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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 tebukun dianggap sebagai bukaan kecil berbentuk baji dan kerikil memenuhi sepenuhnya tebukun dan anulus di antara selongsong dan skrin. Sebuah model beza terHINGGA tiga dimensi telah dibina yang berupaya menyelaku aliran di dalam sistem panca tebukun. 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.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS	xv
	LIST OF UNITS	xviii
	LIST OF ABBREVIATIONS	xix
	LIST OF APPENDICES	xx
 1	 INTRODUCTION	 1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objectives	2
	1.4 Scopes	2
 2	 THEORY OF SAND CONTROL	 4
	2.1 General Aspects of Sand Production	4
	2.2 Factors Influencing Sand Production	6
	2.2.1 Production Rate and Drag Force	7
	2.2.2 Natural Consolidation	7

2.2.3	Multiphase Flow	8
2.3	Consequences of Sand Production	9
2.3.1	Erosion of Surface Equipment	9
2.3.2	Tubular Damage	9
2.3.3	Productivity Loss	10
2.4	Methods of Sand Production	10
2.4.1	Gravel Packing	11
	2.4.1.1 Inside-Casing Gravel Pack	12
	2.4.1.2 Openhole Gravel Pack	12
2.4.2	Sand Control Screens	13
2.4.3	Chemical Sand Control	14
2.4.4	Combination Sand Control	15
2.5	Gravel Pack Design Criteria	15
2.5.1	Gravel Size	16
2.5.2	Gravel Pack Permeability and High-Velocity Coefficient	19
2.5.3	Screen Slot Width and Wire Spacing	21
2.5.4	Gravel Pack Thickness	21

3	PRODUCTIVITY OF GRAVEL-PACKED WELLS	24
3.1	Introduction	24
3.2	Skin Factor	25
3.3	Productivity of Gravel-Packed Wells	27
3.4	Skin Components in Gravel-Packed Wells	32
	3.4.1 Reservoir and Well Geometry	32
	3.4.1.1 Skin due to Partial Penetration	33
	3.4.2 Completion and Perforation Skin	34
	3.4.2.1 Skin due to Formation Damage	34
	3.4.2.2 Skin due to Perforation Geometry	35
	3.4.3 Wellbore Skin	37
	3.4.3.1 Skin due to Linear Flow	

6	RESULTS AND DISCUSSION	76
6.1	Introduction	76
6.2	Validation of Simulation Model	76
6.2.1	Sensitivity Study	77
6.2.2	Field Data Match	83
6.3	Case study	86
6.3.1	Shot density	87
6.3.2	Perforating pattern	92
6.3.3	Phasing angle	95
6.3.4	Perforation length	99
6.3.5	Perforation diameter	100
6.3.6	Gravel permeability	103
6.3.7	Flow rate	105
6.3.8	Relative importance of parameters	107
7	CONCLUSIONS AND RECOMMENDATIONS	109
7.1	Conclusions	109
7.2	Recommendations for future work	110
	REFERENCES	112
	APPENDICES	119
	APPENDIX A Standard Sieve Sizes	
	APPENDIX B Program code	
	APPENDIX C The Gullfaks, Statfjord and Heidrun Fields	
	APPENDIX D Well Data	
	APPENDIX E Sample Completion Diagram	

	Through Perforation Tunnels	37
	3.4.3.2 Skin due to Radial Flow in Annulus Between Casing ID and Screen OD	38
	3.4.3.3 Skin due to Flow Through Screen	38
3.5	Limitation of the Skin Factor Approach	39
4	MODELLING EQUATIONS	43
4.1	Features of the Simulation Model	43
4.2	Fluid Flow in Multiple Perforation Well System	43
4.2.1	Model Structure	44
4.2.2	Law of Mass Conservation	44
4.2.3	The Black Oil Model	47
4.2.4	Darcy's Law	49
4.2.5	Effects of High Flow Rates on on Pressure Drop	50
4.2.6	High-Velocity Coefficient, β	52
4.2.7	Development of Governing Equation	52
4.2.8	Formation of Coefficient Matrix	61
4.2.9	The Iterative Gauss-Seidel Model	63
4.3	Pressure Drop in Casing-Cement Perforation Tunnel	64
5	METHODOLOGY	68
5.1	Overview of Research Work	68
5.2	Computer Program Description	70
5.3	Validation of Computer Program	73
5.4	Gravel-Packed Well Productivity Modeling	73
5.5	Determination of Gravel-Packed Well Productivity	75

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Commonly Available Gravel Sizes (Penberthy and Shaughnessy, 1992)	17
2.2	Commercial Gravel Data (Golan and Whitson, 1991)	20
2.3	Commonly Used Casing and Screen Sizes (Penberthy and Shaughnessy, 1992)	23
3.1	Previous Studies on the Productivity of Gravel-Packed Wells	41

