# PRESSURE DROP ANALYSIS FOR OPTIMUM INSIDE-CASING GRAVEL PACK DESIGN

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*In memory of my grandfather,*

*And in dedication to my parents and brothers.*

## ABSTRACT

A computer simulation program is developed to evaluate the productivity of inside-casing gravel packs. The assumptions are that perforations are treated as small wedges and gravel is assumed to fill the perforation and the casing-screen annulus. A three-dimensional, finite-difference model is developed that is capable of modeling the flow pattern in the multiple perforation system. The high-velocity effects are accounted for by the Forchheimer equation. The pressure drop across the annular gravel pack is calculated based on the skin factor. The simulator was successfully validated against pressure drop data of actual gravel-packed wells. The resulting package can be used to study the effect of gravel-packed well parameters on overall productivity. The well parameters studied are perforation length, diameter, density, angle, pattern, gravel permeability and flow rate.

# ABSTRAK

Satu program penyelaku telah dibangunkan untuk menilai produktiviti pek kerikil dalam selongsong. Andaian yang dibuat ialah tebukan dianggap sebagai bukaan kecil berbentuk baji dan kerikil memenuhi sepenuhnya tebukan dan anulus di antara selongsong dan skrin. Sebuah model beza terhingga tiga dimensi telah dibina yang berupaya menyelaku aliran di dalam sistem panca tebukan. Kesan aliran halaju tinggi diambil kira oleh persamaan Forchheimer. Beza tekanan di dalam pek kerikil di antara selongsong dan skrin dikira berdasarkan faktor kulit. Program penyelaku ini telah disahkan menggunakan data beza tekanan telaga pek kerikil yang sebenar. Pakej ini boleh digunakan untuk mengkaji kesan parameter telaga pek kerikil ke atas produktiviti secara amnya. Parameter-parameter yang dikaji adalah panjang penebukan, diameter penebukan, ketumpatan penebukan, sudut fasa, corak penebukan, ketertelapan kerikil and kadar alir.

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $C\mu$ | - | Uniformity constant |
| $\beta_G$ | - | Solids distribution ratio |
| *CRI* | - | Cuttings Re-Injection |
| $P_R$ | - | Reservoir pressure, psi |
| $P_{wf}$ | - | Well flowing pressure, psi |
| $\Delta P_{ideal}$ | - | Ideal pressure drop, psi |
| $\Delta P_{skin}$ | - | Skin pressure drop, psi |
| $q$ | - | Flow rate, bpd |
| $m$ | - | Viscosity, cp |
| $B$ | - | Formation volume factor, rb/stb |
| $k$ | - | Absolute permeability, mD |
| $h$ | - | Height of production zone, ft. |
| $r_e$ | - | Drainage radius, ft. |
| $r_w$ | - | Wellbore radius, ft. |
| $S_t$ | - | Total skin |
| $Dq$ | - | High-velocity skin factor |
| $D$ | - | High-velocity factor |
| $b$ | - | Fractional penetration |
| $h_D$ | - | Dimensionless pay thickness |
| $h_p$ | - | Limited interval open to flow, ft. |
| $h$ | - | Total formation thickness, ft. |
| $k_v$ | - | Vertical formation permeability, mD |
| $S_d$ | - | Formation damage skin |
| $k_d$ | - | Damaged zone permeability, mD |
| $r_d$ | - | Damaged zone radius, ft. |
| $S_s$ | - | Skin due to collapsed perforation |

| | | |
|---|---|---|
| $n$ | - | Number of perforations |
| $r_p$ | - | Perforation radius, in. |
| $d_p$ | - | Perforation diameter, in. |
| $S_l$ | - | Skin due to linear flow through perforation tunnel |
| $k_f$ | - | Formation permeability, mD |
| $k_g$ | - | Gravel permeability, mD |
| $h_t$ | - | Total formation thickness, ft. |
| $L_p$ | - | Perforation length, in. |
| $D'$ | - | High-velocity skin, $psi^{-1}$ |
| $S_r$ | - | Skin due to radial flow between casing and screen |
| $k_r$ | - | Formation permeability in radial direction |
| $r_l$ | - | Casing inner radius, in. |
| $r_{scr}$ | - | Screen outer radius, in. |
| $S_{dev}$ | - | Skin due to slanted wellbore |
| $S_{pc}$ | - | Skin due to partial penetration |
| $m_x$ | - | x-component of mass flow vector, $[ML^{-2}T]$ |
| $\Delta t$ | - | Time interval, [T] |
| $\phi$ | - | Porosity, fraction |
| $\widetilde{q}$ | - | Strength of sink, $[ML^{-3}T]$ |
| $u_x$ | - | Velocity in x-direction, [L/T] |
| $\Delta x, \Delta y, \Delta z$ | - | Length in x, y, and z direction, [L] |
| $\partial$ | - | Partial differential operator |
| $\nabla$ | - | Divergence operator |
| $r$ | - | radius |
| $[V_l]$ | - | Volume of a fixed mass of component $l$ |
| $Sl$ | - | Saturation of phase $l$ |
| $g_c$ | - | Gravitational acceleration, $ft/s^2$ |
| $\gamma$ | - | Specific gravity |
| $k_x, k_y, k_z$ | - | Permeability in x, y and z directions |
| $k_{rl}$ | - | Relative permeability of phase $l$ |
| $\boldsymbol{u}$ | - | Velocity vector |

| | | |
|---|---|---|
| $\delta$ | - | Turbulence correction factor |
| $V_{ijk}$ | - | Volume of gridblock (i,j,k) |
| $Q_{ijk}$ | - | Source/sink term |
| $TR, T\theta, TZ$ | - | Radial, angular and vertical transmissibility |
| $\alpha$ | - | Angular phasing |
| $\lambda R, \lambda\theta, \lambda Z$ | - | Radial, angular and vertical mobility |
| $b_o'$ | - | Slope of $b_o$ versus p curve |
| $b_w'$ | - | Slope of $b_w$ versus p curve |
| $q_o$ | - | Oil flow rate |
| $q_w$ | - | Water flow rate |
| $L_o$ | - | Oil mobility |
| $L_w$ | - | Water mobility |
| $c, a, g, b, f, z, s, d, x$ | - | Matrix coefficients |
| $u_{i,j,k}$ | - | Pressure solution for block i,j,k |
| $v$ | - | Iteration counter |
| $e$ | - | Tolerance |
| $\Delta P_{tun}$ | - | Pressure drop along casing-cement tunnel, psi |
| $\Delta P_{agp}$ | - | Pressure drop across annular gravel pack, psi |
| $\Delta P_{perf}$ | - | Pressure drop along perforations, psi |
| $\Delta P_{tot}$ | - | Total pressure drop, psi |
| $\Delta P_{oh}$ | - | Pressure drop in openhole case, psi |
| $\Delta P_{oh}$ | - | Pressure drop in perforated case, psi |
| $S_v$ | - | Vertical pseudoskin |

# LIST OF UNITS

| | | |
|---|---|---|
| bbl | - | barrel |
| cp | - | centipoise |
| psi | - | pound per square inch |
| % | - | percentage |
| mD | - | millidarcy |
| in | - | inch |
| ft | - | feet |
| $ft^2$ | - | square feet |
| $in^2$ | - | square inch |
| rb | - | reservoir barrel |
| stb | - | standard barrel |
| SPF | - | shots per foot |
| bpd | - | barrels per day |
| s | - | second |
| $m^3/s$ | - | cubic meter per second |
| h | - | hour |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| PR | - | productivity ratio |
| TCP | - | tubing conveyed perforating |
| ID | - | inner diameter |
| OD | - | outer diameter |
| IPR | - | inflow performance relationship |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Oil and gas are produced from unconsolidated or poorly consolidated sandstones in many areas of the world, in shallow, geologically young formations that offer little or no natural cementation to hold the individual grains together. As petroleum fluids are produced from such formations, loose or friable sand particles may be drawn into the wellbore, the quantity of which depends on a number of factors that include natural intergranular cementation, compaction, intergranular friction, fluid properties, and flow rate.

Sand production is undesirable for many reasons, the most important being erosion damage and plugging of equipments and the well. The industry spends millions of dollars every year on cleaning out sand from wells and other related problems. Also, substantial production quantities are lost or deferred in the process. Therefore, it is important to understand the mechanism of sand production and the measures that can prevent and/or control them. Among the various sand control methods available today, cased-hole gravel packing is predominant in the industry worldwide (Sherlock-Willis, 1998).

## 1.2 Problem Statement

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 technique is normally implemented, the most popular of which is the inside-casing gravel pack. The use of gravel pack causes decline in the well productivity, which is characterized by the additional pressure drop across the devices and is often aggravated by high velocity flow. A method is sought to quantify more accurately, the additional pressure drop in the inside-casing gravel pack so that its effect on the well productivity can be ascertained. The ability to predict the additional pressure drop across the well will eventually dictate the gravel pack configuration. Good prediction of the performance of a gravel-packed well is also important in optimizing the well equipment design, resulting in cost-effective well design and higher production.

## 1.3 Objective

Using pressure drop analysis to determine the optimum value of each parameter involved in the gravel pack design.

## 1.4 Scopes

In order to fulfil the above objectives, the study is to encompass the following scopes:

- Numerical and analytical modeling of the inside-casing gravel pack.
- Calculations of additional pressure drop in the inside-casing gravel pack.

- Analysis of the factors that may influence the productivity of inside-casing gravel packs as follows
    - Perforation patterns: inline, inplane and spiral
    - Phasing angle: 0°, 30°, 60°, 90° and 120°
    - Perforation density: 2, 4, 6 and 12 SPF
    - Flow rate: 250, 500 and 1000 bpd
    - Gravel permeability: 5000, 10000 and 20000 mD
    - Perforation penetration: 2, 4, 6, 8, 10 and 12 in.
    - Perforation diameter: 0.5, 0.7 and 1 in.
- Studies on actual field cases of sand production problems using the computer package for validation purposes.

isolation. Taguchi analysis on this work will reveal the relative importance of each parameter, leading to a methodology of optimum gravel pack design.

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