An Improved Model to Simulate Mud (Drilling Fluid) Dispersion through Porous Media

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ABSTRACT: *An improved model of mud dispersion has been introduced in this work. The advantages of this model consist of a new analytical correlation for dispersivity by using resistivity log data and using a new aspect of capacitance dispersion model. Mathematical formulations were expressed, solved by numerical model taking advantage of actual log and formation data. Achieved results yielded reasonable values and trends which can be used to predict the drilling fluid concentration near wellbore region and interpret the well log data. In comparison with the previous models (Civan and Engler, 1994; Donaldson and Chernoglazov, 1987), this model uses more reasonable data and assumptions making it closer to real conditions.*

KEY WORDS: *Formation damage, Diffusivity equation, Dispersion, Drilling mud.*

INTRODUCTION

Filtration loss and loss of circulation in drilled payzone during drilling operation are causes of loss of millions of dollars in oil and gas drilling industry. In addition, they cause damage of hydrocarbon reservoirs in terms of reduction in productivity of a drilled well and increasing the costly operation of well stimulation. The seriousness of that damage depends on the nature of the formation, the composition and properties of the drilling fluid, and therefore, the drilling conditions. Usually the drilling fluid pressure is greater than the formation pore pressure. As a result there maybe invasion by whole drilling fluid and solids from the drilling fluid, as well as invasion by drilling fluid filtrate.

As mud filtrate invades the porous media, it develops

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a damaged zone around the wellbore. To asses the damaged area, the filtration concentration as a function of distance from the well bore and time of invasion must be determined. The filtrate concentration can be investigated by convective-dispersion equation and its associated conditions. The invasion profile is assumed to be unsteady-state radial and isothermal [1].

As it is shown in Fig. 1, mud filtrate creates different concentration areas at different times around the wellbore.

Donaldson et al. [2] developed a "leaky-piston" filtrate invasion and convection-dispersion filtrate transport model applicable to cases involving drilling mud that can mix with the formation fluid. This model considers the dispersion of the mud filtrate within the formation fluid in a single-phase fluid system to estimate the salinity variation in the near wellbore region, but neglects the effect of mud fines invasion. This model was formulated for linear flow and the filter cake effect is simulated by a practical correlation. Although a potential empirical correlation was mentioned, the dispersion coefficient was treated as a constant in numerical solution. In addition a linear model instead of radial model was used even though a radial transient state convection-dispersion equation was discussed. The effect of porosity on mud filtrate transport was not considered.

Civan et al. [1] improved the above mentioned model so as to predict the distribution and mixing of mud filtrate in the reservoir surrounding a well during drilling operation. Model equations were converted to dimensionless form for scaling purpose and computational convenience, and solved numerically by *Crank-Nikelson* method.

The aim of this paper is to present the improved model for simulation and prediction of the distribution and mixing of mud filtrate in the reservoir surrounding a well during drilling operations by applying the reasonable dispersion coefficient derived from the resestivity log data of this study and applying dispersion capacitance model.

NUMERICAL SOLUTION

Neglecting the porosity alteration and the liquid compressibility effects, the species transport model for radial flow in porous media is as follow:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\vec{D}\frac{\partial C}{\partial r}\right) = \frac{\vec{V}}{\phi}\frac{\partial C}{\partial r} + \frac{\partial}{\partial t}(C) \qquad (1)$$

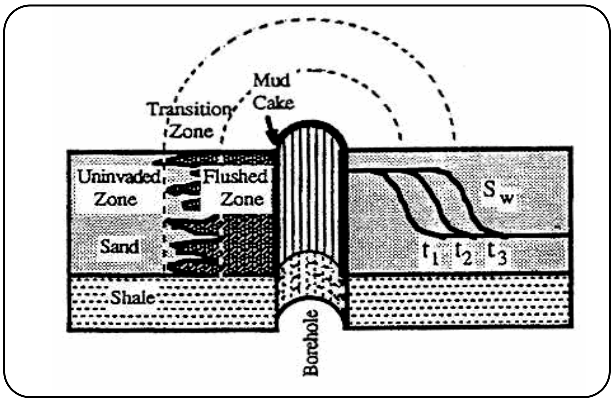

Fig. 1: Detailed schematic of the various zones and the mud filtrate invasion profile at different times in near well bore formation [3].