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Sand production during a four-rate test (Golan and Whitson, 1991,after Mullins <i>et al.</i> , 1974)	5
2.2	Two Mechanisms of Mechanical Retention (Golan and Whitson, 1991)	11
2.3	Inside-Casing Gravel Pack (Golan and Whitson, 1991)	13
2.4	Openhole Gravel Pack (Golan and Whitson, 1991)	13
2.5	Screen-Only Completion (Golan and Whitson, 1991)	14
2.6	Sand control techniques (Penberthy and Shaughnessy, 1992)	15
2.7	Effect of Gravel/Sand Size Ratio on Sand Control and Productivity (Penberthy and Shaughnessy, 1992)	18
2.8	Example of a Gravel Pack Design (Penberthy and Shaughnessy, 1992)	19
2.9	Horizontal cross-section of a gravel-packed well, showing the gravel pack thickness	22
3.1	Flow Path Along an Inside-Casing Gravel Pack Completion (Golan and Whitson, 1991)	25
3.2	The actual IPR versus the IPR developed from the ideal well model (Golan and Whitson, 1991)	26
3.3	Nomograph for Perforated Well Productivity (Locke, 1981)	36

4.1	General Structure of Simulation Model	44
4.2	Schematic of fluid flow through a porous medium	45
4.3	The Form of Matrix A for a (3x3x3) system	61
4.4	Schematic of Casing-Cement Perforation Tunnel	64
5.1	Flow Chart of the Overall Research Work	68
5.2	General Flowchart of Computer Program	71
5.3	Well model (side view)	73
5.4	Well model (top view)	73
6.1	Effect of varying the number of radial grids	78
6.2	Effect of reducing angular and vertical permeabilities	78
6.3	Effect of varying the number of angular grids	80
6.4	Effect of varying the number of vertical grids	80
6.5	Sensitivity to timestep size	81
6.6	Measured and predicted pressure drops for 10 wells	83
6.7	Contribution of the well sections on total additional pressure drop	84
6.8	Additional pressure drop versus shots per foot	87
6.9	Vertical skin correlations (Karakas and Tariq, 1991)	88
6.10	Productivity ratio (PR) versus shot density	89
6.11	Productivity ratio (PR) versus shot density for natural completion	90
6.12	Contribution of perforations outside casing to total additional pressure drop	91
6.13	Pressure drop versus flow rate for inline, inplane and spiral perforating pattern ($k_r=500$ mD, $k_\theta=k_z=2$ mD)	92
6.14	Pressure drop versus flow rate for inline, inplane and spiral perforating pattern ($k_r=500$ mD, $k_\theta=k_z=100$ mD)	94
6.15	Pressure drop versus flow rate for inline, inplane and spiral perforating pattern	

	($k_r = k_\theta = 500$ mD, $k_z = 50$ mD)	94
6.16	Perforation pressure drop versus phasing angle	95
6.17	Pressure distribution around wellbore, 0° phasing (Karakas and Tariq, 1991)	96
6.18	Pressure distribution around wellbore, 180° phasing (Karakas and Tariq, 1991)	97
6.19	Pressure distribution around wellbore, 120° phasing (Karakas and Tariq, 1991)	97
6.20	Pressure distribution around wellbore, 90° phasing (Karakas and Tariq, 1991)	98
6.21	Perforation pressure drop versus perforation penetration for inline and spiral patterns	99
6.22	Productivity ratio as a function of perforation penetration (Hong, 1975)	100
6.23	Perforation pressure drop versus perforation diameter	101
6.24	Productivity ratio versus perforation diameter (Locke, 1981)	101
6.25	Darcy pressure drop and high-velocity pressure drop versus perforation diameter	102
6.26	Perforation pressure drop versus gravel permeability	103
6.27	Darcy and high-velocity pressure drops for various gravel permeabilities	104
6.28	Contribution of Darcy and high-velocity components in pressure drop along casing-cement tunnels	105
6.29	Pressure drop in casing-cement tunnel versus flow rate	106

LIST OF SYMBOLS

$C\mu$	-	Uniformity constant
β_G	-	Solids distribution ratio
CRI	-	Cuttings Re-Injection
P_R	-	Reservoir pressure, psi
P_{wf}	-	Well flowing pressure, psi
ΔP_{ideal}	-	Ideal pressure drop, psi
ΔP_{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, $[\text{ML}^{-2}\text{T}]$
Δt	-	Time interval, [T]
ϕ	-	Porosity, fraction
\tilde{q}	-	Strength of sink, $[\text{ML}^{-3}\text{T}]$
u_x	-	Velocity in x-direction, $[\text{L}/\text{T}]$
$\Delta x, \Delta y, \Delta z$	-	Length in x, y, and z direction, [L]
∂	-	Partial differential operator
∇	-	Divergence operator
r	-	radius
$[V_l]$	-	Volume of a fixed mass of component l
S_l	-	Saturation of phase l
g_c	-	Gravitational acceleration, ft/s^2
γ	-	Specific gravity
k_x, k_y, k_z	-	Permeability in x, y and z directions
$k_{r,l}$	-	Relative permeability of phase l
u	-	Velocity vector

δ	-	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
α	-	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
ΔP_{tun}	-	Pressure drop along casing-cement tunnel, psi
ΔP_{agp}	-	Pressure drop across annular gravel pack, psi
ΔP_{perf}	-	Pressure drop along perforations, psi
ΔP_{tot}	-	Total pressure drop, psi
ΔP_{oh}	-	Pressure drop in openhole case, psi
ΔP_{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

LIST OF APPENDICES

APPENDIX NO.	TITLE	PAGE
A	Standard Sieve Sizes	119
B	Program Code	121
C	The Gullfaks, Statfjord and Heidrun fields	161
D	Well Data	164
E	Sample Completion Diagram	165

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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