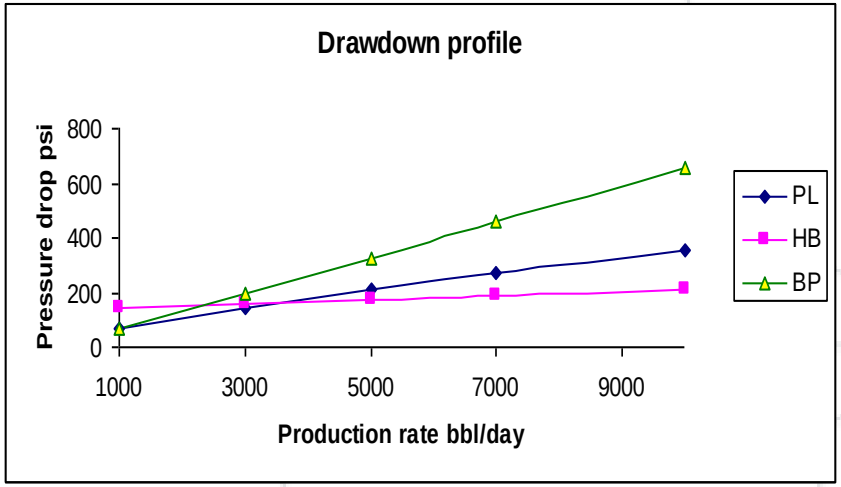
$$Mobility_{effective} = \frac{kl_{eff}}{\mu}$$

- PVT Property
- Heavy oil-Non-Newtonian fluid
- Need to understand rheology

Rheology of Heavy Oil

- About Rheology
- Non-Newtonian fluid
- Rheological characterisation required
- Different drawdown for all rheological models (power-Law, Herschel Bulkley, Bingham Plastic)
- Accurate rheology prediction with time





Mobility & Technical issues

$$Effective\ \ Mobility = \frac{kl_{eff}}{\mu}$$

k_a & k_r

- Pore size
- Porosity
- Grain cementation due to steam injection & depletion

- Transient property
- Composition with time

- Effective length
- Inflow profile
- Horizontal well productivity and injectivity models

Rheology and Drawdown

- From Porosity & absolute permeability
  - D_{pore} Blake-Kozeny-Carman Equation
  - Pore velocity: Rectangular/Circular drainage profile
  - Shear rate
  - Effective viscosity for BP, HB & PL
  - Drawdown for known flow rate (using Babu's model)

Models for Shear Rate vs Effective Viscosity

PSEUDOPLASTIC

$$\gamma = \frac{24 \times V_{pore}}{D_{pore}} \left[3 + \frac{1}{n} \right]$$

V_{pore} = pore velocity, ft/sec

D_{pore} = pore diameter, in

$$\mu_{effective} = K \times \gamma^{n-1}$$

BINGHAMPLASTIC

$$\gamma = \frac{96 \times V_{pore}}{D_{pore}} + 160 \times \frac{\tau_y}{\mu_p}$$

