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The theory of the automatic phase selection controller and its performance analysis

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ABSTRACT

Bottom water coning, to a large extent, will shorten the reservoir anhydrous production time and seriously affects horizontal well performance. As a result, the comprehensive benefit of the exploitation is damaged, which is the restriction of horizontal efficient key during the development of bottom water reservoir. At present most of the oil fields in China are facing high water-cut and low oil production traditional ICD (Inflow Control Device) is only suitable for the well before water breakthrough, and affects little after water breakthrough. Therefore, a new water control tool, automatic phase selection controller (PSC), has been developed based on the current technical difficulties and practical problems in the exploitation of oil field by horizontal wells in China. Automatic phase selection controller based only on the fluid properties and flow path to distinguish fluid and limit the output of the water without the use of any moving parts. The flow field analysis, sensitivity analysis, erosion analysis, water control ability and comparison analysis of ICD pressure drop are carried out by using CFD software. Simulation results indicate that: (i) the pressure drop generated by the water flow in the PSC is higher than the oil flow in it, and the main reason is the water rotating at a high speed in the tool to produce higher pressure drop and oil will not rotation; (ii) the pressure drop of the fluid flow through the valve is mainly determined by the viscosity and flow rate of the fluid, and the density of the fluid is very low; (iii) the sand carrying liquid can cause the erosion damage to the PSC, but the erosion rate is very small and at affordable range; (iv) the higher the water content is, the greater the pressure drop across the valve is; (v) as soon as water breaks through into the well PSC would be able to provide more flow resistance than nozzle type ICD. The experimental results show that the PSC can be applied to restrict water production after water breakthrough in the well and the CFD software can be used in the design and performance analysis of the PSC. Engineering application has been used to verify indoor simulation and the results show that PSC has potential practical application in increasing oil recovery.

1. Introduction

Horizontal wells, which are a kind of high efficient development methods with less wells and high yield, have been widely used to develop thin oil reservoir, bottom water reservoir, crack reservoir, heavy oil reservoir, marine shallow water, deep water reservoir, and unconventional oil and gas reservoir (Joshi, 1991; Ferreira et al., 1996). But problems appear in different types of reservoirs during the production of horizontal wells. What's more, complex structure wells have become increasingly prominent. Especially for the edge/bottom water reservoir, edge/bottom water coning quickly, and horizontal well water cut rise fast, resulting in difficult water detection and plugging, which seriously impact horizontal well mining and total benefit and has become the bottleneck restricting the development of horizontal wells (Regulacion and Shahreyar, 2011; Zadeh et al., 2012; Banerjee et al., 2013). The best way to solve this problem is to use Autonomous Inflow Control Device(AICD) to the control output of water which is developed on the basis of the inflow control technology (Least et al., 2012a, 2012b). AICD can not only balance the production fluid profile, eliminate heel-to-toe phenomenon, reduce annulus flow effect, extend the production life of oil well, but also distinguish fluid and limit water output. This can greatly improve single well production and is suitable for strong heterogeneity reservoir with edge or bottom water.

Compared with ICV (Inflow Control Valve) (Abllah et al., 2011; Rahman et al., 2012; Botechia et al., 2014) completion technology, AICD completion technology does not need electronics, control lines, thus greatly improving the reliability. Compared with traditional ICD (Jones et al., 2009; Garcia et al., 2009) completion technology, AICD strengthened the limitation on the water after

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Nomenclature

Δp	total pressure drop of fluids in the PSC, Pa
Δp_L	annular flow pressure drop, Pa
Δp_N	flow slot pressure drop, Pa
Δp_S	nozzle pressure drop, Pa
λ	frictional pressure loss coefficient, dimensionless
l	length of annular channel, m
d_l	hydraulic diameter of annular channel, m
Q	flow rate, m^3/s
A_l	cross section area of annular channel, m^2
Q_{cal}	calibration volumetric mixture flow rate, m^3/s
ρ_{cal}	calibration density, kg/m^3
μ_{cal}	calibration viscosity, Pa s
ρ_{mix}	mixture density, kg/m^3
μ_{mix}	mixture viscosity, Pa s
A_S	cross section area of flow slot, m^2
l_S	length of flow slot, m
d_S	hydraulic diameter of flow slot, m
A_{Sin}	entrance area of flow slot, m
A_{Sout}	export area of flow slot, m

water breakthrough, and improved the balance control effect of production fluid profile, it is more advantageous to improving horizontal well reservoir recovery.

