A Short Note on Inflow Performance Related to ICD's

and

Facts and Fiction about Inflow Control Devices

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Bio:
Bernt S. Aadnoy, PhD, is a Professor of Petroleum Engineering at the University of Stavanger in Norway. He has been in the oil industry since 1978, having started with Phillips Petroleum in Odessa, Texas and later working in operations for Phillips Ekofisk in Norway. In 1980, he began working for Rogaland Research and built a full-scale offshore drilling rig for research purposes. This facility, named Ullrigg, still conducts research both in well technology and in rig automation.

From 1989-90, he worked as a drilling engineer for Statoil, and then for Saga Petroleum until 1994. At that time, he became a tenured professor at the University of Stavanger and is now engaged in the Petroleum Engineering department.

Bernt has done consultancy work for many oil companies, and has been an advisor for the Petroleum Safety Authority since 2003.

He was adjunct professor at the University of the Faroe Islands from 1998-2003, where he built a petroleum engineering program focused on future deep water exploration activities. Additionally, he was a visiting professor at the University of Calgary in 2009.

Dr. Aadnoy holds a Mechanical Engineering degree from Stavanger Technology, a B.S. degree in Mechanical Engineering from the University of Wyoming, an M.S. degree in Control Engineering from the University of Texas, and a PhD in Petroleum Rock Mechanics from the Norwegian Institute of Technology. He has authored more than 120 publications, primarily in the areas of drilling and rock mechanics, as well as reservoir engineering and production. He has also authored two books, Mechanics of Drilling and Modern Well Design, and is currently finishing his third book, Fundamentals of Rock Mechanics. He was chief editor for the recently published SPE book, Advanced Drilling and Well Technology.

His knowledge of the petroleum industry is widely recognized, and he has been called upon on numerous occasions as an expert witness, particularly regarding ICD's, (inflow control devices).

Bernt is a member of the Society of Petroleum Engineers, the Norwegian Academy of Technological Sciences, the Russian Academy of Natural Sciences, and The Passive Inflow Control Technology Forum (www.inflowcontrol.com).
He continues as a guest speaker at several international conferences a year and has received numerous awards over the years, and was the 1999 recipient of the SPE International Drilling Engineering Award.

A Short Note on Inflow Performance Related to ICD's

1. Darcy flow

Inflow from the reservoir is governed by the radial inflow equation, which is derived from Darcy's law:

$$Q = \frac{2\pi kh}{\mu} \frac{P_{reservoir} - P_{well}}{\ln \frac{r_e}{r_w}}$$

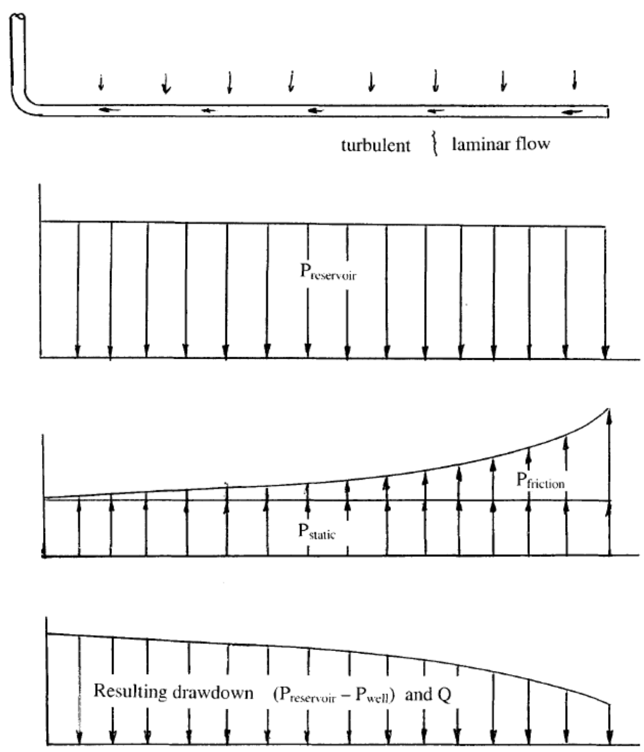
Please observe that the flow rate is proportional to the drawdown (reservoir pressure minus borehole pressure) and the permeability *k*, and inversely proportional to the fluid viscosity μ.