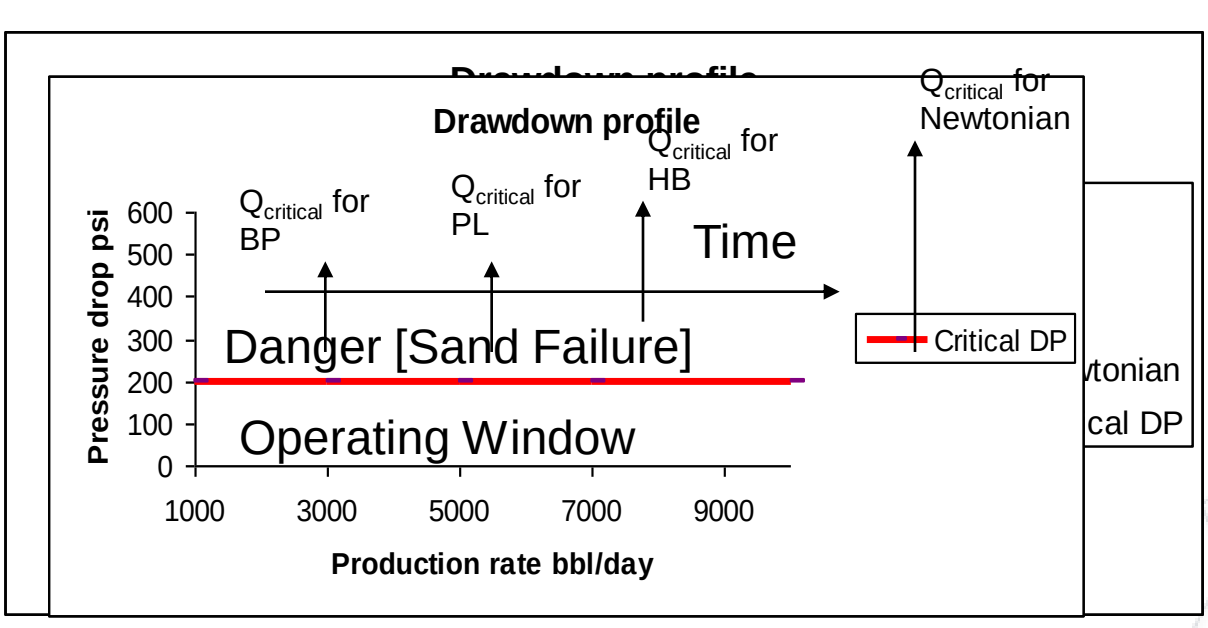
$$\mu_{effective} = \frac{\tau_y}{\gamma} + \mu_p$$

Effective viscosity calculations

	Shear rate 1/sec			Effective viscosity cp		
Vpore ft/sec	Power Law	HB	BP	PL	HB	BP
2.25645E-07	0.050011	0.046057883	1645.4944	63.04663	155.626947	60.57624
6.76935E-07	0.150032	0.13817365	1645.58619	47.17391	56.3710192	60.57622
1.12822E-06	0.250053	0.230289417	1645.67798	41.22245	36.4924731	60.5762
1.57951E-06	0.350074	0.322405184	1645.76977	37.71864	27.9621413	60.57618
2.25645E-06	0.500106	0.460578835	1645.907455	34.32906	21.554724	60.57615

Rheology & Drawdown contd..

