Understanding Inflow and Injection Control Devices: Using Completion Tools to Manipulate Reservoir Performance

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Tiny Action, Big Benefits

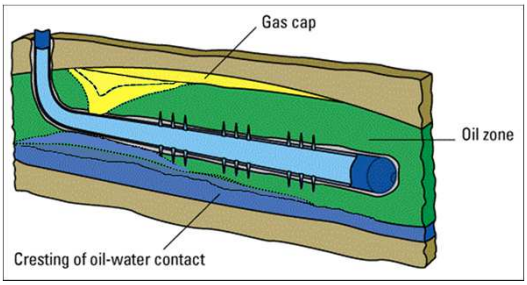
How do I build a well that recovers the most hydrocarbon possible in the most economical way?

By designing a completion that compliments the natural flow behavior of the reservoir-- one that delays unwanted fluid production, mobilizes desired fluid that otherwise might not be produced, and adds a level of control between the well and the reservoir face.

Agenda

- Why use inflow/injection control devices (ICDs)?
- How do ICDs work?
- What is ICD “autonomy”?
- What is needed to design an ICD completion?
- Case Studies
- Questions

The Heel-to-Toe Effect



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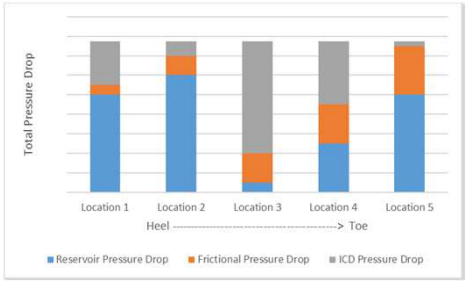
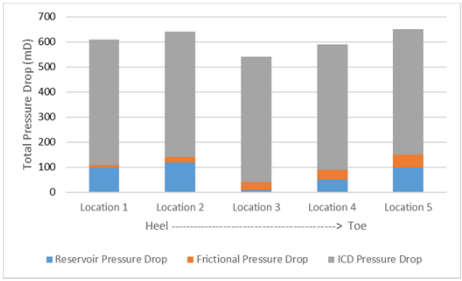
Improved Conformance



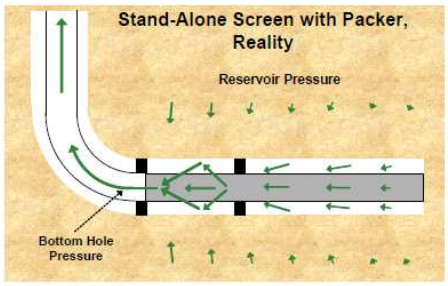
Poll Question

- Based on what you know so far, would you design an ICD completion with:

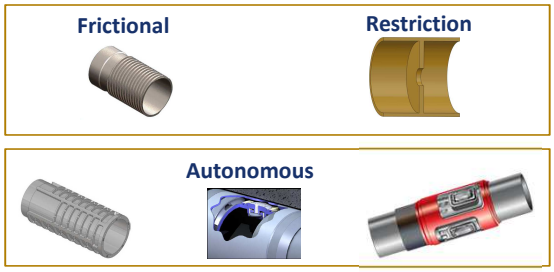
Variable vs. Uniform Setting



The Importance of Compartmentalization

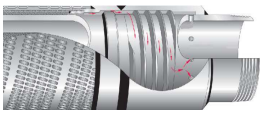


An Overview of the ICD Market



Frictional ICDs

- First ICDs ever used
- Channels, long-tubes
- Pressure drop created by drag along the walls of the flow path
- Sensitive to viscosity of the working fluid



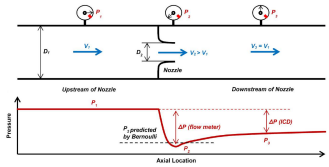
$$\Delta P = \frac{128\mu LQ}{\pi d^4} \propto \mu Q$$

Restriction ICDs

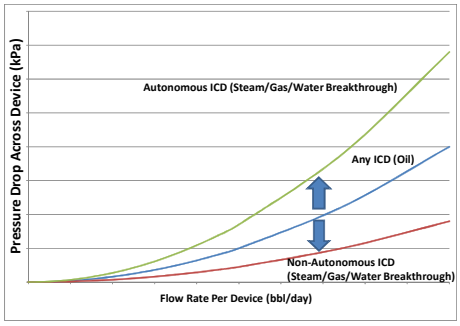
- First to offer field-adjustability
- Overlaps with existing knowledge
- Viscosity-insensitive to ~25 cP
- New operational risks: erosion, plugging, deposition
- Poor multiphase characterization?

$$\Delta p = \frac{\rho V^2}{2}\left[\left(\frac{1}{\sigma}\right)^2 - 1\right]\frac{1}{C_d^2}$$