For rw<r<re and t>0, this equation is subjected to the following initial condition:

$$C=0 \qquad r_w \le r \le r_e \; ; \; t = 0 \qquad (2)$$

And two boundary conditions:

$$C=C0 \qquad r = rw \; ; \; t > 0 \qquad (3)$$

$$\frac{\partial C}{\partial r} = 0 \qquad r = re \; ; \; t > 0 \qquad (4)$$

The first boundary condition is Dirichlet type and the second one is Neuman type [4]. The following auxiliary equation is required for solution of the problem. The volumetric flux can be expressed by:

$$V = \frac{q}{2\pi rh} \qquad (5)$$

Where the empirically-derived mud filtration rate accounting for the filter cake effect can be written as:

$$q = a\exp(-bt) \qquad (6)$$

Where “a” and “b” are empirical constants which are approximately 0.08 m3/hr and 1.67×10^{-5} 1/hr respectively [2]. The dispersion coefficient used in this model is defined in the following way [5]:

$$\vec{D} = \text{Dis} \times \vec{v} \qquad (7)$$

Where “Dis” is the derived dispersivity obtained from resistivity log data to be explained more next and $\vec{v}$ is the velocity vector. Also the dispersivity correlation has been used for the capacitance model of dispersivity as Eq. (8) [6,7].

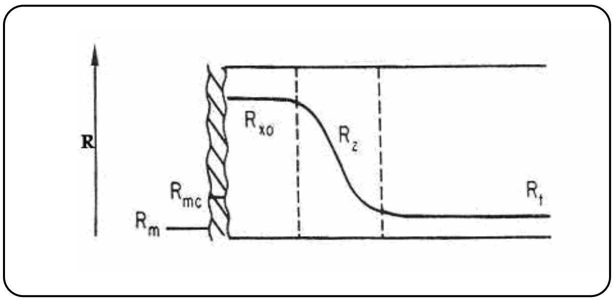

Fig.2: Resistivity profile in a brine saturated formation.

$$Dis_e = Dis_L + \frac{(1-f)^2}{\left(\frac{M}{V_e}\right)} \quad (8)$$

For computational convenience, Eqs.1-4 are written in dimensionless form as shown in Appendix B. The dimensionless convection-dispersion equation (Eq. B-11) and its boundary conditions are as follows:

$$\frac{Dis \times \phi \times e^{-bt_D t_0}}{2r_w}\frac{1}{r_D}\frac{\partial^2 C_D}{\partial r_D^2} - \frac{e^{-bt_D t_0}}{2}\frac{1}{r_D}\frac{\partial C_D}{\partial r_D} = \frac{\partial C_D}{\partial t_D} \quad (9)$$

I.C: CD=0, $t_D = 0$, $1 \le r_D \le r_{De}$ (10)

B.C: CD=1 tD>0, rD=1 (11)

$$\frac{\partial C_D}{\partial r_D} = 0 \text{, tD>0, rD=rDe} \quad (12)$$

Eqs.9 to12 are solved by fully implicit method as described in Appendix C.

Deriving Dispersivity from Resistivity log data

As mud filtrate invades the formation, it changes the resistivity of formation as shown in Fig.2. *Chen et al.* investigated the depth of invasion of water base mud by using a resistivity log data and using the pseudo-geometrical concept as follow [7].

$$D_i = D_h \exp\left[\frac{2\pi h_d}{k_d}\left(\frac{R_{lld} - R_t}{Rlls - R_t}\right)\right] \quad (13)$$

For medium-porosity formations, and

$$D_i = D_h \exp\left[\frac{2\pi h_d}{k_d}\left(\frac{R_{lld} - R_t}{Rxo - R_t}\right)\right] \quad (14)$$

for high-porosity formations.

By equalizing the depth of invasion and miscible zone width, the following correlation is derived for dispersivity which is elaborated more in Appendix A:

$$Dis = \frac{D_i}{3.625^2}\phi \quad (15)$$

Several correlations in terms of other rock properties such as porosity, permeability and heterogeneity have been proposed to calculate dispersivity parameter [8, 9]. Some of these correlations prove good accuracy in lab scales while others are suitable for field application. Only the so-called correlation of deriving dispersivity from log data, has been proposed by *Chen et al.* in 1992 as follow [9,10]:

$$Dis = 104.3 \times 10^{-5} \quad \sigma_H \tau\left(\frac{1-\phi}{\phi}\right)\sqrt{\frac{K}{\phi}} \quad (16)$$

Where σ_H is heterogeneity-related parameter calculated from one of the two following correlations [9-12].

$$\sigma_H = 1.2876e^H \quad (17)$$

$$\sigma_H = H \quad (18)$$

Chen et al. obtained a reasonable match of lab data by combining correlations (16) and (18), although it wasn't well matched with their presented correlation of dispersivity and heterogeneity, demonstrating that the above combination does not have good accuracy for heterogeneous cases such as in field application [9, 10]. Combination of *Chen et al.* correlation and correlation (17) has been used to check the accuracy of the model of this study. For this purpose data from Iranian south reservoir were used [13].