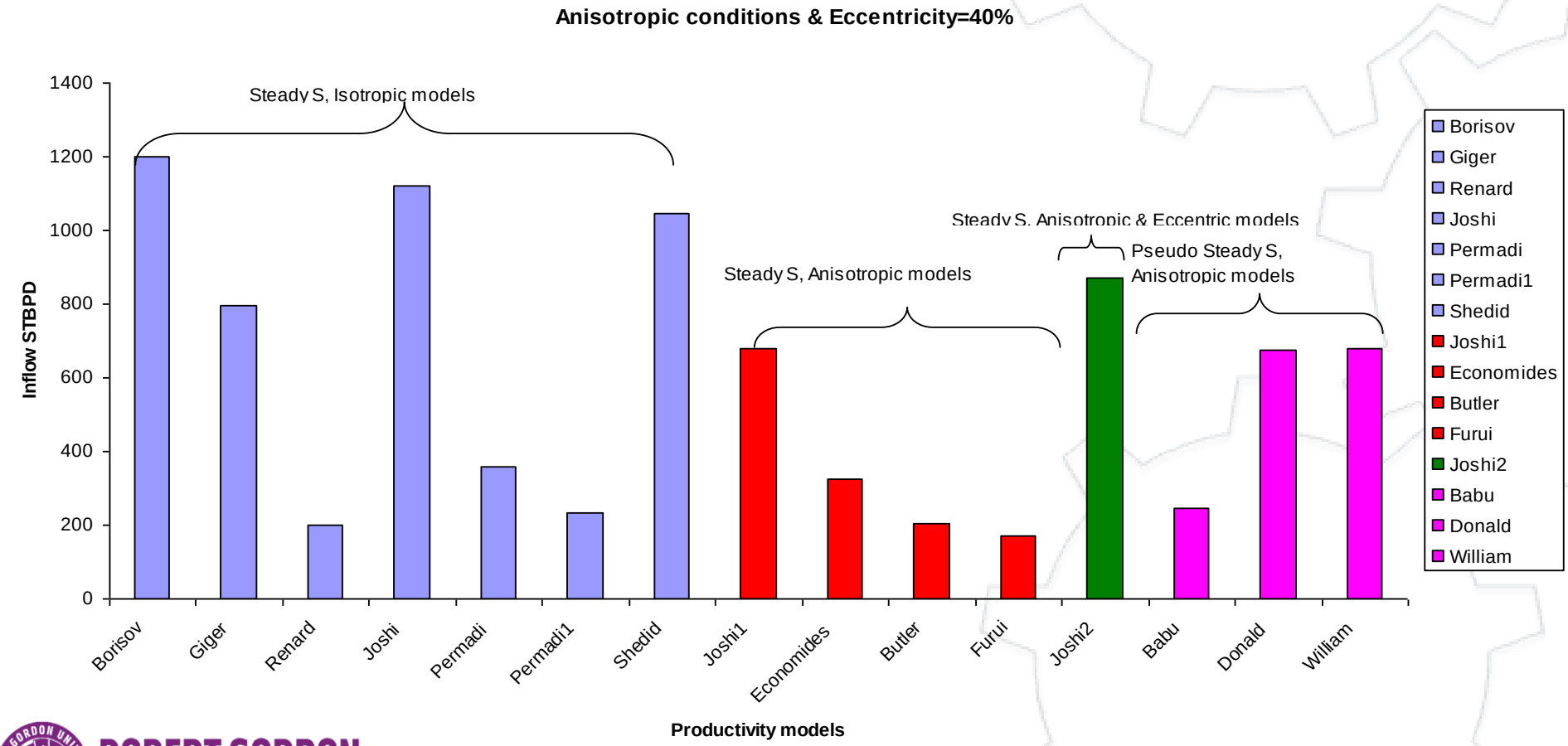
- In SAGD-Rheology is time dependant
  - Initially BP……due to steam…PL/HB or even Newtonian



- Important to understand-
- Real time Rheology
- Effective mobility

Comparison of HW Models

- 20-25 Productivity models for horizontal well
- No accurate model for heavy oil



Critical Issues

- Rheology of Heavy Oil with Steam
- Inflow and Injectivity Flow Pattern
- Optimum HW Lateral Length
- SOR
  - Steam Injection Rate
- Heavy Oil PVT Properties
- Reservoir Characteristics
  - K_r
  - Texture

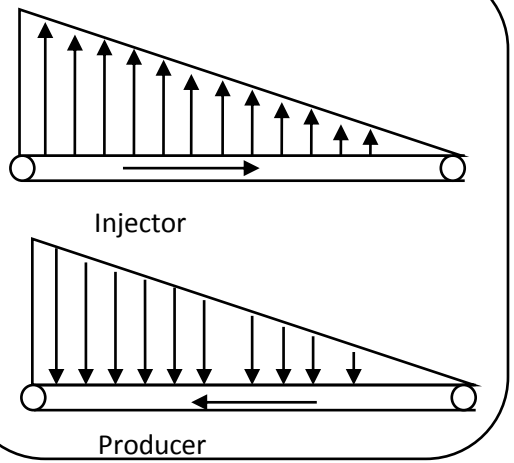
Critical issues contd..