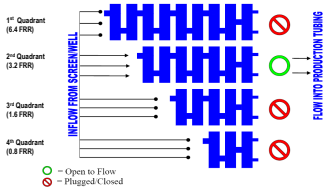
$$\sigma = (d/D)^2$$

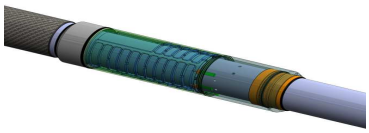


Autonomous ICDs

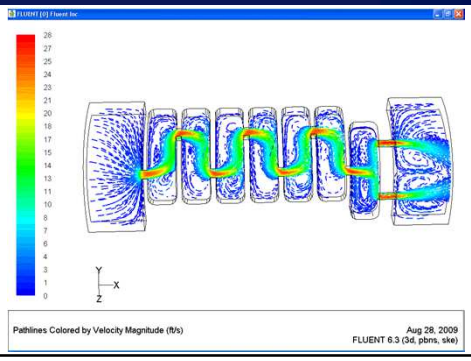


Hybrid Autonomous ICD

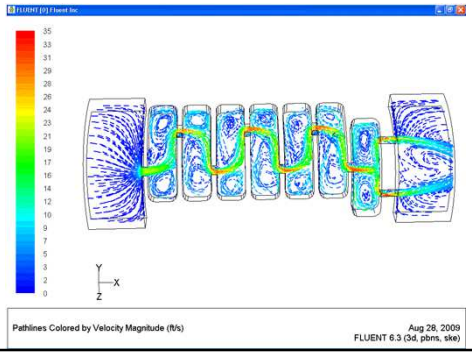




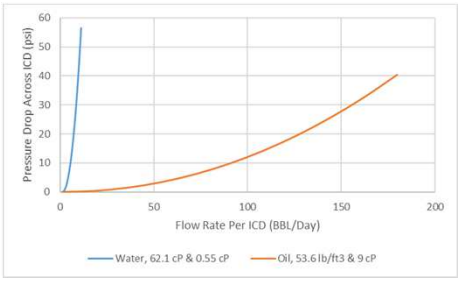
Fluid Dynamics in the Device (Oil, 189 cP)



Fluid Dynamics in the Device (Water, 1 cP)



Hybrid Autonomous ICD Performance (Single Phase)

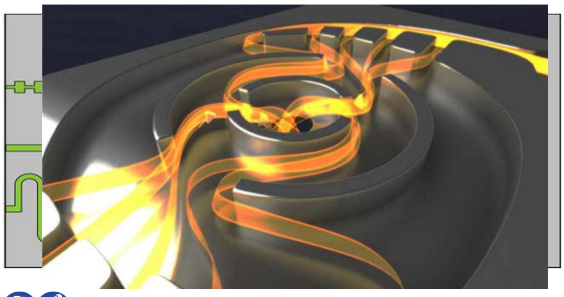


Hybrid Autonomous ICD

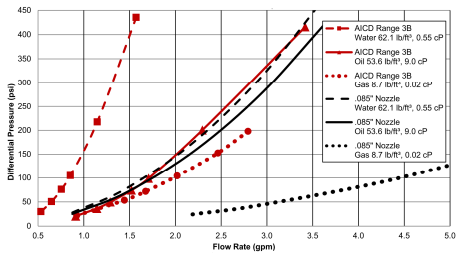
- Largest flow area
- No moving parts
- Bi-directional
- Largest run history

Fluidic Diode

Fluidic Diode



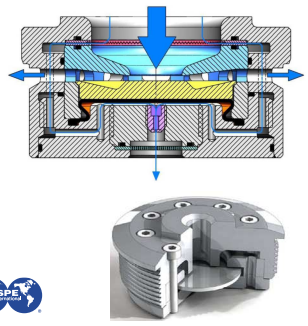
Published Performance (Single Phase)



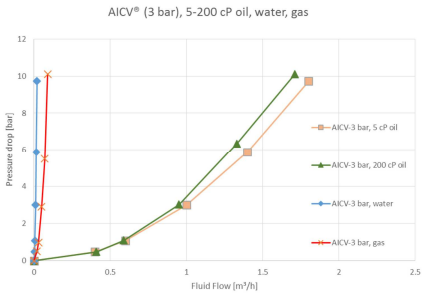
Fluidic Diode

- Greater choking of unwanted fluid than the autonomous hybrid ICD
- Unidirectional in behavior
- Viscosity-sensitive
- Run history in South/Latin America
- Similar operational risks as a restriction-style ICD?

