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Reservoir simulator-friendly model of fluid-selective, downhole flow control completion performance

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ABSTRACT

Wells with long production/injection intervals (e.g. horizontal or multi-lateral wells) can be equipped with flow control completion (FCC), which allows zonal control of in/out-flow and is a proven method to improve sweep efficiency, extend well life, and reduce the production volumes of unwanted fluids. The application of FCC is essential to development of many oil fields with complex geology, uncertain reservoir description, close to contact completions or unfavourable mobility ratio.

FCC technology keeps developing, for instance the recently introduced Autonomous Inflow Control Device (AICD) or Valve (AICV) strongly reacts to unwanted phases (gas or water) restricting their flow in-situ, which improves recovery as well as reduces the volume of unwanted fluids and the production uncertainty.

This paper presents a novel approach to incorporate into a reservoir simulator the flow performance of a downhole flow control completion equipped with flow control devices discriminating flowing fluids, e.g. reacting to water/gas flow distinctly differently than to oil. AICDs and AICVs are examples of such devices. The novel approach is verified by numerical simulation and is further compared against the traditional modelling approach on a reservoir model.

In the case of oil and water/gas flow, the multi-modal response of the device is new in the industry, and the reservoir simulators are not yet up-to-date to model such performance. The segregated flow in the annulus results in the device(s) reacting sequentially to either oil or water/gas, as opposed to the "homogeneous flow" modelling approach that is traditionally assumed in reservoir simulators. Capturing the sequential reaction of the device to either oil or water/gas in a reservoir simulator is challenging. The equations derived here solve this problem, and offer a more accurate way of modelling autonomous flow control completion performance in a commercial reservoir simulator.

This work is an important contribution to the advanced well completion technology modelling and evaluation. This technology is likely to define the future of advanced wells.

1. Introduction

Advanced well construction designs, such as AWCs (Advanced Well Completions) that control the fluid flow at the reservoir sandface, improve oil recovery and reduce the need for well intervention. AWCs are a field-proven technology that has been widely installed in thousands of wells to modify the production or injection well's inflow/outflow rate profile along the well. New AWC designs that additionally improve the waterflood's performance by reacting to water breakthrough have recently become available. The paper will present novel methods to model the flow performance of such AWCs.

Sections 1.1 and Appendix A briefly discuss AWCs, their history, design, impact on well performance and application envelope.

1.1. Advanced well completions (AWCs)

AWCs have Flow Control Devices (FCDs) installed in the production tubing in front of the production or injection intervals. FCDs (one or several) can be installed as frequently as on every tubing joint, often amounting to hundreds per well. Annular flow isolation (e.g. gravel pack or packers) is also preferred as it further improves the AWC's performance. Fig. 1 illustrates a schematic view of an AWC in an open-hole, production well with three packers; though AWCs are also perfectly used in wells with a cased hole, with multiple laterals, in injection wells, etc.

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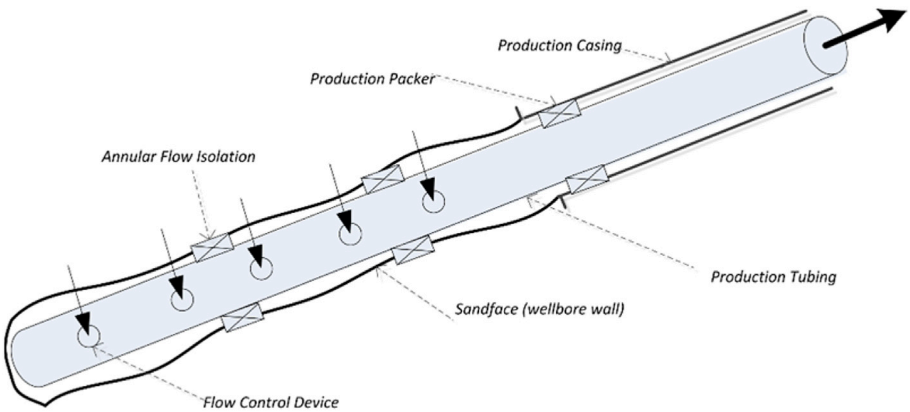

Fig. 1. Schematic view of a well with AWC.

The operating principle of an AWC is simple: the pressure drop across an FCD is non-linearly dependent of the fluid flow rate (Equation (1)); unlike the pressure drop across the reservoir that is essentially linearly dependent on the (liquid) rate. This ensures that there is an increased pressure drop across the AWC for those inflow zones between adjacent packers producing at a higher production rate when compared to the less productive zones. The result is a more uniform inflow/outflow profile along the length of the completion. FCDs can be generally classified as Passive (a fixed restriction), Active (the restriction can be controlled) and Autonomous (no control, but an autonomous reaction to the presence of an unwanted fluid). A good overview of the evolution of AWC technology, the available types (see also Fig. 2) and their applications can be found in (Al-Khelaiwi, 2013; Eltaher, 2017).