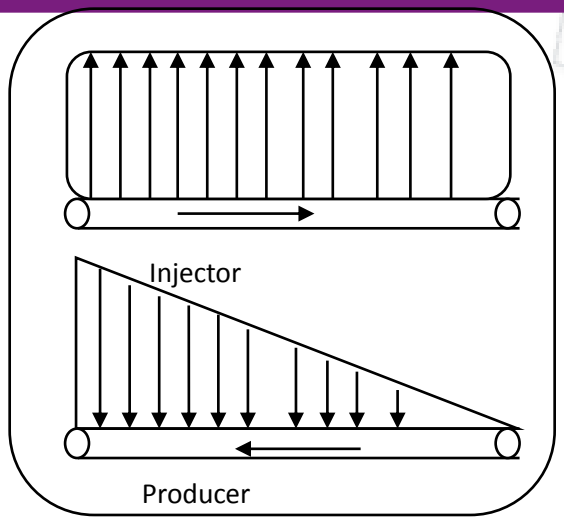
Steam →
- Steam quality
- Steam temperature
- Steam injection pressure
- Injection rate

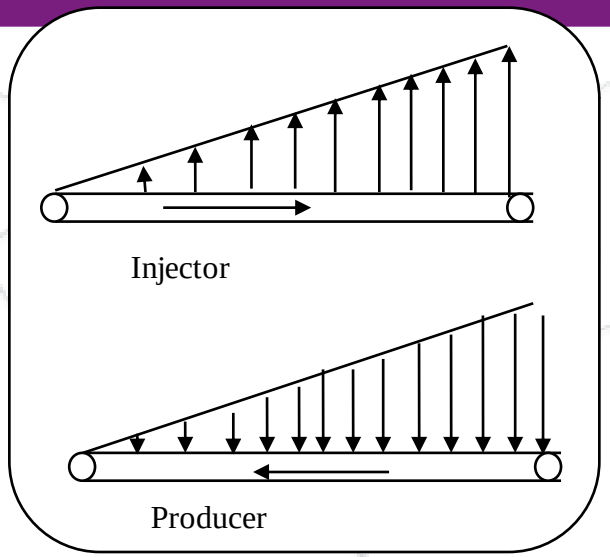
Injector & Producer →
- Well length
- Well spacing
- Well orientation

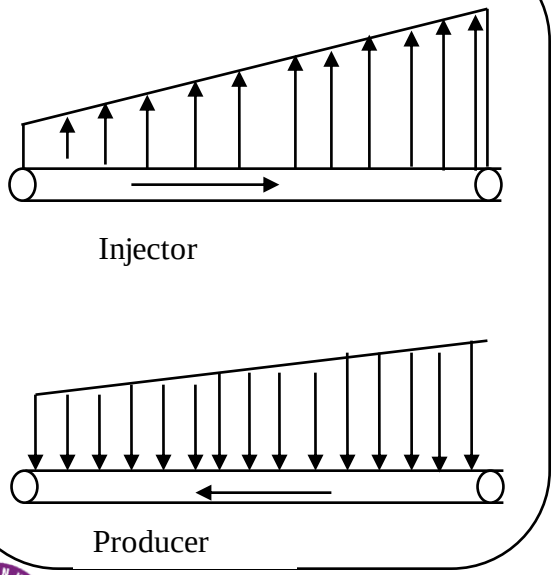
Reservoir →
- Multiphase flow
- Growth of steam chamber
- Steam interaction with oil