Rate-Controlling ICD



Published Performance (Single Phase)



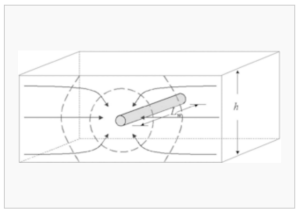
Rate-Controlling ICD

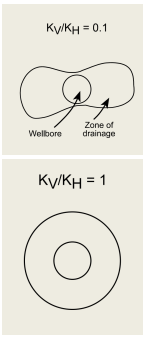
- Relies on moving part
- Strongest choking effect for unwanted fluids
- Only autonomous ICD that can “shut off” unwanted fluid (with caveat!)
- Highest operational risks in use

Poll Question

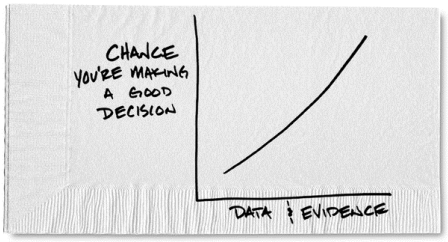
- Can we have too much autonomous choking?

The Fear with Autonomy

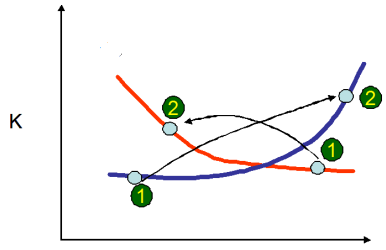




So how do we decide?



Modeling Over Time

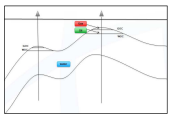


South China Sea Example

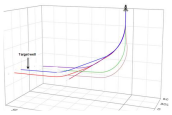
Difficulties for this lateral with strong aquifer:

- Sandstone reservoir, thin oil layer (25 to 30 ft)
- Strong aquifer
- Frictional pressure drop (1/3 to 1/5 of drawdown): long trajectory (2250 ft), high flow rate(average fluid rate: 7K to 10K bbl/d)
- Heterogeneity (heterogeneity coefficient is about 6)
- Mobility ratio (M>1)

Reservoir model for two completion designs

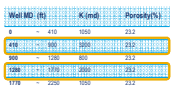


Cross-section profile of reservoir

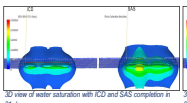


3D view of target well

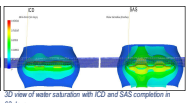
South China Sea Example



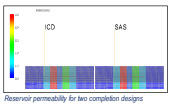
Permeability assumption along lateral



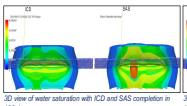
3D view of water saturation with ICD and SAS completion in 31 days



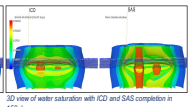
3D view of water saturation with ICD and SAS completion in 63 days



Reservoir permeability for two completion designs

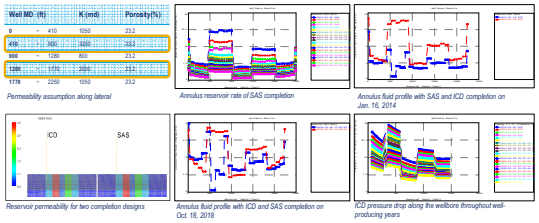


3D view of water saturation with ICD and SAS completion in 106 days



3D view of water saturation with ICD and SAS completion in 152 days

South China Sea Example



Permeability assumption along lateral

Annulus reservoir rate of SAS completion

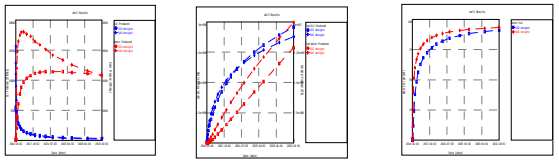
Annulus fluid profile with SAS and ICD completion on Jan. 16, 2014

Reservoir permeability for two completion designs

Annulus fluid profile with ICD and SAS completion on Oct. 16, 2018

ICD pressure drop along the wellbore throughout well-producing years

South China Sea Example



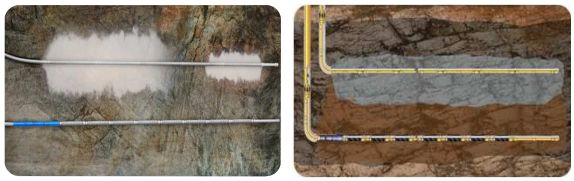
Daily water and oil production

Cumulative water and oil production

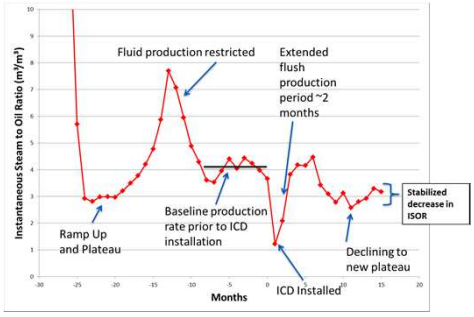
Water cut

Completion	Cum Oil (10^6 bbl)	Cum water (10^6 bbl)
SAS Completion	5.28	29.35
ICD Completion	5.74	23.82

Can Uneven Profiles Be Corrected After the Fact?



Steam-Assisted Gravity Drainage Example



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Questions