SUPER WELL WITH STRESSED SCREEN

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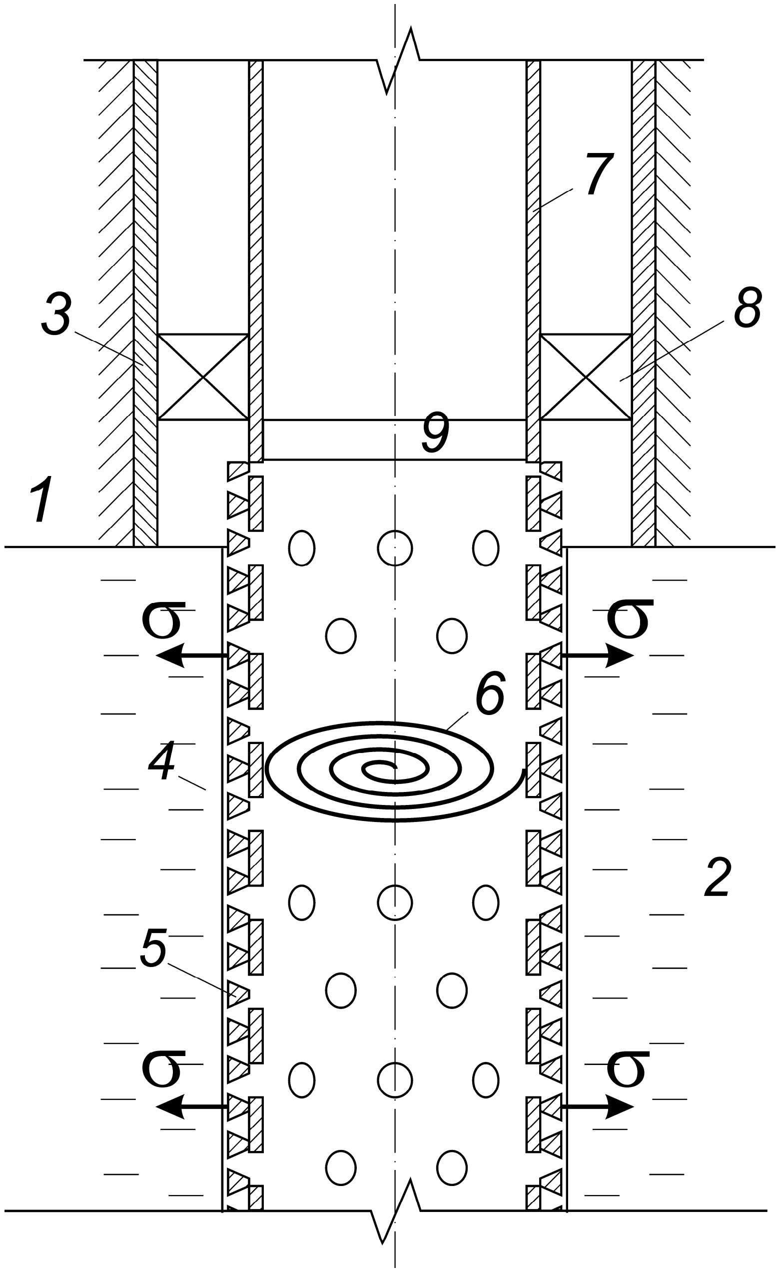


Well completion with stressed screen

1 – bed cover
2 – reservoir bed
3 – casing
4 – wellbore wall
5 – sand screen
6 – creation of mechanical stresses
7 – lift pipe
8 – packer
9 - disconnector

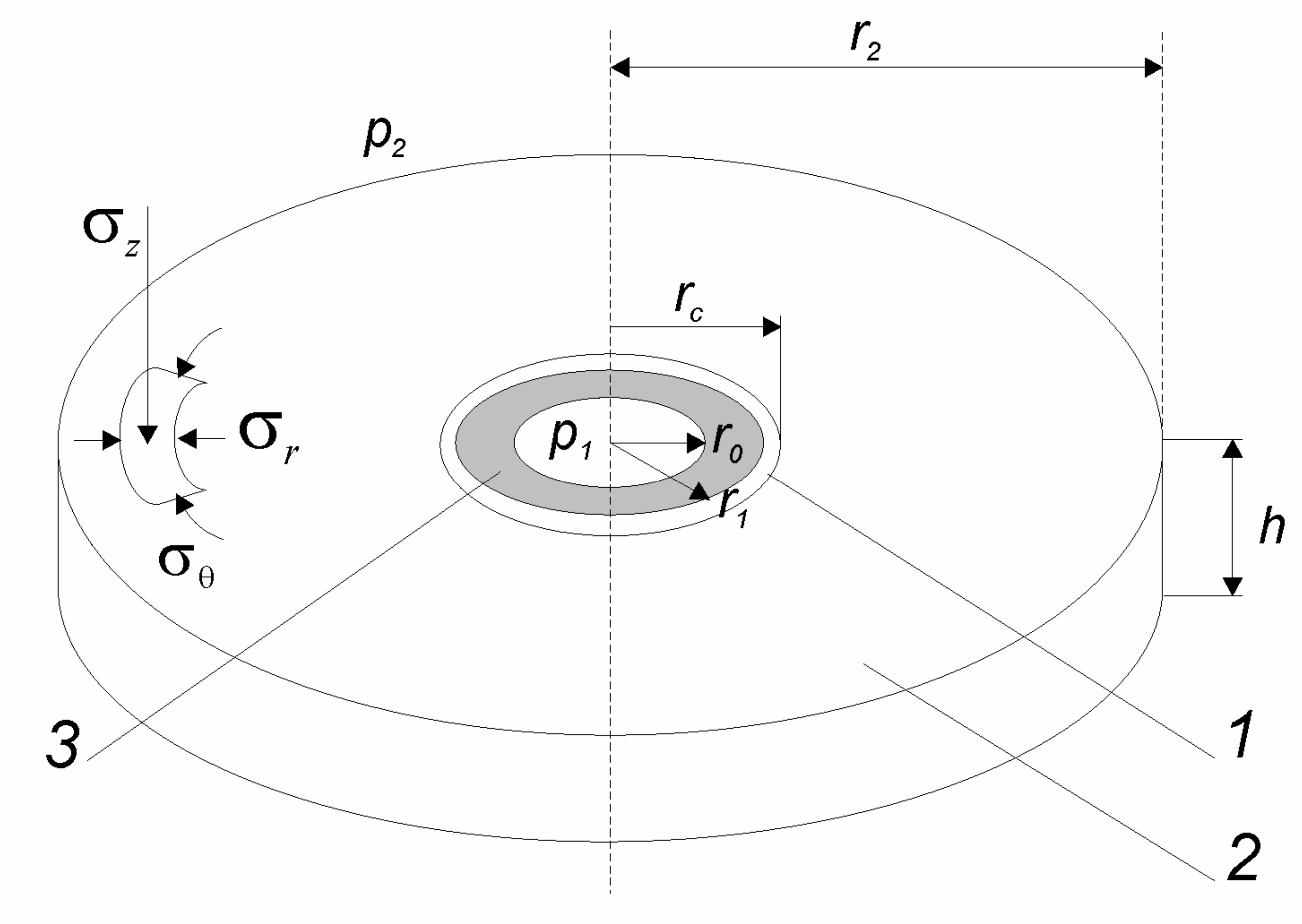


Illustration of stressed state near SS positioned in a homogeneous reservoir; 1 - the zone of plastic deformation; 2 - the zone of elastic deformation; 3 - the SS.

Fluid flow near a stressed screen

Forchheimer equation:

$$\frac{dp}{dr} = \frac{\mu}{k}u + \beta_D \rho u|u|$$

p - fluid pressure, *r* - is the radial distance from center of wellbore, μ – viscosity, *k* - permeability, β_D - non-Darcy flow coefficient, ρ - fluid density, *u* - filtration velocity

$$p(r) = p_2 + \frac{\mu q p_{at} z T}{2\pi k h p_2 T_0} ln \frac{r}{r_2} + \frac{\beta_D q|q| \rho_{at} p_{at} z T}{4\pi^2 h^2 p_2 T_0}\left(\frac{1}{r_2} - \frac{1}{r}\right)$$

p_2 – fluid pressure at outer boundary, p_{at} - atmospheric pressure,
q – wellbore production rate, ρ_{at} - gas density at atmospheric pressure,
r_2 – outer boundary radius, *T* – reservoir temperature,
T_0 – 293 K, temperature, *z* – coefficient applied to ideal gas compressibility to account for non-linear behavior at high pressures

Elastic deformation of a bed in a vicinity of stressed screen

radial stress:

$$\sigma_r(r) = \frac{2\nu p_0 + \beta p_2(1-2\nu) - (0.5-\nu)\beta A}{2(1-\nu)}\left(1 - \frac{r_1^2}{r^2}\right) + \frac{r_1^2}{r^2}\sigma_{r0} + $$

$$+ \frac{(1-2\nu)}{2(1-\nu)}\beta\left[p(r) - \frac{r_1^2}{r^2}p_1 + \left(\frac{r_1}{r^2} - \frac{1}{r}\right)B\right]$$

angular stress:

$$\sigma_\theta(r) = \frac{2\nu p_0 + \beta p_2(1-2\nu) - (0.5-\nu)\beta A}{2(1-\nu)}\left(1 + \frac{r_1^2}{r^2}\right) - \frac{r_1^2}{r^2}\sigma_{r0} - $$

$$- \frac{(1-2\nu)}{2(1-\nu)}\beta\left[p(r) + A + \frac{r_1^2}{r^2}p_1 + \frac{B}{r} - \frac{r_1}{r^2}B\right]$$

vertical stress:

$$\sigma_z(r) = p_0 + \beta\frac{(1-2\nu)}{1-\nu}\left[p(r) - p_2\right]$$

ν - Poisson ratio of the rock, $1\text{-}\beta$ – ratio of material and volume compressibilities of sandstone, σ_{r0} – compressive radial stress of screen, p_0 - overburden pressure

Initial data for stressed screen and UGS

Poisson's ratio for the screen	0.25
Poisson's ratio for the sandstone	0.3
Reservoir thickness (m)	10
Young's modulus of a sandstone (MPa)	$4*10^4$
Young's modulus of the screen (MPa)	$2*10^5$
External diameters of screens (cm)	10.9
Thicknesses of walls of screens (cm)	1.65
Cohesive strength of sandstone (KPa)	10
Failure angle (degrees)	60
Overburden pressure (MPa)	20.7
The fluid pressure at outer boundary (MPa)	7.4
Permeability (Darcy units)	1
Wellbore production rate (millions m^3/day)	2

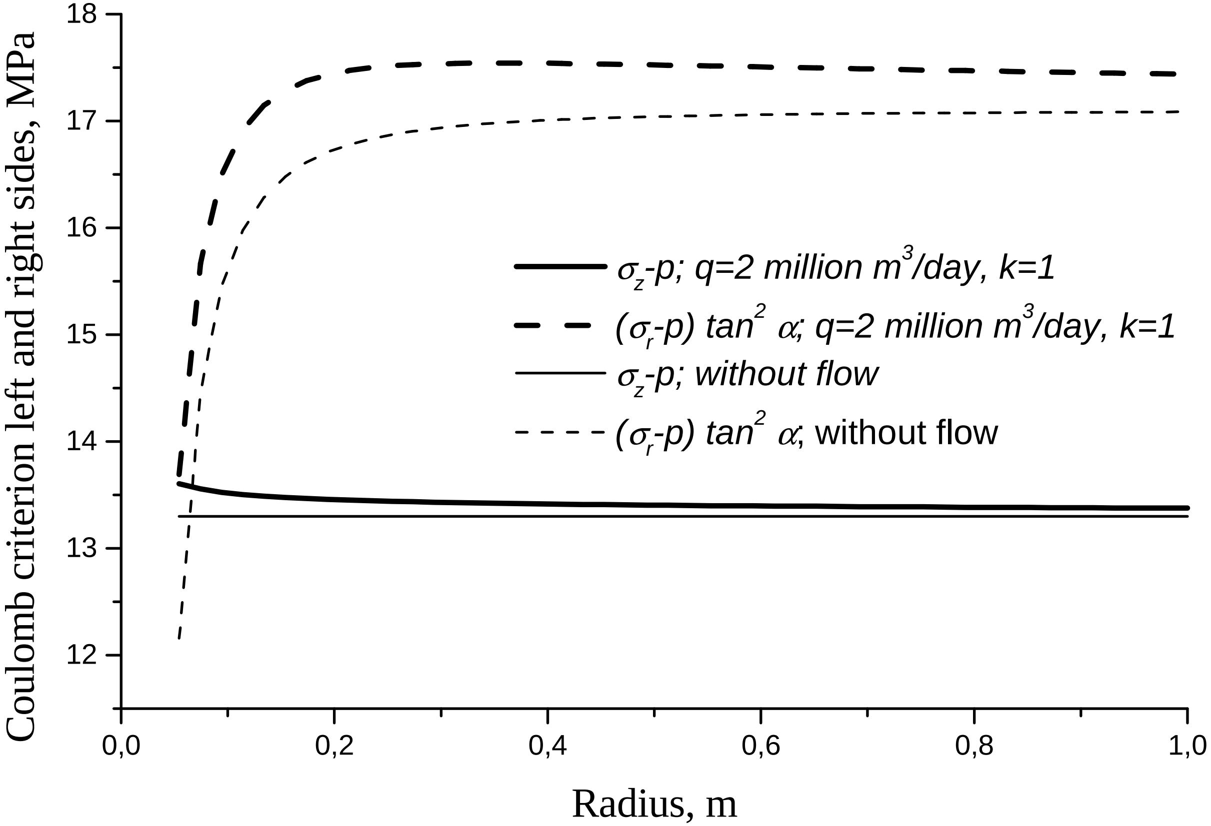
Coulomb failure criterion

$$\left(\sigma_z - p\right) = 2S_0 \tan\alpha + \left(\sigma_r - p\right)\tan^2\alpha$$

σ_z - maximal stress
σ_r - minimal stress
S_0 - cohesive strength

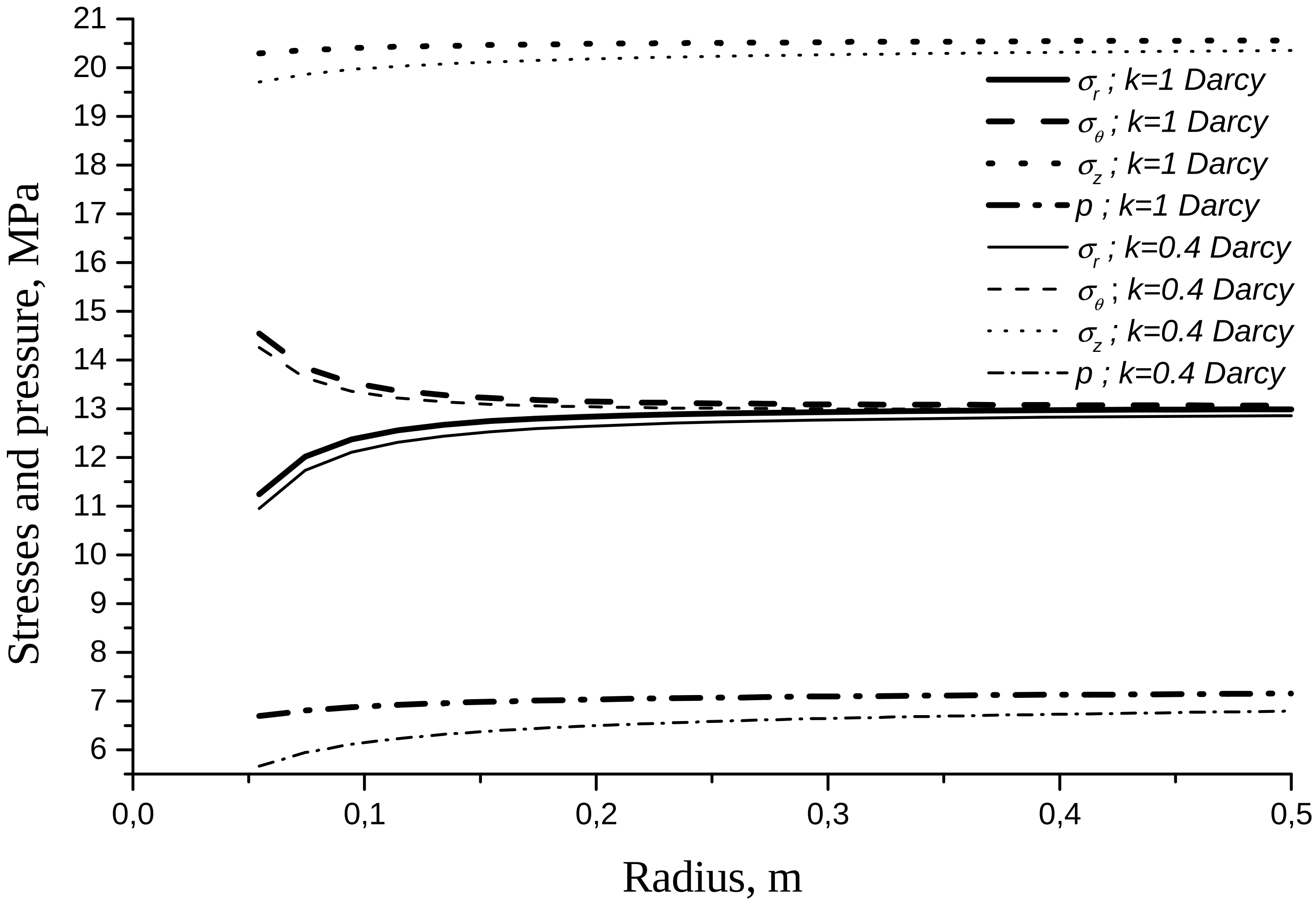
$\alpha = \frac{\pi}{4} + \frac{\varphi}{2}$ - failure angle