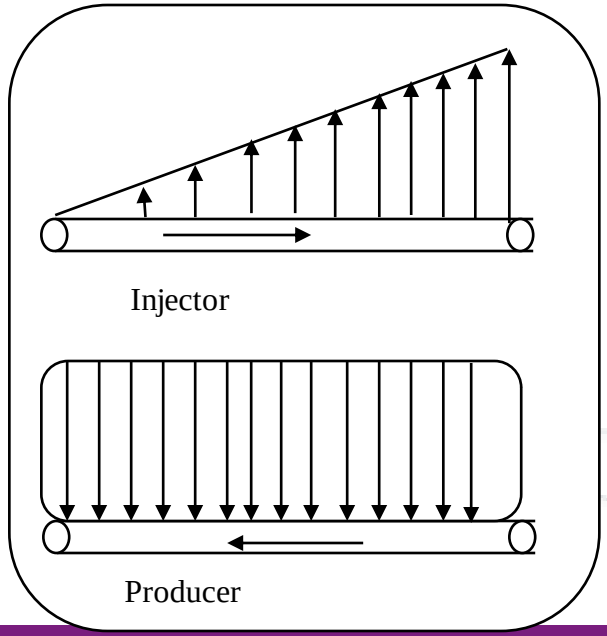
Inflow Patterns

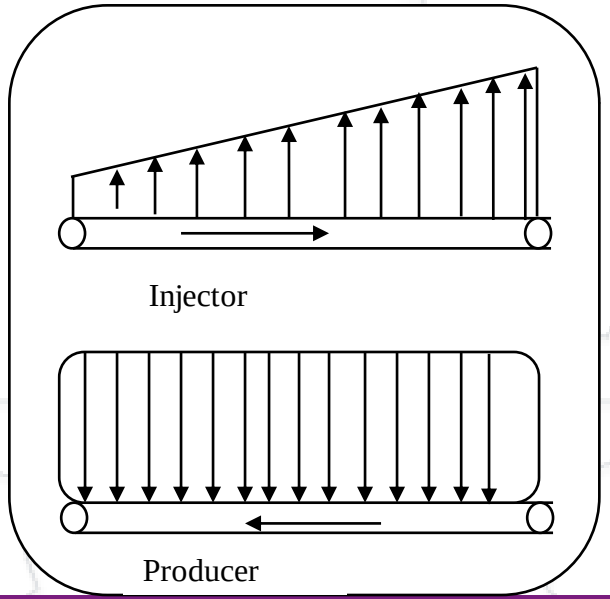












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Key PVT Properties

- Effective Viscosity
  - Shear Viscosity
  - Bulk Viscosity
- Thermal Coefficient
- Formation Volume Factor
- Density
- Compressibility

