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# DEVELOPMENT OF A PERFORMANCE EVALUATION METHOD OF MECHANICAL SAND RETENTION TECHNIQUES

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## ABSTRACT

The production of sand from poorly consolidated formation is a problem that has plagued the oil and gas industry for a long time. The problem of sanding can be alleviated by producing under the critical flow rate that triggers sand production. However, this critical production rate is usually small and uneconomical. Therefore, some form of sand control is employed of which the mechanical sand retention, i.e. gravel pack and sand control screen are the most popular. The use of sand control devices inevitably causes decline in well productivity, which is characterized by the additional pressure drop across the device(s). The drop in productivity is often aggravated by high velocity and two-phase flow. A computer simulation program will be developed to evaluate the productivity of gravel pack and sand control screen with a few assumptions such as semi-steady state flow around the wellbore, perforations are treated as perfect cylinders and the annulus between the perforation and screen is completely filled with gravel. For screen only completion, the natural sand bridging will not be considered. For the gravel pack, a three-dimensional, two-phase finite difference scheme will be developed that is capable of modeling the dispersed flow pattern, which exists in the gravel pack. The effect of turbulence would be accounted for by means of the Forschheimer's Equation. A dedicated, CFD based model will be used to study the fluid flow across sand control screens. The pressure drop associated with perforations will be calculated using correlations based on the finite-element modeling. Such phenomena as partial penetration, drilling damage and perforation damage will be included. The resulting package can be used to study the effect on overall productivity of such factors as perforation density, geometry, flow rate and fluid properties.

**Key Words** : Sand Control, Gravel Pack, Screen, Computer Modelling, Sand Production

## Background

Petroleum is often produced from unconsolidated or poorly consolidated sandstone reservoirs found in the shallow or geologically young formations. As petroleum fluids are produced, loose sand particles may be drawn into the wellbore. This is the phenomenon of sand production, which is itself a manifest of factors such as wellbore instability and weak intergranular cementation and compaction. Sand production is undesirable for many reasons, the most important being erosion damage and plugging of equipments and the well.

Gravel packing and sand control screen are popular sand control methods but could cause decline in the well productivity, which is characterized by the additional pressure drop across the devices. The drop in productivity is aggravated by high velocity and two-phase flow effects.

The problem of fluid flow across a gravel pack had been studied by previous investigators such as Oyeneyin (1987 ), Yildiz et.al (1988) and Pucknell et.al (1992), and they have focused on different aspects of the gravel pack system. Their studies have been compromised by assumptions that one-phase flow and laminar flow prevail. In reality, it is more than likely that two-phase flow will occur and high velocity effect can be significant in the gas wells. While sand control screen is an important component of the sand control system, its effect on productivity has been overlooked; and the industry has chosen to use the overly simplified skin factor approach to calculate the pressure drop across the screen.

This study aims to quantify the additional pressure drop incurred by the use of gravel pack and sand control screen by numerical modelling.

## Methodology

The fluid flow pattern in a gravel pack system is depicted as follows. The fluid flow pattern changes from a radial to a converging one as it approaches the perforations because the fluid will choose the path that offer the least flow resistance. The fluid then takes a linear flow path as it enters the perforation before flowing divergently into the gravel pack and screen, and finally enters the wellbore as shown in Figure 1. The modelling equations used to calculate the pressure drop across each of the components are discussed in the ensuing sections.

