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Reservoir Formation Damage Due to Water Injection Wells

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Abstract

Water injection is an integral constituent of most field development scenarios, It has been considered for enhanced oil recovery (the heavy oil). This injection may take place for secondary recovery and pressure maintenance such as sea water injection associated with most injection schemes is injectivity decline; where the rate of injection decreases over time at a given constant injection pressure gradient. The phenomenon of injectivity decline is comprised of multiple phenomena such as internal filtration, external filter cake build-up, fracture propagation, relative phase changes within the matrix rock and the associated permeability decline due to each of the described phenomena.

In this thesis addresses some of the key phenomena associated with injectivity decline. Most of the transport models describing the transport and capture of contaminants in the injection fluid within the matrix porous medium. The external filter cake build-up, an erosion model was derived based on the interaction of forces acting on a retained particle on the surface of the external-filter cake for both rectilinear and radial geometries. We postulate that during some initial period, an internal filter cake is formed. We refer to the time at which no more particles invade the rock, i.e. the time at which the initial layer of external filter cake is completely formed, as the transition time.

The prediction of particle capturing and particle retention by mathematical model is an essential stage during planning and design of above-mentioned industrial processes.

Keywords:

Formation Damage, Water Injection, External cake build up, Filtration, Transition Time

1. Introduction:

External filter cake is the term used to describe the particles and droplets retained at the interface of a porous medium. An example of such an interface is the fracture face of the wellbore of an open hole injection well. The principle of external filter cake build-up is based on the multi-layer retention of the

suspended particles carried by the permeate flux onto the porous medium's interface. This retention of particles occurs due to different phenomena including size exclusion whereby the suspended particles are too large to enter into the porous medium; i.e. at the wellbore or fracture face (Barkman and Davidson) **[1].**

An alternative mechanism for the development of an external filter cake is that of transitioning from internal filtration to external filter cake build-up. In this scenario, the small suspended particles exhaust the porous medium's ability to retain particles and pore throats at some penetration depth are plugged corresponding to a non-percolation threshold.

Consequently, the suspended particles are retained by sieving between the porous medium's face and the critical penetration depth until all retention sites are exhausted. Subsequently, the suspended particles are retained at the surface of the porous medium and an external filter cake is built up.

The time at which the non-percolation threshold is reached and external filter cake starts building up is referred to as the transition time.

Multiple phenomena associated with external filtration remain unresolved. These include the concept of transition time, the varying constituency of the cake, the consequent variance in cake properties, and the

phenomena responsible for limiting the cake thickness. For example, consider the concept of transition time: Wennberg and Sharma **[2]** had postulated that the transition time coincides with the filling up of a critical fraction of the porosity, arbitrarily set at 50%. Da Silva et al. **[3]** adopted this critical porosity hypothesis in their impedance based formation damage model.

Similarly, the constituency and consequent properties of the external filter cake continue to be studied by different researchers (Tien et al.) **[4]** as a comprehensive model has not been established. Another

important aspect of external filter cake build-up that remains unresolved is the understanding and modelling of the phenomena limiting its growth in crossflow scenarios. It is experimentally evident that not all of the particles transported by the permeate flux to the porous medium's or membrane's interface are deposited (Altmann and Ripperger) **[5]**.

Song and Elimelech **[6]** introduced a general model that can account for both the concentration polarisation layer and external cake formation by considering both the hydrodynamic and thermal energies of the system and identifying an appropriate critical filtration number. An alternative approach is that of conducting force analyses on the particles constituting the cake in the wellbore, in the fractures, or simplified laboratory geometries. Such analyses indicate that the cross-flow drag force is the most likely candidate for the back-transport of particles in typical injection schemes deployed in the petroleum industry.

2. Mass Conservation

The volumetric balance conducted on either the liquid phase or the solid particles yields the following one di- mensional convection-dispersion reaction equation **[7]**.

$$\frac{\partial}{\partial t}(\phi c + \sigma) + \frac{\partial Q}{\partial x} = 0 \qquad (1)$$

$$\phi \frac{\partial c}{\partial t} + u(x)\frac{\partial c}{\partial x} + \frac{\partial \sigma}{\partial t} = 0 \qquad (2)$$

