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On the filtrate drilling fluid formation and near well-bore damage along the petroleum well

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ABSTRACT

In the present paper, the modeling of the filtrate drilling fluid as long as near well-bore damage has been taken into account. The damage experiments have been achieved to assess the initial/final permeabilities and fluid flow rate as well as damage ratio. Some drilling Binghamian fluid formulations which have been painstakingly prepared at laboratory (Akkal et al., 2013), are applied into the numerical modelings to examine and choose the optimized drilling fluids. The coupled diffusion–advection and Forchheimer's equations are used for all numerical experiments including/excluding the inertia effects for both static and dynamic cases (Civan, 2007). The cake formation thickness and filtrate fluid invasion through various samples have been investigated.

1. Introduction

1.1. Overall review on the filtrate drilling and wellbore damage

To achieve oil well drilling, several equipments should be taken into account. As illustrated in Fig. 1(a), these equipments are essentially represented by a swivel, a stalk of training and a train of stalk which is connected at the end of the train by a drill bit (Lummus and Azar, 2008). As the hole gets deeper, the pipes are added to the drill bit to allow it to dig further. These lengths of drill pipe form the drill string. During the drilling process, the drilling fluid is steadily injected. This fluid is prepared in mud pits and then it is injected into the stalk until the drill bit where it goes in charge of debris formed in the bottom hole (Fig. 1(a)).

As shown in Fig. 1(b), the drilling fluid must be recycled before next injection. To perform this matter, the fluid must undergo different treatments, e.g. screening and adding product, to rematch its initial physiochemical characteristics and to ensure the same functionalities. These functionalities can be summarized as the cuttings removal, keeping at the dispersion state, holding the external layer of the oil wells at the stable conditions and controlling the formation fluids entering to the oil well (Darley and Gray, 1988; Civan, 2007; Caenn et al., 2011). To pursue the abovementioned conditions, various types of drilling fluids can be used according to the continuous phase, i.e. Oil Based Mud (OBM), Water Based Muds (WBM) and Foam/Gas Mud (FGM).[5]

The choice of a fluid type depends closely on the drilled formations, depth and well pressure. These fluids often contain two phases, i.e. oily and aqueous phases. These two phases will be stabilized by means of the surfactants and organoclays (OC). The

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[5] The Oil Based Muds (OBM) are the inverse emulsions, whereas the Water Based Muds (WBM) are mainly dispersions. The latter mud case, i.e. Foam/Gas Mud (FGM), has the dispersed phase in a gaseous form. More detail about the abovementioned drilling fluids can be found out and addressed in Patel et al. (2007) and Khodja et al. (2010a).

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Nomenclature

Constants

β	inertial flow coefficient (1/m)
β_f	cake inertial flow coefficient (1/m)
β_c	cake inertial flow coefficient (1/m)
μ	filtrate viscosity (Pa s)
ρ	fluid filtrate density (kg/m^3)
ξ	Baker's velocity exponent coefficient (–)
K	permeability (m^2)
K'	consistency constant (kg/m/s$^{(2+n')}$)
k_c	cake permeability (m^2)
k_d	deposition rate coefficient (1/m)
k_e	erosion rate coefficient (s/m)
k_f	filter fluid permeability (m^2)
L	sample length (m)
L_f	filter length (m)
V_p	plastic viscosity in the Bingham plastic model (Pa s)
x	Distance (m)
Y_v	yield value in the Bingham plastic model (Pa)
n'	flow index (constant)

Used abbreviations

DR	damage ratio
OC	organoclay(s)