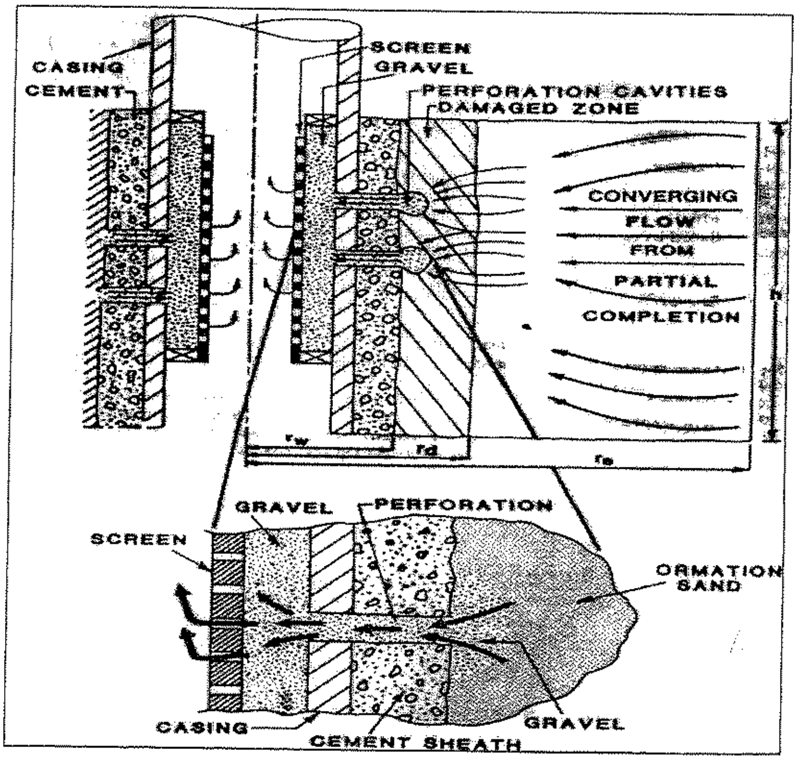

**Figure 1 : Flow Path Through an Inside-Casing Gravel Pack Completion (Golan et. al., 1991)**

### Pressure Drop Across Gravel-Packed Perforation

The equations developed by Ates and Kelkar (1997) will be used to calculate the two-phase pressure drop across a perforation packed with gravel. The equations are derived based on the radial form of the Forschheimer equation, which makes the solution valid for both laminar and turbulent flow conditions. The equation may be written in the final form of

$$P_{wfs}^{\ 2} - P_p^{\ 2} = aq_{op}^{\ 2} + bq_{op} \tag{1}$$

where

$$a = \left(\frac{4.6\times10^{-14}\beta P_b(\mu_o B_o)_{P_b}}{L_p^{\ 2}}\right)\left\{\frac{1}{r_p}-\frac{1}{r_c}\right\}\left(\frac{\rho_{do}}{\mu_o}+\frac{0.0764\gamma_g\tilde{R}_s}{5.615\tilde{\mu}o}\right)$$

and

$$b = \left(\frac{\ln\left(\frac{r_c}{r_p}\right)P_b(\mu_o B_o)_{P_b}}{3.54\times10^{-3}k_c L_p}\right)$$

$\tilde{\mu}o$ and $\tilde{R}_s$ are defined at $\frac{P_{wfs}+P_p}{2}$. Hence, the solution procedure to find the pressure drop across the perforation requires trial and error. The pressure drop across the perforation, $\Delta P_{perf}$, is the difference between $P_{wfs}$ and $P_p$, i.e.

$$\Delta P_{perf} = P_{wfs} - P_p \tag{2}$$

### Fluid Flow in Gravel Pack

The fluid flow in gravel pack will be studied using three-dimensional, two-phase finite difference method. The method is deemed suitable as it can adequately model the dispersed, three-dimensional flow within the gravel pack and can easily be modified to accommodate various operating conditions, i.e. different perforation density, perforation geometry, gravel pack thickness and production rate. The governing equation is developed by combining the Law of Mass Conservation and Darcy's Law. The β- or black oil model is assumed to represent the hydrocarbon system.

The Law of Mass Conservation, as described by Aziz and Settari (1979) can be written as

$$-\nabla\rho u = \frac{\partial}{\partial t}(\rho\varphi) + \tilde{q} \tag{3}$$

And, adopting the cylindrical coordinate system (r,θ,z) it becomes

$$-\left(\frac{1}{r}\frac{\partial \rho r u_r}{\partial r}+\frac{1}{r^2}\frac{\partial \rho u_\theta}{\partial \theta}+\frac{\partial \rho u_z}{\partial z}\right)=\frac{\partial}{\partial t}(\rho\varphi)+\tilde{q} \tag{4}$$

The Darcy's Law relates the phase velocity and pressure differential. In a single-phase flow condition, this is written as

$$u=-\frac{k}{\mu}(\nabla P-\gamma\nabla z) \tag{5}$$

For multiphase flow, the law is extended as

$$u_\ell=-\frac{kk_{r\ell}}{\mu_l}(\nabla P_\ell-\gamma_\ell\nabla z) \tag{6}$$

where $k_{r\ell}$ is the relative permeability to a particular phase $\ell$.