2. Characteristics of current AICD types

Traditional ICD is designed to restrict flow by creating additional pressure which cannot distinguish between water and oil and limiting water also limits the oil output (Voll et al., 2014). And traditional ICD is able to carry out the optimum design according to the actual situation of the initial stage of the production well, but well performance is in constant change with the continuous output of fluid that is difficult or even impossible to foresee. Once the traditional ICD is installed, there is no simple way to adjust its inflow characteristics. Therefore the drainage characteristics that is optimal only at the initial stage of the production of the well, becomes poor with time as the well starts to mature. To solve this problem, several major oil companies have designed a new generation of ICD—Autonomous Inflow Control Device (AICD). The main AICD types are as follows.

Counterweight Flapper AICD (Crow et al., 2006) can selectively shut in areas where undesired fluids coning has broken into the wellbore, thus improving drainage efficiency. This AICD is based on archimedes principle that used the density of the fluid to open and shut off the flow of unwanted fluids. This AICD has complicated structure and containing moving parts which show low reliability.

The RCP valve (Mathiesen et al., 2011; Halvorsen et al., 2012) is on the basis of the principle of Bernoulli equation that fluid dynamic pressure and local pressure loss are constant, and controlled valve disc opens and switches in the body through the change of different fluid viscosity which flowing through the RCP valve. The disc may be damaged by the pressure difference exerted on it if the difference is larger than a certain value.

Fluidic diode-type AICD (Least et al., 2012a, 2012b, 2013a, 2013b, 2013c, 2013d; Fripp et al., 2013) restricts the flow of undesirable fluids by changing the geometry of the flow path. The AICD has two main functions: one is to identify the basis of its viscosity, and the second is to restrict the flow when undesirable fluids are present. However, the device has only a small oil viscosity range available for each certain design.

A new autonomous inflow control device (Sang et al., 2014; Zeng et al., 2014) is proposed based on the combination of ICD and water swelling rubber. The AICD is mainly used for controlling water, which means the higher the water saturation, the higher the rubber expansion, and the greater the pressure drop. The defect of this type of AICD is that with the expansion of rubber, the valve flow area is reduced. This will limit the output of water, but also limit the output of oil.

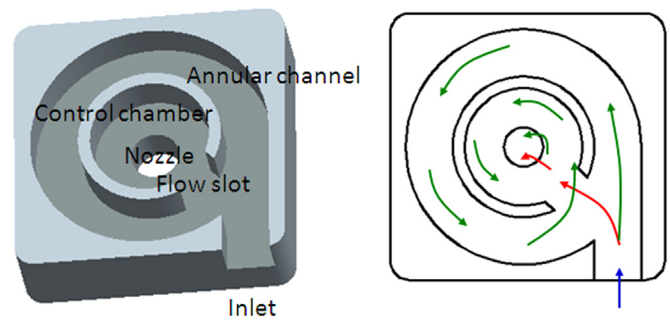

Fig. 1. Schematic of the PSC.

3. The PSC technology

The Phase Selection Controller (PSC) is based on the principle of the three-way pipe (Fig. 1). Upon water breakthrough, oil, which has higher viscosity, will directly flow into the control chamber through flow slot and flow out after throttling by nozzle. Water, which has lower viscosity, will flow into the control chamber and rotate at high speed in the control chamber after fully prewhirl in the annular channel. The closer the water is near the nozzle, the greater rotation speed. Oil does not rotate in the PSC without rotation pressure drop. Water rotates at a high speed in the PSC, resulting in large rotating pressure drop. Therefore, the pressure drop of the flow over the PSC is greater than the pressure drop of the oil flow through it. As a consequence, the PSC limits the output of water.

Before water breakthrough, PSC, like traditional ICD, creates a choke to help balance influx and delay water. After water breakthrough, the PSC will automatically separate oil and water according to the flow path geometry and fluid property. The PSC is designed to function without moving parts, intervention, electronics, control lines, which greatly improve its reliability. The PSC is applicable to strongly heterogeneous edge/bottom water reservoir, especially suitable for high water cut reservoir.

Fluids will generate pressure loss when flow through the PSC due to internal friction of the fluid and fluid particle collisions between each other. The pressure loss mainly produced in flow slot, annular channel and nozzle, therefore, the total pressure drop of fluids in the PSC is composed of three parts, annular flow pressure drop, flow slot pressure drop and the nozzle pressure drop.

$$\Delta p = \Delta p_L + \Delta p_N + \Delta p_S \quad (1)$$

(1) Annular flow pressure drop

The pressure drop in annular channel includes frictional pressure loss along the path and the local pressure loss, and the pressure drop formula is as follows: