



# Modeling Nanoparticles Effects on Optimization of Acid Dissolution Performance and Self-diverting in Carbonate Reservoirs and Compare it with Conventional Acid

Peyman Bahmani<sup>1</sup>, Siavash Riahi\*<sup>1</sup>, Maysam pournik<sup>2</sup>, and Babak Aminshahidy<sup>3</sup>

1 Institute of Petroleum Engineering, School of Chemical Engineering, College of Engineering, University of Tehran, Tehran, Iran

2 Mewbourne Schole of Petroleum and Geological Engineering, University of Oklahoma, OK, USA

3 Department of Petroleum Engineering, AmirKabir University of Technology, Tehran, Iran

riahi@ut.ac.ir

DOI: 10.22078/pr.2018.2714.2251

Received: May/15/2018

Accepted: August/21/2018

## INTRODUCTION

Fluid is more mobile in high permeable media than low permeable one; therefore, the movement and the forward is faster in the first one. This is important because low permeable media often require acidizing. At this stage, a diverter agent is felt to move the acid to the low permeable areas; consequently, the efficiency of well stimulating is enhanced, and the operation is done well.

## EXPERIMENTAL PROCEDURE THEORETICAL FOUNDATIONS

In 2005, a model for studying the acidizing of carbonate cores with hydrochloric acid has been provided by Pangda et al. Moreover, the devel-

oped model for acid gels has been obtained by the power law fluid equation (Equation 1):

$$|u|^{n-1} u = \frac{k}{\mu_{eff}} \cdot \nabla P \quad (1)$$

The mass equilibrium equation for fluids in a finite element (continuity equation) is expressed by the following equation (Equation 2) [1].

$$\frac{\partial \varepsilon}{\partial t} + \nabla \cdot u = 0 \quad (2)$$

Then, two transition equations are considered, one for the base acid and the other for the gelling agent (as seen in Equations 3 and 4). It is clear that the solubility term appears only in the base acid transfer equation and the gelation factor only plays a diversion role:

$$\frac{\partial (\varepsilon C)}{\partial t} + \nabla \cdot (UC) = \nabla \cdot (\varepsilon D_e \cdot \nabla C) - k_c a_v (C - C_s) \quad (3)$$

$$\frac{\partial(\varepsilon C_p)}{\partial t} + \nabla \cdot (UC_p) = \nabla \cdot (\varepsilon D_{ep} \cdot \nabla C_p) \quad (4)$$

There are two modes of constant injection rate and constant pressure drop to solve this set of equations. Due to the easier adjustment of the injection rate, it is usually more logical and more common to conduct a constant injection rate in both laboratory and reservoir scale.

### RANDOM WALKING PARTICLE TRACKING<sup>1</sup>

Modeling the transport of nanoparticles in heterogeneous porous media relies on Lagrangian methods and in particular, Random Walking Particle Tracking method. Moreover, the transport of a nanoparticle is caused by advection and diffusion where the convection part is affected by fluid velocity and longitudinal dispersivity while the diffusion part is affected by transverse dispersivity and brownian motion. In this approach, the Lagrangian approach is used for investigating advection term. In addition, Eulerian approach is used for diffusion term. It is obvious that location of each particle can be obtained longitudinally and transversely by using RWPT method. [2]

### STICKING EFFICIENCY

sticking efficiency is defined when there are repulsive and attractive forces between nanoparticle-nanoparticle and nanoparticle-surface. It is worth noting that these two energies may cause 100% of collisions not to stick or connect. In presentation of electrostatic repulsive force and van der waals attractive force, the sticking efficiency is expressed as (Equation 5):

$$\alpha = \left( (R_i + R_j) \int_{R_i+R_j}^{\infty} \frac{\exp(\frac{E_T}{k_B T})}{S^2} ds \right)^{-1} \cdot \left( (R_i + R_j) \int_{R_i+R_j}^{\infty} \frac{\exp(\frac{E_{vdw}}{k_B T})}{S^2} ds \right) \quad (5)$$

$E_T$  is the sum of repulsive and attractive energies. If collision efficiency between a nanoparticle and another nanoparticle is obvious, then:

$$E_T = E_{vdW-NN} + E_{EDL-NN} \quad (6)$$

And if the collision efficiency between nanoparticle and collector is obvious, then:

$$E_T = E_{vdW-NC} + E_{EDL-NC} \quad (7)$$

where  $E_{vdW-NN}$  is the van der waals between a particle and another particle,  $E_{vdW-NC}$  is attractive energy between particle and collector,  $E_{EDL-NN}$  is the electrostatic repulsive energy between a particle and another particle,  $E_{EDL-NC}$  is energy between particle and collector,  $k_B$  is Boltzman constant, and  $T$  is the absolute temperature.