The high velocity effects are accounted for by adding a turbulence correction factor δ to Darcy's Law, i.e.

$$u_\ell=-\frac{\delta_\ell kk_{r\ell}}{\mu_l}(\nabla P_\ell-\gamma_\ell\nabla z) \tag{7}$$

with $\delta_\ell$ the turbulence factor for phase $\ell$.

The governing equation for one-phase flow through the gravel pack in three-dimensional cylindrical co-ordinates (r,θ,z) is

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\delta_r\lambda R\left(\frac{\partial P}{\partial r}-\gamma\frac{\partial h}{\partial r}\right)\right]+\frac{1}{r^2}\frac{\partial}{\partial \theta}\left[\delta_\theta\lambda\theta\left(\frac{\partial P}{\partial \theta}-\gamma\frac{\partial h}{\partial \theta}\right)\right]+\frac{\partial}{\partial z}\left[\delta_z\lambda Z\left(\frac{\partial P}{\partial z}-\gamma\frac{\partial h}{\partial z}\right)\right]=\Psi\frac{\partial P}{\partial t}+q \tag{8}$$

The governing equation is discretized in space in the directions of r, θ and z for both the oil and water phases. In this study, it is assumed that capillary pressure is negligible so that the oil and water phase pressure are equal, i.e. $P_o=P_w=P$. The governing equation is also discretized in time into timesteps Δt, such that numerical solutions are sought on discrete time levels, i.e. $t_o=0$, $t_1=\Delta t,\ldots,t_n=n\Delta t$. The time discretization is accomplished by the forward difference approach. Finally, the two-phase IMPES (Implicit Pressure Explicit Saturation) method is used to combine the governing equations for the oil and water phases. This difference is written for each grid point and the resulting system of equations is collected and expressed in matrix form as

$$\mathbf{AP}=\mathbf{D} \tag{9}$$

where **A** is a diagonal matrix of seven diagonals, **P** is the solution matrix and **D** is a matrix of values which are constant at a particular timestep. Equation 8 is solved using the iterative BSOR (Block Successive Over Relaxation) method for the pressure at the innermost part of the gravel pack prior to the screen, i.e. $P_{gp}$. The pressure drop across the gravel pack, $\Delta P_{gp}$, is the difference between $P_p$ and $P_{gp}$, i.e.

$$\Delta P_{gp} = P_p - P_{gp} \tag{10}$$

Pressure Drop in Sand Control Screen

The semi-empirical relationship developed by Su and Gudmundsson (1993) for horizontal wells will be adapted in calculating pressure drop within sand control screen. The total pressure drop is attributed to pipe wall friction, perforation friction, mixing effects and acceleration effects. The pressure drop due to friction along the screen opening, $\Delta p_{opening}$ can be calculated from the Darcy-Weisbach Equation, as expressed in Equation 9.

$$\Delta p_{opening} = \frac{f}{2}\frac{L_s}{D_s}\rho u_s^2 \tag{11}$$

where

$$f = \left\{-1.8\log\left[\frac{6.9}{Re} + \left(\frac{\varepsilon}{3.7D}\right)^{1.11}\right]\right\}^{-2} \tag{12}$$

In vertical wells, the pressure drop due to perforation roughness is zero. The pressure drop due to flow acceleration, $\Delta P_{acc}$, is calculated as follows,

$$\Delta p_{acc} = \rho\left(u_2^2 - u_1^2\right) \tag{13}$$

while the mixing pressure drop, $\Delta P_{mix}$, calculated as

$$\Delta p_{mix} = -0.031\left(\frac{q}{Q_2}\right) \qquad \text{for}\left(\frac{q}{Q_2}\right) < \text{critical rate} \tag{14}$$

$$\Delta p_{mix} = 760\left(\frac{q}{Q_2}\right) \qquad \text{for}\left(\frac{q}{Q_2}\right) > \text{critical rate} \tag{15}$$

Since the components of pressure drops are cumulative, the total pressure drop can be computed as the sum of all pressure drop components, as expressed in Equation 16.

$$\Delta P_{total} = \Delta P_{perf} + \Delta P_{gp} + \Delta P_{opening} + \Delta P_{acc} + \Delta P_{mix} \tag{16}$$

## Development of Computer Program

A computer program will be written in Fortran language. The program can be used to calculate the total pressure drop across gravel packed wells for various production rates. Sensitivity studies can be performed using the program to ascertain the effects of certain parameters on the performance of the gravel packed wells. The program will start with the evaluation of two-phase pressure drop in perforations. The relationships developed by Ates and Kelkar (1997) are adopted for use in the program. In the second part, the program will calculate the two-phase pressure drop in a cylindrical shaped gravel pack using a three-dimensional, two-phase finite difference model. Finally, the pressure drop across the sand control screen (the last portion of the gravel pack assembly) will be considered. The empirical relationship developed by Su and Gudmundsson (1994) will be used for this purpose. The total pressure drop can be computed as the sum of all pressure drop components, as expressed in Equation 16.

## Validation of Computer Program

Part I of the program (gravel-packed perforation) will be compared with similar procedures developed by Karakas and Kelkar (1993) using the conditions specified in their paper. Part II of the program (gravel pack) will be validated against the numerical approach considered by Yildiz and Langlinais (1988) for one-phase flow with the prescribed specifications. The validity of the two-phase flow will be investigated using the conventional black oil simulator BOAST 98 and the skin factor approach. The computer program with its full feature can be validated against the results of specially designed laboratory experiments such as those of Pham (2000) or field data.

## Application of Computer Program

The computer program is expected to provide calculation of pressure drop for various flow rates, which is important is NODAL analyses. The program shall enable future investigation of the effects of important factors such as flow rate, gravel pack characteristics, perforation characteristics and fluid properties on the performance of gravel packed wells. The program can be used as a tool to determine the best sand control practice for various operating conditions. The capability of the computer program can be extended by including the pore blocking effects described by Oyeneyin et.al. (1994) that requires meticulous laboratory work.

## Nomenclature

a = constant
b = constant
B = formation volume factor, $ft^3$/scf
k = absolute permeability, md
$L_p$ = perforation length, ft
P = pressure, psi
$q_{op}$ = oil flow rate through a single perforation, stb/d
r = radius, ft
$R_s$ = solution GOR, scf/stb
$\beta$ = velocity coefficient, $ft^{-1}$

$g$ = specific gravity
$\mu$ = viscosity, cp
$\rho$ = density, lbm/ft$^3$
$\nabla$ = divergence operator
$\phi$ = porosity, fraction
$\tilde{q}$ = mass flux rate, lbm/ft$^2$ s
$\partial$ = difference operator
$u$ = fluid velocity, ft/s
$k_{r\ell}$ = relative permeability to phase $\ell$ , dimensionless
$\delta_\ell$ = turbulence factor of phase $\ell$, dimensionless
$\Psi = \frac{\varphi}{B}$, dimensionless
$q$ = mass flow rate, lbm/s
$t$ = time, s
$\mathbf{A}$ = coefficient matrix
$\mathbf{P}$ = solution matrix
$\mathbf{D}$ = matrix of constant values
$L$ = length, ft
$D$ = diameter, ft
Re = Reynolds Number
$\Delta P$ = pressure drop, psi
$Q_2$ = bulk flow rate beyond screen opening, ft$^3$
$\varepsilon$ = roughness height, ft

**Subscripts**
b = bubble point
c = crushed zone
do = dead oil
g = gas
o = oil
p = perforation
wfs = well flowing at sand face
r = in r direction
$\theta$ = in $\theta$ direction
z = in z direction
s = screen opening
1 = in screen opening
2 = beyond screen opening

## References

1. Ates, H. and Kelkar, M.G. (1987), SPE 37512 "Two-Phase Pressure Drop Predictions Across Gravel Pack." Society of Petroleum Engineers.
2. Aziz, K., Settari, A. (1979). "Petroleum Reservoir Simulation." Elsevier Applied Science.
3. Bigno, Y. and Oyeneyin, M.B. (1994), SPE 27342 "Investigation of Pore-Blocking Mechanism in Gravel Packs in the Management and Control of Fines Migration." Society of Petroleum Engineers.

4. Golan, M., Whitson, C.H. (1991). "Well Performance." *Second Edition*, Prentice-Hall Inc., New Jersey.
5. Pham, V.C. (2000), "The Relationship Between Reservoir Rock Compaction and Sand Production." M.Eng. Thesis, Universiti Teknologi Malaysia.
6. Su, Z. and Gudmundsson, J.S., SPE 28800 "Pressure Drop in Perforated Pipes: Experiment and Analysis." Society of Petroleum Engineers.