As it is inferred from Table 1, the correlation achieved during this study shows a good compatibility with the *Chen et al.* correlation.

RESULTS AND DISCUSSIONS

Eqs. 9-12 are solved numerically by the implicit method. A parametric study has been conducted to determine the optimum values of grid points numbers (N), time increments (Δt_D) for the numerical solution using the grid system shown in Fig. 3.

As capacitance model parameters were unknown, their values are assumed reasonable. The input and calculated data are as given in Table 2. Log data have been gathered from one of the Iranian southern reservoir [13].

Table 1: Comparison of Disp from present study with the Disp from Chen et al. model.

Data	ϕ (Frac)	K (md)	Disp.this study(m)	Disp.Chen Correlation (m)	AAD%
1	0.15	2.5	0.0144	0.0161	11.893
2	0.16	3.5	0.0154	0.0166	7.790
3	0.17	5.5	0.0163	0.0182	11.230
4	0.20	15	0.0192	0.0209	8.760
5	0.22	27	0.2113	0.2226	6.845
6	0.25	40	0.2319	0.2262	2.445

Table 2: Input and calculated data.

Porosity	0.25
Resistivity Log data	From related well log
Payzone Thickness	52.426 m
Wellbore Radius	0.11 m
Mass transfer coefficient	0.4 1/hr
Fractional flow	0.9 (fraction)
b	1.67×10^{-5} 1/hr
a	0.08 m^3/h
Radius of investigation	10 m
Time of investigation	300 hr
Calculated depth of invasion(Eqs.A-1,A-2)	1.261 m
Calculated dispersivity (Eq.A-7)	0.0232 m

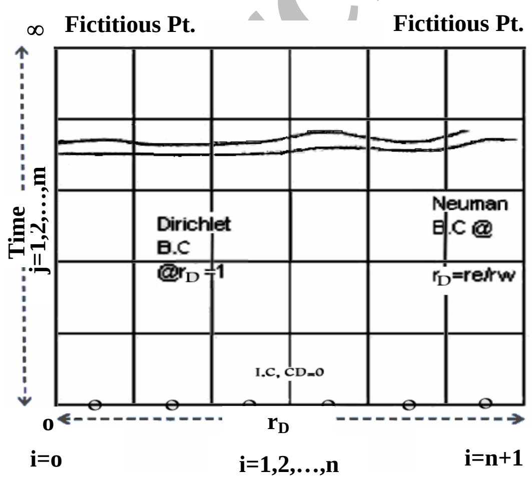

Fig. 3: Solution domain and grid system.

For the purpose of optimizing grid numbers and time increments, present model is run with above mentioned data. Fig.4 illustrates the effect of the variable Δt_D on plot of mud filtrate dimensionless concentration (C_D) versus radial dimensionless distance (r_D) at a constant grid size of 200. There is an insignificant difference between the result for Δt_D=0.5 and 0.1. Therefore, Δt_D=0.5 was assumed for this situation. The effects of different grid sizes on the filtrate concentraiton are compared at Fig.5 using the optimum time increment; i.e., 0.5. The value of N ranges from 50 to 250. As it can be seen, an increase in the number of grid size, results in a rapid convergence to the correct solution. In this case, N_{opt} equals 200.

Fig.6 shows the concentration versus radial distance at different times while Fig.7 is the concentration versus time at different radius distances; all parameters in these two figures are dimensionless. As it was predicted, the mud concentration front moves forward as time passes.

Finally, a parametric study has been conducted to analyze the effect of the most relevant parameters on the present model. These are: dispersivity, fractional flow, mass transfer coefficient, volumetric flow rate and formation thickness exposing to flow.

As shown in Figs. 8 and 9, formation thickness exposing to flow and volumetric flow rate significantly affect the concentration profile of drilling mud. At the thickness of 100m, concentration profile drastically falls compared to its value at 10m-thick formation. Also raising the volumetric flow rate from 0.001m^3/h to 2m^3/h, pushes the concentration profile considerably forward along the distance from well.

As it is depicted from Fig.10, change in dispersivity has some effects on mud dispersion, but not as considerable effect as volumetric flow rate and formation thickness exposing to flow have. The difference occurred between the trend of low values (0.05 and 1m) and high values (5 and 10 m) .

The effect of mass transfer coefficient is considerable only at lower values, such as 0.000001 1/hr, where the slope is smooth in comparison with high values e.g. 0.01 1/hr where the trend is almost vertical, according to the Fig. 11. However, there is no significant difference between values of 0.01, 0.5 and even an abnormal value such as 4.0 1/hr. Finally, fractional flow does not have important effect on concentration profile

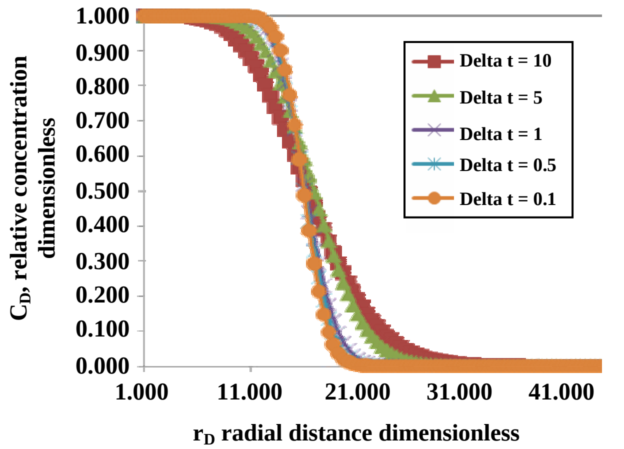

Fig. 4: Comparison of the effect of Δt on mud filtrate dimensionless concentration number of grid =250, dimensionless Time=25.5.

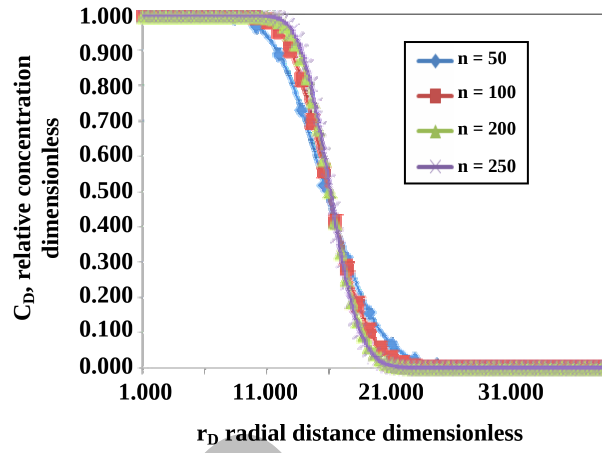

Fig. 5: Comparison of the effect of grid number (N) on mud concentration dimensionless ΔtD=0.5, Dimensionless Time=25.5.

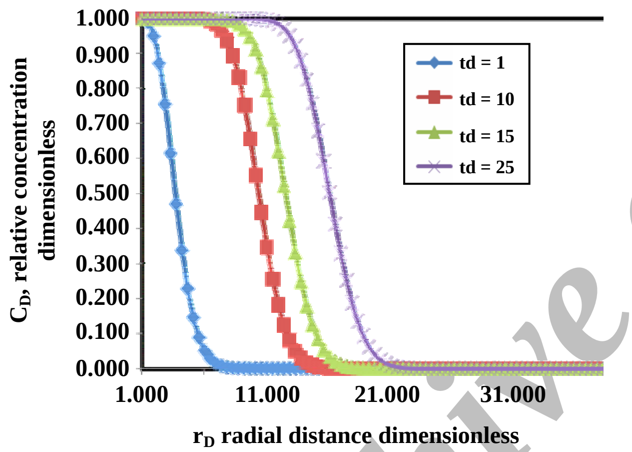

Fig. 6: Dimensionless concentration curve at different dimensionless times.

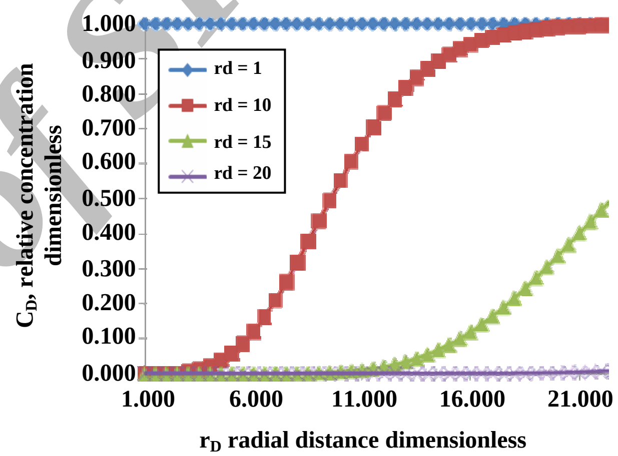

Fig. 7: Dimensionless concentration curve at different dimensionless radii.