AWCs are well suited to wells producing from zones of differing reservoir quality, such as heterogeneous reservoirs, differentially depleted layers, compartmentalized reservoirs, multiple-reservoir developments, unfavourably saturated (e.g. oil-rim) reservoirs, etc. AWC well construction can be horizontal, deviated, or multi-lateral with the severity of the heterogeneity-related problems increasing as the well-reservoir contact length increases. Passive AWC is also frequently installed to reduce the heel-to-toe effect in homogeneous reservoirs developed with long horizontal wells.

Passive AWC comprises a range of commercial ICD types (Fig. 2) of differing design and tolerance to erosion and their response to the properties of the flowing fluid. However, all ICDs are essentially a fixed restriction whose performance can be described by:

$$\Delta P_{ICD} = a\, Q^2 \qquad (1)$$

in which the ‘strength’ parameter a relates the extra pressure drop ΔP_{ICD} added by an ICD restriction to the square of the flow rate Q. More information on ICD types and the formulae to find the strength a for each ICD type can be found in e.g. (Al-Khelaiwi, 2013).

Active FCDs, often called Interval Control Valves (ICVs), vary in design (Fig. 2) depending on their source of power and control signal (electric or hydraulic), how many positions can be chosen (usually between 2 and 10), etc. Equation (1) also describes the pressure drop across an ICV for a given position. The well's production is controlled by setting the zonal ICV positions according to the current or expected production situation. More information on ICV types, their applications and control can be found in e.g. (Haghighat Sefat et al., 2016).

The recently introduced technology: Autonomous Inflow Control Device (AICD) and Valve (AICV) react to “unwanted” (in oil production) fluid phases (i.e. free gas and water) restricting their flow in-situ and improving recovery. The AICD/AICV (or, in general, AFCD – Autonomous Flow Control Device) performance is described separately for single-phase oil flow and for single-phase water or gas flows, since these performances differ significantly. However, in both cases their single phase flow performance can be acceptably matched by Equation (1) (this observation was used by e.g. (Eltaher et al., 2014) to reparametrize the AFCD performance formula). *Also note that even until this day the stand-alone AFCD multiphase flow performance is still difficult to model accurately, with some new approaches recently published (*Eltaher et al.,

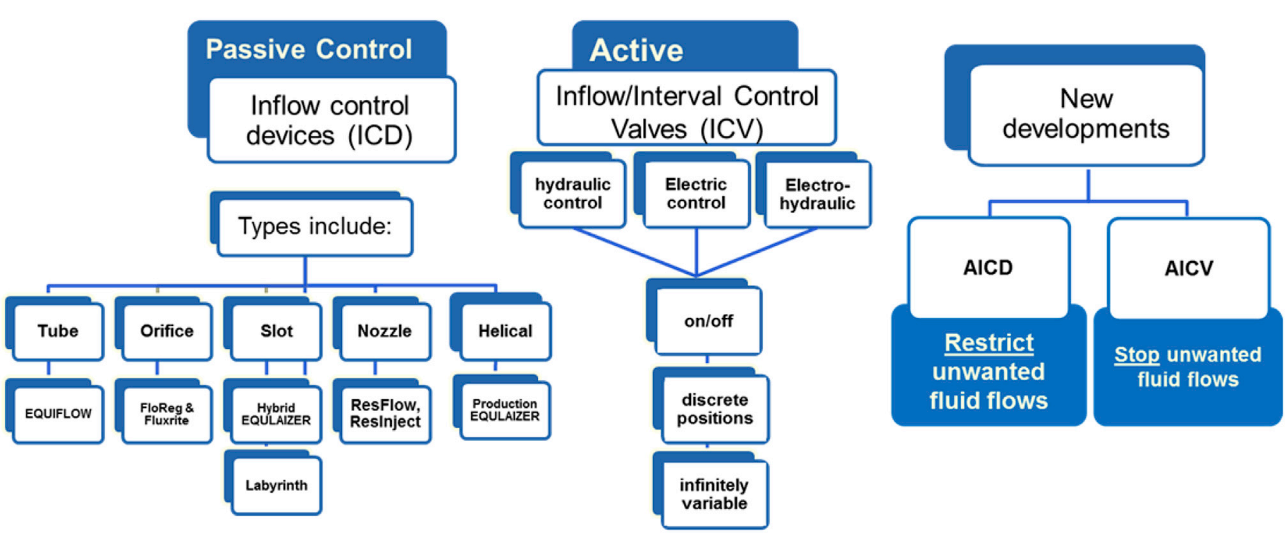

Fig. 2. Downhole Flow Control Device types.