φ - angle of internal friction



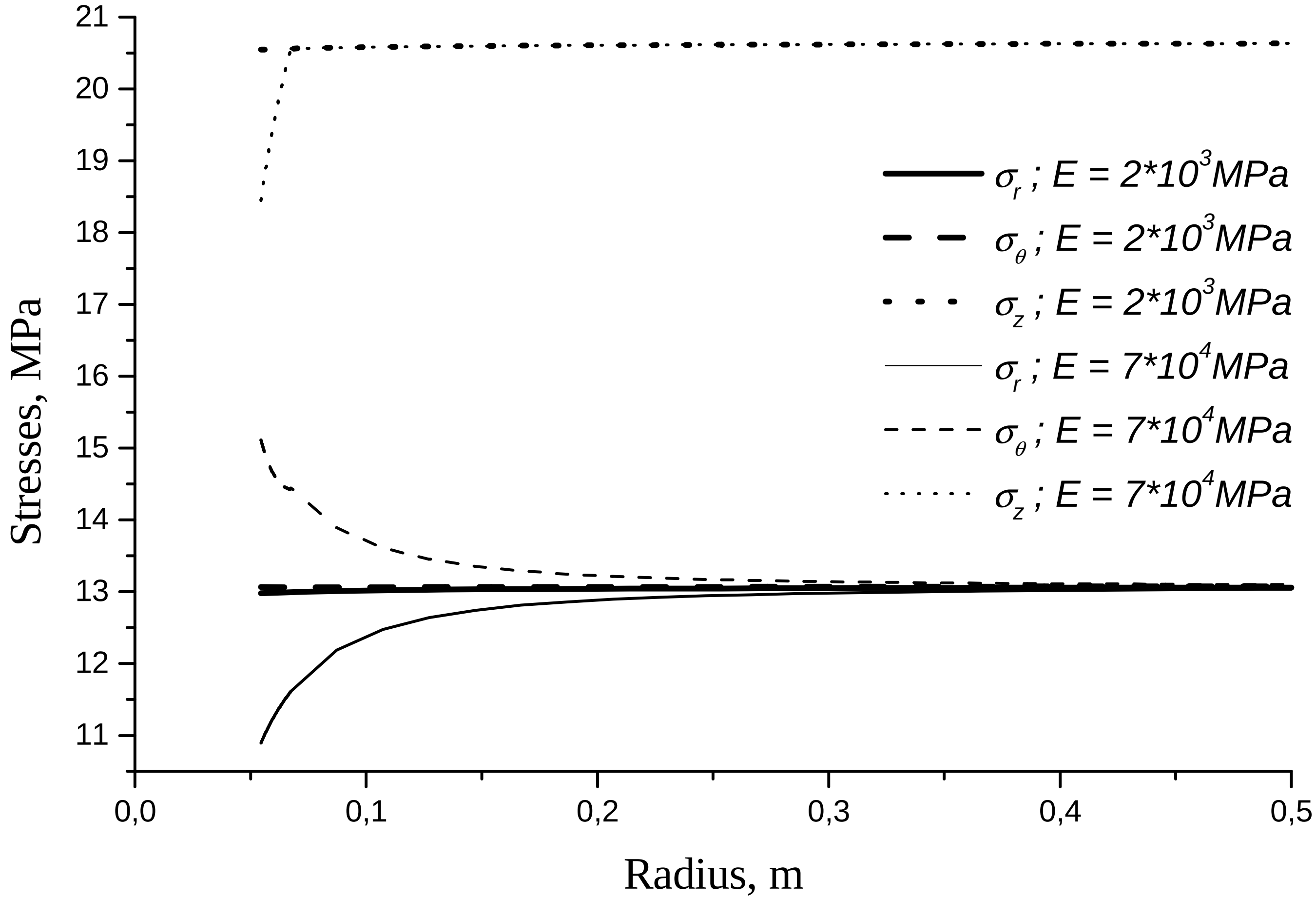
Left and right sides of the Coulomb criterion; $\sigma_z - p$ (full curve), $2S_0 \tan\alpha + (\sigma_r - p)\tan^2\alpha$ (broken curve); q=2 million m^3/day, k = 1 Darcy (thick curve) and without flow (thin curve); $S_0 = 0$.