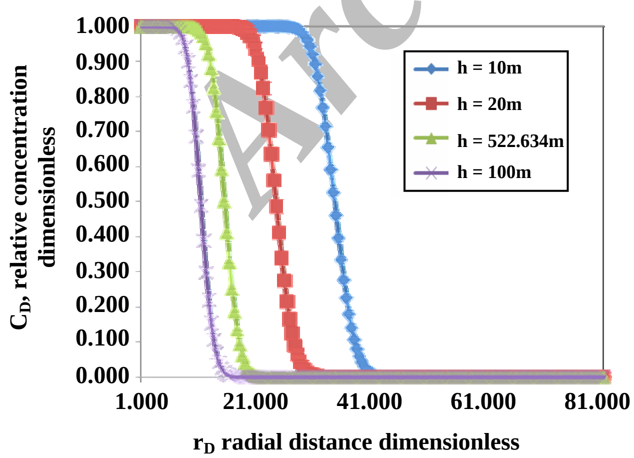

Fig. 8: Effect of Payzone height on mud filtrate dimensionless concentration.

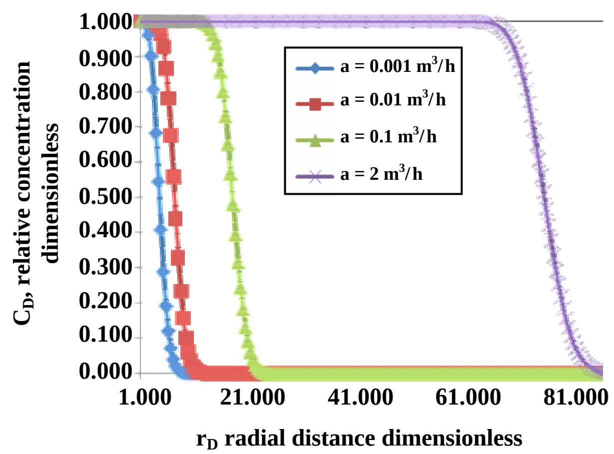

Fig. 9: Effect of Flow rate (a) on mud filtrate dimensionless concentration.