3. Kinetic Equation

The kinetic equation describes the dynamic interaction between the suspended particles, the deposited particles and the porous medium. Iwasaki **[8]** introduced the filtration coefficient, λ, in his formulation of the kinetic equation:

$$\frac{\partial \sigma}{\partial t} = \lambda u(x) c \qquad (3)$$

It is generally accepted het for deep bed filtration phe-nomena covering the water injection field the filtration function is dependent on previous retention $\boldsymbol{\sigma}$ only. Thus:

$$\lambda = \lambda(\boldsymbol{\sigma}) \qquad (4)$$

So, the filtration theory in the field of petroleum engineering, is defined as following equations:

$$\frac{\partial}{\partial t}(\phi c+\sigma)+\frac{\partial Q}{\partial x}=0 \qquad (1)$$

$$\phi\frac{\partial c}{\partial t}+u_p\frac{\partial c}{\partial x}+\frac{\partial \sigma}{\partial t}=0 \qquad (2)$$

$$\lambda=\lambda(\boldsymbol{\sigma}) \qquad (4)$$

The net increase of particles within an infinitesimal filter volume equals the particles entering the volume on the upstream side minus the particles leaving the volume on the downstream side minus the particles leaving the volume on the downstream side minus the loss of particles to the formation through deposition.

4. Filtration Coefficiant

The filtration coefficient changes as particle deposition proceeds. This can be written in as:

$$\lambda=\lambda_0F(\sigma) \qquad (5)$$

The filtration coefficient is a dynamic property that changes with the specific deposit. The value of λ increases during the initial stages of filtration, this process called filter ripening. Iwasaki described the ripening period with an equation

$$\frac{\lambda}{\lambda_0}=1+b\sigma \qquad (6)$$

The deposited particles can themselves act as collectors for subsequent retention of flowing particles. If, however, the surface forces between the deposited and suspended particles are strongly repulsive, λ is likely to decrease with time as the collectors are progressively coated with deposited particles. If particles continue to deposit, they will finally begin bridging the pore throats and if the conditions allow a majority of the pore throats to be bridged, the external filter cakes starts forming.

5. The Transition Time concept

In developing filtration models, both internal and external filter cakes need to be accounted for because both are generally present in the filtration process. We postulate that during some initial period, an internal filter cake is formed. As more particles are trapped on the surface of the rock, a point is reached where very few particles can invade the rock and an external filter cake begins to build.

We refer to the time at which no more particles invade the rock, i.e. the time at which the initial layer of external filter cake is completely formed, as the transition time. The transition time can be obtained by calculating the trapping efficiency as a function of the number of previously deposited particles. The trapping efficiency is defined as the fraction of suspended particles trapped in the porous media.

If we can determine the conditions under which particles will form the internal and external filter cakes and the time required to form the initial layer of external filter cake, then the entire filtration process can be approximated by applying an internal cake-filtration model before the transition time and an external cake-filtration model after the transition time. Pure external filtration can be obtained in the limit $t^*\rightarrow 0$ and pure internal filtration can be obtained in the limit $t^*\rightarrow\infty$.

Some authors declared that the effect of penetrated particles on formation permeability may be dominant only at the early stages of injection (Khatib **[9]**). Once the cake is established and reaches a characteristic thickness, these effects are generally negligible compared to those of filter cake properties.

Here, we operate in terms of the filtration coefficient, rather than the collection efficiency and postulate that the time development of any filtration theory can be approximately described by the simplest stated equation:

$$\frac{\lambda}{\lambda_0} = 1 + b\sigma \qquad (6)$$

To derive the transition time, from equation (6) we solve the differential equation:

$$\frac{\partial \sigma}{\partial t} = \lambda_0(1 + b\sigma)uc \qquad (7)$$

And find the solution for constant flow rate is:

$$\sigma = \frac{1}{b}\left(e^{\lambda_0 buct} - 1\right), \qquad b \neq 0$$

$$\sigma = \lambda_0 buct \qquad b = 0 \qquad (8)$$

Little experimental data are available on the transition time and the corresponding specific deposit just below the surface. The critical porosity therefore needs to be estimated from theoretical arguments.

If the initial pore space of a formation is completely filled with particles, the remaining porosity will be the product of formation porosity and the filter cake porosity. A reasonable guess could be that about 50% of the pore space is being filled before the cake starts forming.

6. Conclusion

Both internal and external filter cakes are considered in the new model by introducing the term, transition time that has been derived mathematically.

The external filtration build up in front of the surface of the porous medium can be described by a filtration coefficient that may vary with time. The initial filtration coefficient can be determined from correlations derived for conditions under which attractive forces act between formation grains and injection particles.

Where the repulsive forces exist, the filtration coefficient must be determined from experiments. The cake porosity is not constant and varies with applied pressure, particularly for compressible particles.

7. Nomenclator

t : Time,

x : Spatial coordinate in the direction of flow,

ϕ : Effective porosity,

c : Volumetric concentration of suspended particles with respect to the pore volume,

σ : Volumetric concentration of retained particles with respect to the bulk volume,

u(x) : Permeate superficial velocity,

λ : Filtration coefficient,

t^* : Transition Time,

ϕ^* : Critical porosity,

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