- Impact of P & T

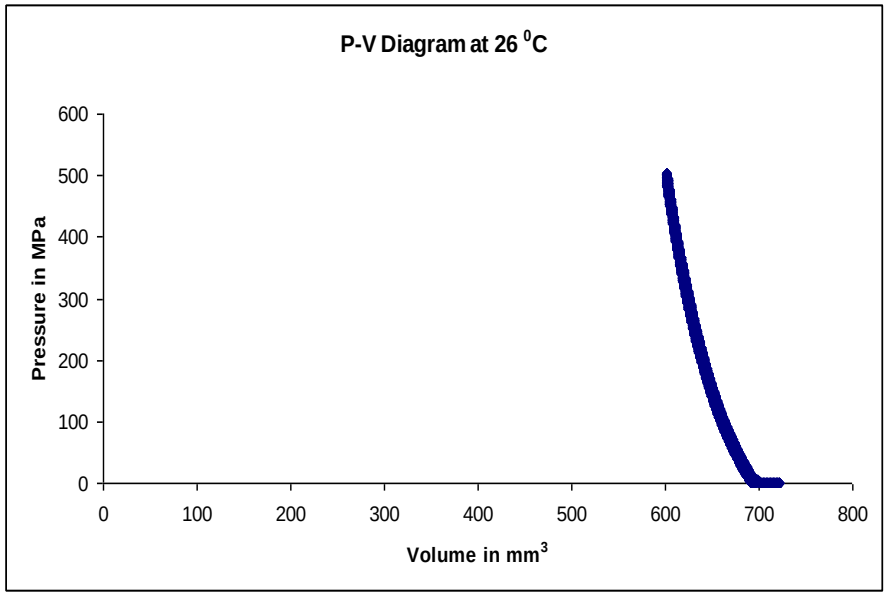
PVT Analysis

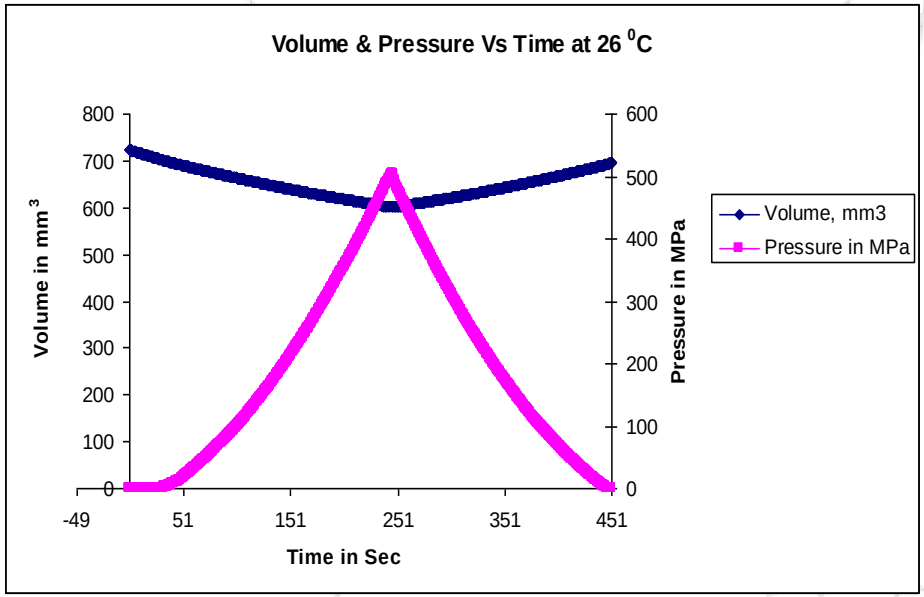
$$Mobility_{effective} = \frac{kl_{eff}}{\mu}$$

- Track on rheology with steam injection & time
- Shear and Bulk Viscosity
- Impacts on reservoir delivery
- Semi-empirical
- Database – Micro-PVT
- PVT properties- Viscosity Density, Thermal coefficient, Formation factor, compressibility