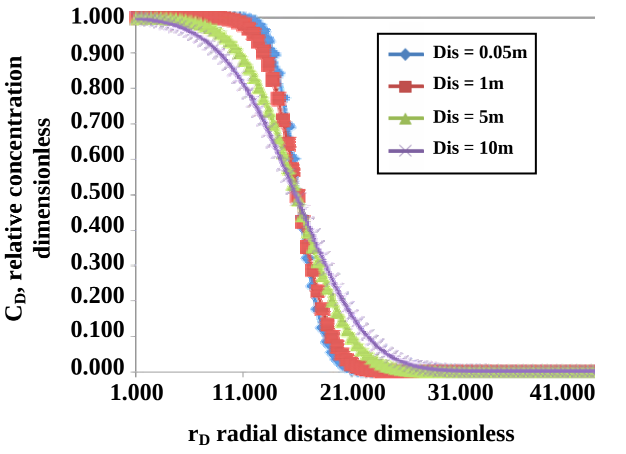

***Fig. 10:** Effect of Dispersivity on mud filtrate dimensionless concentration.*

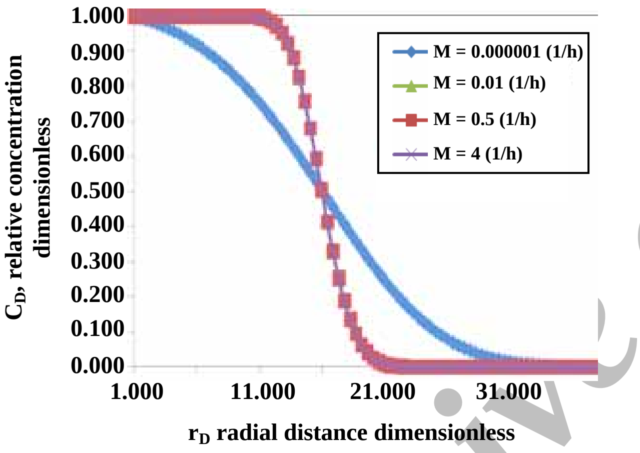

***Fig. 11:** Effect of Mass Transfer Coefficient of capacitance model (M) on mud filtrate dimensionless concentration.*

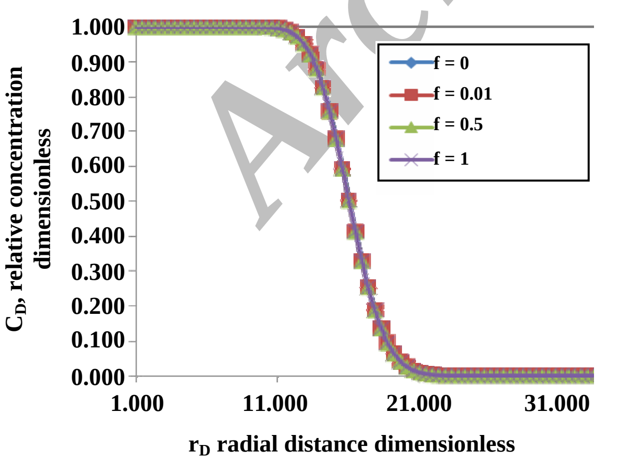

***Fig. 12:** Effect of Flow fraction of capacitance model (f) on mud filtrate dimensionless concentration.*

of mud dispersion as it is seen in Fig. 12; there are not many differences between fractional values of 0.0 and 0.9.

CONCLUSIONS

1- An improved model is developed for modeling of mud filtrate invasion into the formation. The physical model is rigorously described by a convection-dispersion equation and its associated condition in the porous media. Advantages are applying the derived correlation of dispersivity from resistivity log data and using the newly described aspect of dispersion phenomena in porous media. The present model simulates drilling mud dispersion with reasonable accuracy.

2- The dispersivity correlation obtained in this study introduces a good accuracy to calculate this factor from resistivity and porosity log data. Compared with the previous correlation of calculating dispersivity, it uses less data (Resistivity, Sonic or Density log) and has more accuracy in field application.

Appendix A: Dispersivity from resistivity log data

As mentioned earlier depth of invasion can be calculated from resistivity log data according to *Chen et al.* [7] formula as follow:

$$D_i = D_h \exp\left[\frac{2\pi h_d}{k_d}\left(\frac{R_{lld} - R_t}{Rlls - R_t}\right)\right] \quad \text{(A-1)}$$

For medium-porosity formations, and

$$D_i = D_h \exp\left[\frac{2\pi h_d}{k_d}\left(\frac{R_{lld} - R_t}{Rxo - R_t}\right)\right] \quad \text{(A-2)}$$

For high-porosity formations.

According to the depth of invasions definition, at the point that invasion stops, the concentration is nearly zero. Therefore depth of invasion is appropriatly equal to miscible zone width, so by inserting it in the miscible zone width which is as follow [14-17]:

$$x_{10} - x_{90} = 3.625\sqrt{\vec{D}_l t} \quad \text{(A-3)}$$

So Depth of invasion is:

$$Di = 3.625\sqrt{\vec{D}_l t} \quad \text{(A-4)}$$

After rearranging above equation, it changes to:

$$\vec{D}_l = \frac{D_i^2}{3.625^2 \times t} \quad \textbf{(A-5)}$$

According to the dispersivity definition, it becomes as follow:

$$\text{Dis} = \frac{\overrightarrow{D_l}}{\frac{\overline{\overline{v}}}{\phi}} = \frac{\frac{\overrightarrow{D_i}^2}{3.625^2 \times t}}{\frac{\overline{\overline{v}}}{\phi}} = \frac{\overrightarrow{D_i}^2}{3.625^2 \times t \times \overline{\overline{v}}}\phi \qquad \text{(A-6)}$$

The following equation has been derived for the dispersivity after assumption of $\overline{\overline{v}} \times t \rightarrow D_i$ which is approximately true at the time invasion stops:

$$\text{Dis} = \frac{D_i}{3.625^2}\phi \qquad \text{(A-7)}$$

Appendix B: Derivation of dimensionless Convection-Dispersion equation

The transient convection-dispersion equation is:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\vec{D}\frac{\partial C}{\partial r}\right) = \frac{\vec{V}}{\phi}\frac{\partial C}{\partial r} + \frac{\partial}{\partial t}(C) \qquad \text{(B-1)}$$