Assume a long horizontal well with open hole and no restrictions. Also note that there is parallel flow into the borehole, not serial flow as in a tube. However, the flow along the borehole is cumulative, i.e. it is both parallel and serial.

The figure at right illustrates the coning problem. The consequence of the wellbore pressure drop is a higher flow at the heel of the well.

Controlled by:

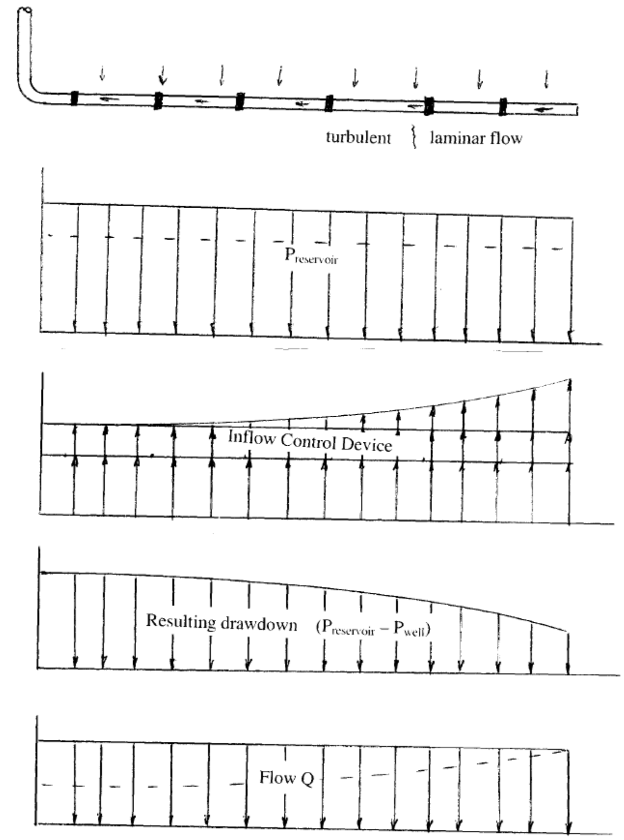
- Viscosity (all Darcy parameters)
- Permeability variations
- Along hole turbulence
- Pressure



Drawdown profile for Darcy controlled open hole horizontal well

2. Current Inflow Control Devices

By installing chokes at regular intervals the inflow can be changed. However, the drawdown is not constant along the well, so different chokes may be applied. The flow is no longer Darcy dependent but a combination of Darcy and choke. During depletion the pressures changes, in particular inside the well that again lead to uneven flow.



Drawdown profile for partial Darcy controlled/partially choked open hole horizontal well

Controlled by:

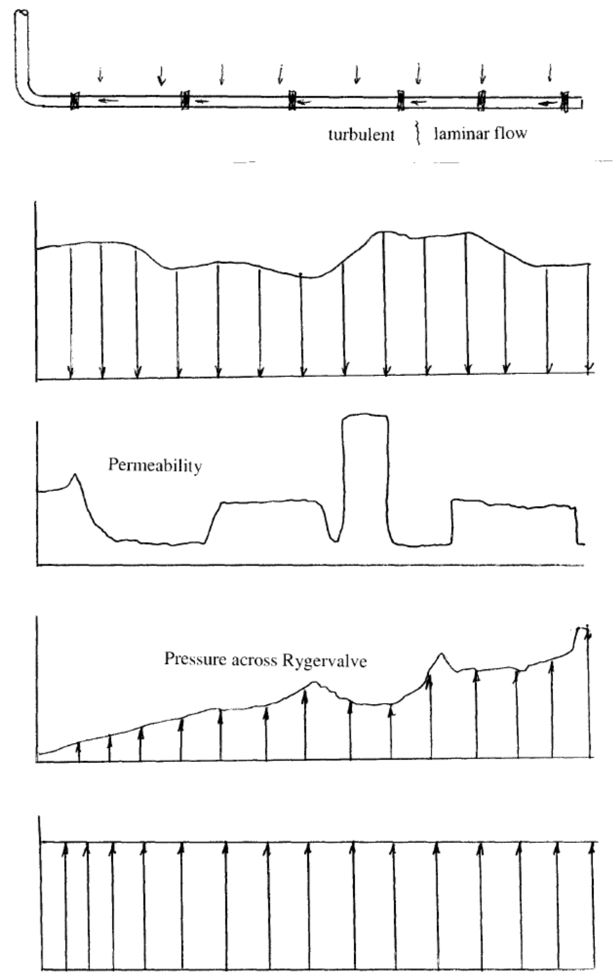
- Along hole turbulence
- Permeability variations
- Density
- Pressure

3. The BECH constant flow valve (AFD)

For illustrative purposes, the reservoir pressure, the permeability and the well pressure are varied. The resulting flow rate is still constant. The flow is no longer dependent on reservoir or wellbore conditions.