- Up to 300 ^{0}F & 50000 psi

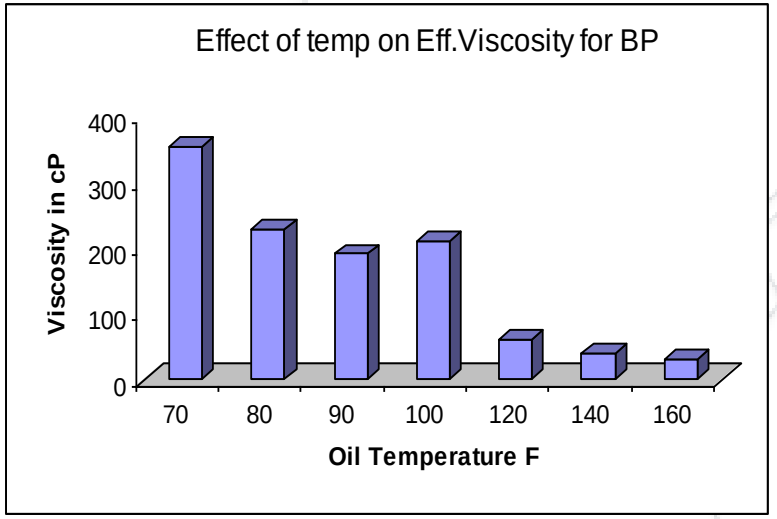
P-V curve from Micro-PVT

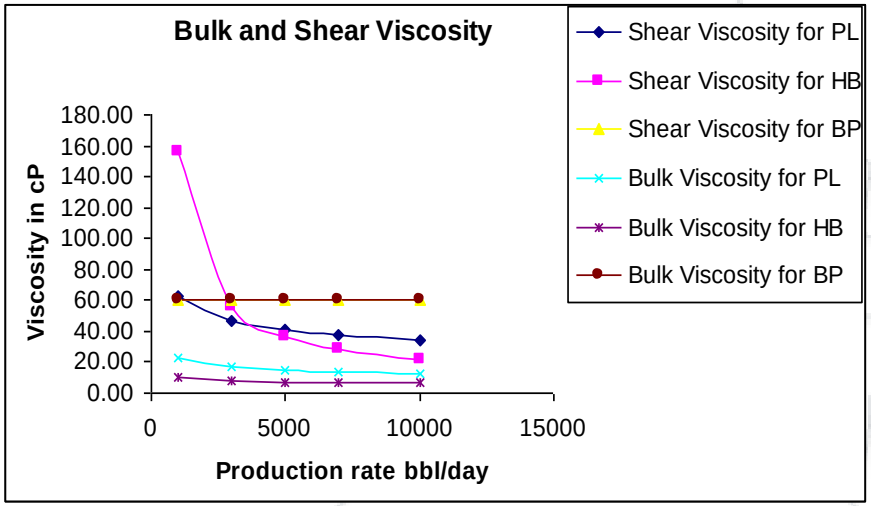




Issues with PVT contd..

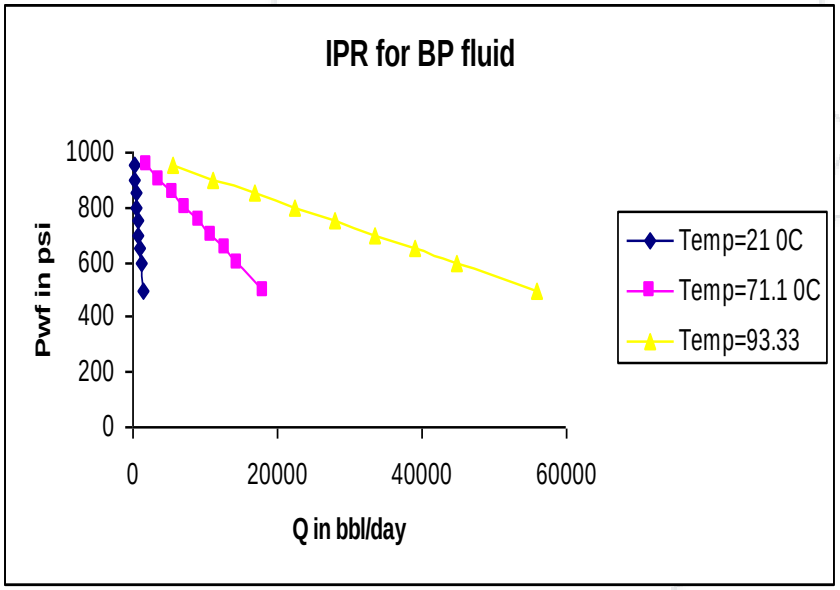
- Viscosity
- Non-Newtonian- Temperature dependent
- Bulk and Shear viscosity





Issues with PVT contd..

- Shear Viscosity contd..
- Impact on IPR
- Depends on not only pore velocity but also drainage profile
- Depends on Steam Oil Ratio (SAGD)
- Different production profile for each rheological model



Summary of ongoing work

- Reservoir simulation
  - Eclipse for benchmarking
  - PLT Data for Validation
- Shortlisted models
  - Furui, Butler and Babu & Odeh
- Need modification for heavy oil application
- Simulation for different critical factors on Eclipse and then modification of shortlisted models
- Develop new model(s)?

Summary of future work

- Fit-for-purpose model(s)
  - Probability Concept
    - [Eclipse + Crystal Ball]?
- Multiphase [Steam + Oil] flow in reservoir Phenomena
  - CFD Simulation
- Steam interaction with heavy oil
- User friendly simulator for Steam Assisted Gravity Drainage (SAGD)

SAGD Simulator