The following dimensionless variables are defined as follows:

$$C_D = \frac{C}{C_0} \qquad r_D = \frac{r}{r_w} \qquad t_D = \frac{t}{t_0} \qquad \text{(B-2)}$$

Where the form of t_0 has been used [1] as follow:

$$_0 = \frac{r_w\phi}{u} = \frac{r_w\phi}{\frac{a}{2\pi r_w h}} = \frac{2\pi r_w^2 h\phi}{a}$$

a = empirical constant equals to 0.08 m3/h

By inserting the above dimensionless parameter in Eq. B-1, it becomes:

$$\frac{1}{r_w^2}\frac{1}{r_D}\frac{\partial}{\partial r_D}\left(r_D\vec{D}\frac{c_0\partial C_D}{\partial r_D}\right) = \qquad \text{(B-3)}$$

$$\frac{\vec{v}}{\phi}\frac{c_0}{r_w}\frac{\partial C_D}{\partial r_D} + \frac{c_0}{t_0}\frac{\partial C_D}{\partial t_D}$$

After simplification it reduced to:

$$\frac{t_0}{r_w^2}\frac{1}{r_D}\frac{\partial}{\partial r_D}\left(r_D\vec{D}\frac{\partial C_D}{\partial r_D}\right) = \frac{\vec{v}}{\phi}\frac{t_0}{r_w}\frac{\partial C_D}{\partial r_D} + \frac{\partial C_D}{\partial t_D} \qquad \text{(B-4)}$$

By defining D0 and v0 as follows:

$$\overrightarrow{v_0} = \frac{a}{2\pi r_w h} \qquad \text{(B-5)}$$

$$D_0 = \text{Dis} \times \overrightarrow{v_0} = \text{Dis} \times \frac{a}{2\pi r_w h} \qquad \text{(B-6)}$$

Where v0 is the velocity at wellbore and time zero, D0 is its related dispersion coefficient and “a” is the constant parameter mentioned above.

By inserting above parameter in Eq. (B-4), it reduced to:

$$\frac{2\pi h\phi D_0}{a}\frac{1}{r_D}\frac{\partial}{\partial r_D}\left(r_D\frac{\vec{D}}{\overrightarrow{D_0}}\frac{\partial C_D}{\partial r_D}\right) = \qquad \text{(B-7)}$$

$$\left(\frac{\vec{v}}{\overrightarrow{v_0}}\right)\frac{\partial C_D}{\partial r_D} + \frac{\partial C_D}{\partial t_D}$$

The empirical correlation for mud filtration rate can be written as[2]:

$q = a\exp(-bt)$

Where variables “a” and “b” are empirical parameters. If the dimensionless form of $t(\text{i.e.}t_D t_0)$ is used it becomes as:

$$q = a\exp(-bt_D t_0) \qquad \text{(B-8)}$$

And so:

$$\left(\frac{\vec{v}}{\overrightarrow{v_0}}\right) = \frac{\frac{a}{2\pi rh}e^{-bt_D t_0}}{\frac{a}{2\pi r_w h}} = \frac{1}{r_D}e^{-bt_D t_0} \qquad \text{(B-9)}$$

$$\frac{\vec{D}}{\overrightarrow{D_0}} = \frac{\text{Dis}}{\text{Dis}_0} \times \frac{\vec{v}}{\overrightarrow{v_0}} = \frac{1}{r_D}e^{-bt_D t_0} \qquad \text{(B-10)}$$

By applying the above equation, Eq. B-7 reduces to:

$$\frac{\text{Dis} \times \phi \times e^{-bt_D t_0}}{r_w}\frac{1}{r_D}\frac{\partial^2 C_D}{\partial r_D^2} - \qquad \text{(B-11)}$$

$$\frac{e^{-bt_D t_0}}{r_D}\frac{\partial C_D}{\partial r_D} = \frac{\partial C_D}{\partial t_D}$$

Initial condition and boundary conditions are dimensionless as a follow:

I. C: CD=0 $t_D = 0$ $1 \le r_D \le r_{De}$ (B-12)

B. C: CD=1 rD=1; $t_D > 0$

$$\frac{\partial C_D}{\partial r_D} = 0 \qquad \text{rD=rDe;} \quad t_D > 0 \qquad \text{(B-13)}$$