Controlled by:

- None (weakly density)



Drawdown profile for flow controlled horizontal well

Summary

The flow in a wellbore completion depends on variations in reservoir pressure, viscosity, permeability distribution and friction along the borehole.

An ICD reduces the Darcy dependence by introducing a choke. This choke is still sensitive to reservoir and wellbore pressure.

The new BECH constant flow valve[1] removes all this dependence and provides a constant flow nearly regardless of variations in these parameters.

Technically speaking, a well can be completed with minimum reservoir knowledge if the constant flow valve is used.

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[1] *Marketed by HANSEN Energy Solutions, LLC (www.hansenenergy.biz)*

Facts and Fiction about Inflow Control Devices

The ICD was initial developed in the early 1990s when water coning caused early water breakthrough in long horizontal wells offshore Norway. Due to the large pressure drop in the long horizontal wellbore completion, the production rates were higher at the heel of the well, leading to early water production. In addition to cost related to cleaning and disposal of produced water, a more severe effect was reduced recovery from the field. The oil at the very end of the well (the toe) was not efficiently produced.

A number of suppliers today offer IDCs for various applications. They present similar descriptions, but also some confusing differences are seen. To avoid misunderstanding we will here present the simple physics of an ICD.

An ICD is one or more nozzles installed in the production tubing. The main purpose is to restrict flow at given locations, e.g. near the heel of a horizontal well. The well-known Bernoulli equation defines the relationships of the nozzle. If the pressure drop is P, the flow rate is Q, the nozzle area is A and the fluid density is ρ, the flow rate is given by:

$$Q = A\sqrt{\frac{2P}{\rho}}$$

This equation is valid for all situations where a restriction is installed in a tubular. All known ICDs therefore follow the same law regardless of design.

Question: If I use 10 small nozzles instead of one large what is the difference in behaviour?

Answer: If the sum of the nozzle areas of the small nozzles equals the one large nozzle, they will behave exactly similar.

Q: What happens to the flow when the reservoir pressure declines?

A: As seen from the equation above if the reservoir pressure drops to 25% of its original pressure, the flow will decrease to 1/2.

Q: Will the ICD work well also in a depleted phase of a reservoir?

A: Unfortunately not. The flow inside the long horizontal tubing is complex, and when the flow decreases, the ICDs may no longer be optimal. Water coning may therefore occur at a later stage of depletion.

Q: Will the flow rate change after water breakthrough in the heel of the well?

A: Yes, again referring to the equation above. If the incoming water has 15% higher density than the produced oil, flow rate will decrease by 8%. This is not a strong effect.

Q: Although the density is often constant in a field, the viscosity may vary significantly during the life of the field. How important is the viscosity?

A: The variations in viscosity are not important. The nozzle alone controls the pressure drop, and because this has a high turbulent flow, variations in viscosity have no effect. This is beneficial because we would not have appreciated the opposite.

Q: Some ICD suppliers argue that they are viscosity sensitive because they are also passing the oil through some tubes in addition to the nozzle. This is not correct then?

A: Actually no for the common ICD scenario. Computer simulations have shown that for viscosity to dominate the pressure drop, the tubes must be <u>much</u> longer than a 10-meter screen section, which is difficult to implement in practice.

Q: If suppliers advertise a combined solution, an ICD consisting of a tube and a nozzle in series, is this not an improvement?

A: Technically speaking it is correct, but usually the nozzle dominates such that variations in viscosity are negligible.

Q: You mean that all usual brands of ICDs actually behave exactly similar?

A: Yes, the ICDs I have studied have design differences, they are all passive choke devices aimed at reducing the flow.

Q: Limiting ourselves to simple mechanical devices, how can we improve the ICD function?

A: An ICD can be considered a first generation flow control, with the limitation that it is statically fixed. A second generation would be an autonomous control valve that by sensing the reservoir pressure using hydraulic feedback could maintain constant flow even during reservoir depletion.