### PARTICLE - COLLECTOR AND PARTICLE-PARTICLE INTERACTION

Particle-collector interaction: attaching or detaching the particles from the surface is explained by Dr. Taghavi's approach. In this way, first two possible parameters, i.e.  $P_p^{att}$  and  $P_p^{det}$  are defined for attachment and detachment of nanoparticles from the surface (as seen in the Equations 8 and 9):

$$P_p^{att} = k_{att} j_{att} Dt \quad (8)$$

$$P_p^{det} = k_{det} Dt \quad (9)$$

Then a random number is selected for each particle (from a uniform distribution ranging between 0 and 1). Those particles whose attachment-detachment probability exceeds the random number are labeled as retained-suspended in the next time-step calculation.

1. RWPT

## PARTICLE - PARTICLE INTERACTION

The sticking of clusters together is considered only due to the relationship of aggregation of particles in k size. Similarly, only one aggregation probability is defined for cluster, with i and j size (as seen in Equation 10):

$$P_{P(i)-P(j)}^{agg} = -\frac{dn_i}{n_i} = a_{PP} h(i, j) n_j Dt \quad (10)$$

A random number is defined for each pair of particles. The pair whose function is higher than random number lead to bigger cluster with new  $i + j = k$  size.

## RESULTS AND DISCUSSION

### EFFECT OF PURE ACID

Initially, the effect of pure acid (hydrochloric acid) is obtained at two different concentrations at constant injection rate. In addition, at a concentration of 10% and an injection rate of 3.5 ml/min due to the slow process of the acid dissolution, the breakthrough time is approximately one hour, and the breakthrough volume is about 8. Also, at a concentration of 15% and the same injection rate of 3.5 ml per minute, this time is reduced to 45 minutes, with a breakthrough volume of approximately 5.8. Moreover, breakthrough time in acid concentration of 15% and an injection rate of 0.3 ml/min is approximately 160 minutes, which according to the injection rate its breakthrough volume is equal to 1.65. Hence, it indicates that the injection rate is 0.3 ml/minute is more optimal and desirable injection rate.

### ACID GEL

To investigate the results caused by diverting in acidizing, five cases by changing the concentration of acid and nanoparticles, as well as the variation

of the injection rate are given in the following. The results are completely independent in these three cases. Moreover, it is worth mentioning that the experimental results are also next to each section.

In alumina, the difference in pH-isoelectric point is higher than that of silica particles; therefore, the particles exhibit more repulsive forces than the silica particles. Less collisions result in particle aggregation, and consequently, the trend of increasing the pressure drop across the core, due to the latency of the gel formation by the alumina particles, starts later than when silica nanoparticles used for gelation. Therefore, in general, when the alumina particles are present in the Nanofluid, a longer latency is observed in the gelation, and the trend of pressure reduction due to the predominance of acid dissolution will be more time consuming.

In a mixture of alumina and silica particles with respect to the mixing percentage of particles, its zero surface charge point is placed between the iep of the silica and the iep of the alumina. It is clear that this mixture forms a stronger gel more rapidly rather than an acidic fluid containing only alumina, resulting in less breakthrough volume [3].

## CONCLUSIONS

According to the results, nanoparticle acids require less breakthrough volume due to acid diverting toward low permeable regions.

## REFERENCES

- [1]. El-Amin M., Sun S. and Salama A., "Modeling and simulation of nanoparticle transport in multiphase flows in porous media: CO<sub>2</sub> sequestration," in Mathematical Methods in Fluid Dy-

namics and Simulation of Giant Oil and Gas Reservoirs, 2012.

[2]. Taghavy A., Pennell K. D. and Abriola L. M., *“Modeling coupled nanoparticle aggregation and transport in porous media: A Lagrangian approach,”* Journal of contaminant hydrology, Vol. 172, pp. 48-60, 2015.

[3]. Bang S., *“Self-diverting nanoparticle based in-situ gelled acids for stimulation of carbonate reservoirs,”* PhD Dissertation, University of Oklahoma, United States, 2017.