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Nomenclatures

a	Average volumetric lost rate (m^3/hr)
AAD%	Absolute Average Deviation
b	Empirical constant (1/hr)
c	Mud concentration (kg/m^3)
D	Dispersion coefficient (m^2/hr)
Dis	Dispersivity (m)
Di	Depth of invasion (m)
Dh	Hole diameter (m)
f	Flow fraction
h	Formation thickness (m)
H	Rock heterogeneity factor
hd	Vertical resolution of deep-laterolog tool(m)
K	Permeability (md)
kd	Calibration coeff. of deep-laterolog tool(m)
M	Mass transfer coefficient (hr-1)
q	Mud filtrate rate (m^3/hr)
r	Radial distance (m)
rw	Wellbore radius (m)
re	External boundary radius (m)
Rlld	Deep laterolog resistivity(ohm-m)
Rlls	Shallow laterolog resistivity(ohm-m)
Rxo	Flashed zone laterolog resistivity (ohm-m)
Rt	True formation resistivity(ohm-m)
t	Time (hr)
v	Flow velocity (m/hr)
x	Cartesian distance

Greek Letters

ϕ	Porosity (fraction)
τ	Tortuosity
σ_H	Hetrogeneity-related parameter

Subscripts

D	Dimensionless
i	Spatial position
n	Number of grid blocks
o	Initial or maximum value
l	Longitudinal
e	Equivalent

Superscripts

N	Time level

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REFRENCES

[1] Civan F., Engler T., Drilling Mud Filtrate Invasion-Improved Model and Solution, *J. of Petroleum Science and Engineering*, **18** (10), p. 1005 (1994).

[2] Donaldson E.C., Kendall R.F., Userda, Manning F.S., Dispersion and Tortuosity in Sandstones, "Presented for the 51st Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineering of AIME", *SPE6190*, New Orleans, (1976).

[3] a) Civan F., "Reservoir Formation Damage", Gulf Publishing. Co. (2000).
b) Donaldson E.C., Chernoglazov V., Drilling Mud Fluid Invasion Model, *J. of Petroleum Science and Engineering*, **1**(1), p. 3 (1987).

[4] Gerald C.F., Wheatly P., "Applied Numerical Analysis", Addison-Wesley Publishing. Co. (1999).

[5] Sahimi M., "Flow and Transport in Porous Media and Fractured Rock", VCH .Co (1995).

[6] Chen S., Menzie D. E., Modeling of Dispersion Phenomena in Miscible Fluid Flow Through Porous Media, "Presented at the First International Congress of Oil, Gas, Petrochemical", **1**, p. 1 (1990).

[7] Chen S., Thomas C., A Simple Approach to Mud-Invasion Correction for Dual Laterolog Resistivities, "Presented at the SPE Permian Basin Oil and Gas Recovery Conference" *SPE 23962*, Texas (1992).

[8] Harleman D.R.F., Mehlhorn P.F., Rumer R.R., *J. of the Hydraulic Div.,Proc. Amer. Soc. Civil Eng*., p. 67 (1963).

[9] Chen S., "Investigation of Dispersivity as a Reservoir Rock Characteristic and its Determination from Well Logs" Ph.D. Dissertation, the University of Olahoma, Norman, Oklahoma (1991)

[10] Chen S., Thomas C., Menzie D.E., SPWLA 33rd Annual Logging Symposium, (1992).

[11] Prausnitz J. M., *AIChE J*., **4** (1), p. 14M (1958).

[12] Koval E.J., *SPE Jour*., p. 145 (1963).

[13] "Petrophisical Data of Iranian South Reservoir", National Iranian South Oil Company, (2003).

[14] a) Perkins T.K., Johnston O.C., A Review of Diffusion and Dispersion in Porous Media, *Soc Petrol Eng. J.*, **3** (1), p. 70 (1963).
b) Sahimi M., "Flow and Transport in Porous Media and Fractured Rock", VCH Co (1995)

[15] a) Raimondi P., Gardner G.H.F., Patrick G.B., Effect of Pore Structure and Mulecular Diffusion on the Mixing of Miscible Liquids in Porous Media, "AIChE/SPE Joint Symposium", Sanfransisco, Dec.6-9. (1959).
b) "Petrophisical Data of Iranian South Reservoir", National Iranian South Oil Company, (2003).

[16] Stalkup F.I., "Miscible Displacement", SPE Monograph no.8. (1980).

[17] Green D.W., Willhite G.P., "Enhanced Oil Recovery", Richardson Co, Texas, (1998).