Scalar quantities

ϕ_c	cake porosity (m^3/m^3)
ρ_p	particle density (kg/m^3)
τ	tortuosity (–)
τ_{cr}	minimal critical shear stress required to detach particles from the surface of cake (kg/m/s^2)
τ_s	shear stress applied by the mud on the surface of the cake (kg/m/s^2)
$\tilde{\alpha}$	first equation coefficient for flow rate q (kg/m^7)
$\tilde{\beta}$	second equation coefficient for flow rate q (kg/m^4/s)
$\tilde{\gamma}$	third equation coefficient for flow rate q (kg/m/s^2)
ε_s	volume fraction of particles of the cake (m^3/m^3)
A	first equation coefficient for cake formation (1/m)
a	cross sectional area (m^2)
B	second equation coefficient for cake formation (Pa sm^2/kg)
$c(x,t)$	filtrate concentration (kg/m^3)
c_p	particle mass per unit volume contained in the mud (kg/m^2)
D	coefficient of dispersion (m^2/s)
D_0	molecular diffusion coefficient (m^2/s)
D_e	coefficient of convective dispersion (m^2/s)
D_L	longitudinal dispersion coefficient (m^2/s)
D_m	coefficient of molecular dispersion (m^2/s)
d_p	particle diameter (m)
D_i	depth of invasion (m)
Dis	dispersivity (m)
F	formation electrical resistivity factor (–)
f	empirical coefficient for the convective diffusion coefficient D_e (m^{2-g}/s^{1-g})
g	empirical exponent coefficient for the convective diffusion coefficient D_e (–)
h	reservoir thickness (m)
k	Baker's dispersion coefficient (m^2/s)
k_l	longitudinal dispersion coefficient (m^2/s)
k_t	transverse dispersion coefficient (m^2/s)
n_v	velocity exponent (–)
p	fluid pressure (kg/m/s^2)
p_c	slurry application pressure (kg/m/s^2)
p_e	filter outlet side back pressure (kg/m/s^2)
p_w	side surfaces pressure (kg/m/s^2)
q	flow rate carrying the fluid that invaded the reservoir formation (m^3/s)
q_0	initial fluid flow (m^3/s)
R_{ps}	net mass rate of deposition of particles of the slurry to form the cake (kg/m^2/s)
S_{Or}	residual oil saturation (m^3/m^3)
S_{Wi}	irreducible water saturation (m^3/m^3)
t	time (s)
U	average interstitial velocity (m/s)
u_c	volumetric filtration flux (m/s)
x_c	thickness of the cake (m)

Vector quantities

α_D	basic dispersivity (m)
v	mud tangential velocity (m/s)
V_e	interstitial velocity in porous media (m/s)

latter fluids are also non-Newtonian fluids and they can be described via the thixotropic shear-thinning including the yield stress (Dolz et al., 2007; Hamed and Belhadri, 2009; Gonzalez et al., 2011). These drilling fluids circulate in the oil well with high pressure greater than the fluid reservoir in order to avoid the penetration of the fluids from reservoir into the well. Hence, the high pressure will allow the solid particles and the fluid filtrate to invade the non-damaged zone or so-called pay zone around the well and consequently, it sustains the damage formation (Civan, 2007) (Fig. 1(c)). During the invasion of drilling fluid through the reservoir rock, the filtrate fluid will mix and push forward the fluid reservoir. This will induce a damaged zone around the well. It is straightforward to emphasize that the well-bore damage deals with the drastic drop of permeability, whose effect can be seen as the oil productivity loss. The degree of damage depends on several factors such as the characteristics of the drilling fluids, the proprieties of heterogeneous formation and the pressure conditions (Ding et al., 2004; Gentzis et al., 2009; Khodja et al., 2010b; Bennion et al., 1996).

The above-indicated invasion increases the water saturation of the damaged formation during the exposure area period. Therefore, the oil saturation in this area will decrease, which will reduce the oil effective permeability and causes a severe decrease in the annual productivity of oil wells (Bennion et al., 1996; Civan, 2007; Iscan et al., 2007; Cai et al., 2010). Thus, the evaluation of the formation damage, its control and its remediation appear among the tough questions required to be solved to ensure the efficient oil exploitation.[6] A smart simulation model of the damage associated with the laboratory experiments can be utilized as a benchmark guide to prevent and weaken the damage formation.

[6] It is of great importance to mention that the experiments last one day and it nearly costs 3000$ per sample. Moreover, the experimental procedure conducts the destructive tests. Therefore, the analytical and numerical modeling of the reservoir rock drastic drop during the drilling action is extremely essential in understanding of the damage phenomenon and its impact on the oil productivity later on.