Elastic deformation



Stresses in porous material at elastic deformation; *q* = 2 million m^3/day, *E* = $4*10^4$ MPa, for *k* = 0.4 Darcy (thin curves) and *k* = 1 Darcy (thick curves).

Elastoplastic deformations



Radial stress (full curve), tangential stress (broken curve), and vertical stress (dotted curve) at production rate q = 1 million m^3/day, k = 1 Darcy; $E = 7*10^4$ MPa (thin curve) and $E = 2*10^3$ MPa (thick curve); h = 10 m, p_2 = 7.4 MPa, p_0 = 20.7 MPa, ν = 0.3, S_0 = 10 KPa; r_1 = 5.45 cm, Δ = 1.65 cm.

The stability criterion

Critical production rate in the wellbore with a cylindrical stressed screen:

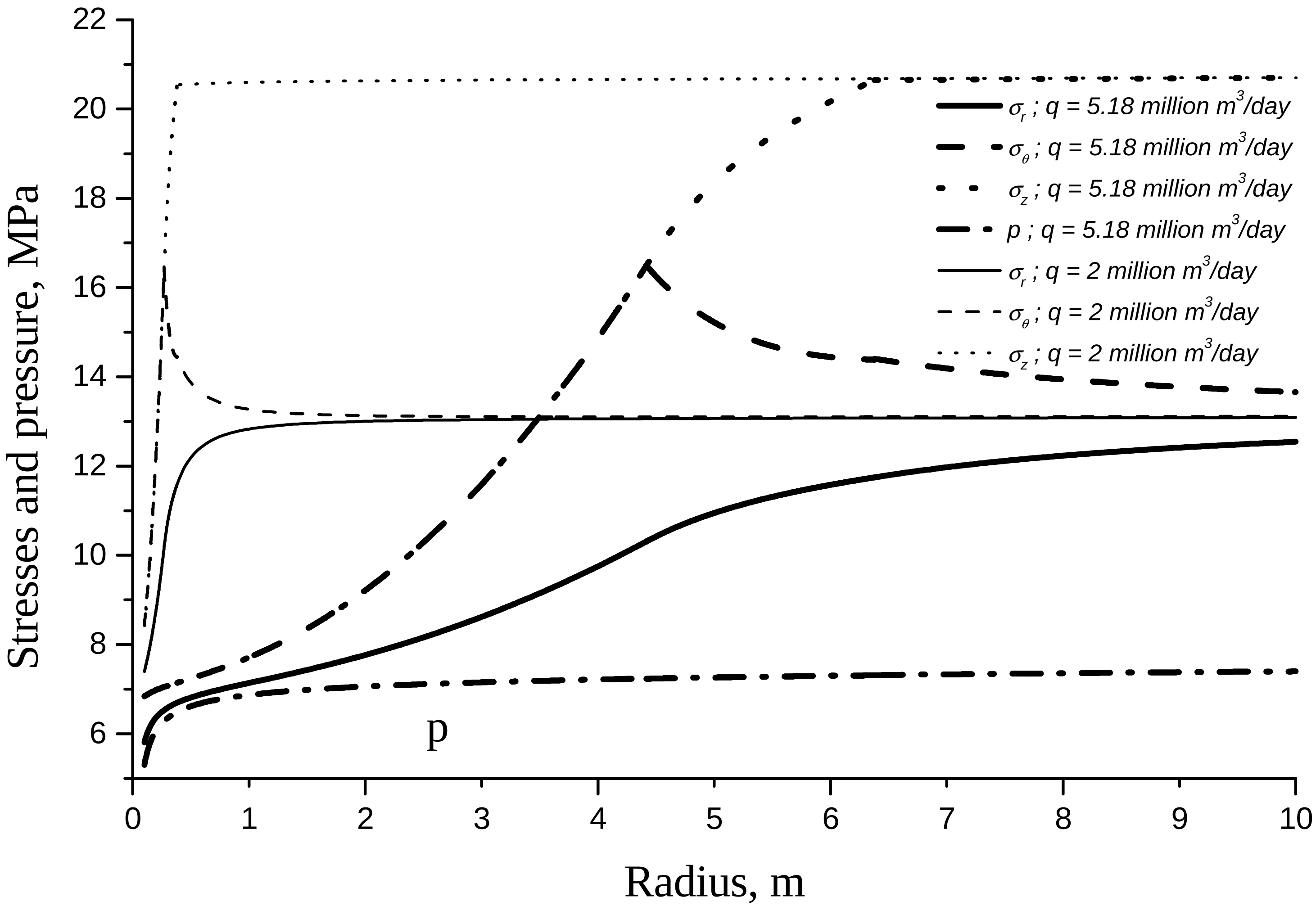
$$q_c = \frac{(t+1)r_1\pi h\mu}{tk\beta_D\rho_{at}}\left\{\left[1+\frac{4[2S_0\tan\alpha + t(\sigma_{r0}-p_1)]\,p_2tk^2\beta_D\rho_{at}T_0}{p_{at}z(t+1)r_1\mu^2T}\right]^{1/2}-1\right\}$$

The effective stress $\boldsymbol{\sigma_{r0}}$ **-** $\boldsymbol{p_1}$ of SS (total radial stress minus bottom-hole pressure) is **4.5 MPa** for initial data listed in the Table 1. Values of the weakly consolidated sandstone cohesive strength $\mathbf{S_0}$ do not exceed **0.1 MPa**. Therefore:

$$2S_0\tan\alpha << t(\sigma_{r0}-p_1)$$

Critical production rate of super well:

$$q_c = \frac{(t+1)r_1\pi h\mu}{tk\beta_D\rho_{at}}\left\{\left[1+\frac{4t^2(\sigma_{r0}-p_1)p_2k^2\beta_D\rho_{at}T_0}{p_{at}z(t+1)r_1\mu^2T}\right]^{1/2}-1\right\}$$



Stresses and fluid pressure at a production rate ***q* = 5.18 million m^3/day**, close to critical (thick curve) and at q = 2 million m^3/day (thin curve); effective stress $\boldsymbol{\sigma_{r0} - p_1}$ **= 0.5 MPa** at h = 10 m, p_2 = 7.4 MPa, p_0 = 20.7 MPa, ν = 0.3, E = 4*10^4 MPa, S_0 = 10 KPa; r_1 = 10 cm, k=1 Darcy.

Collaps of the inner spherical shell for perforations (Bratli and Risnes, 1981)

failure criterion:

$$p - \sigma_r = \sigma_t$$

σ_t - uniaxial tensile strength

There are no effective tensile stresses for SS with sufficient compressive radial stress!

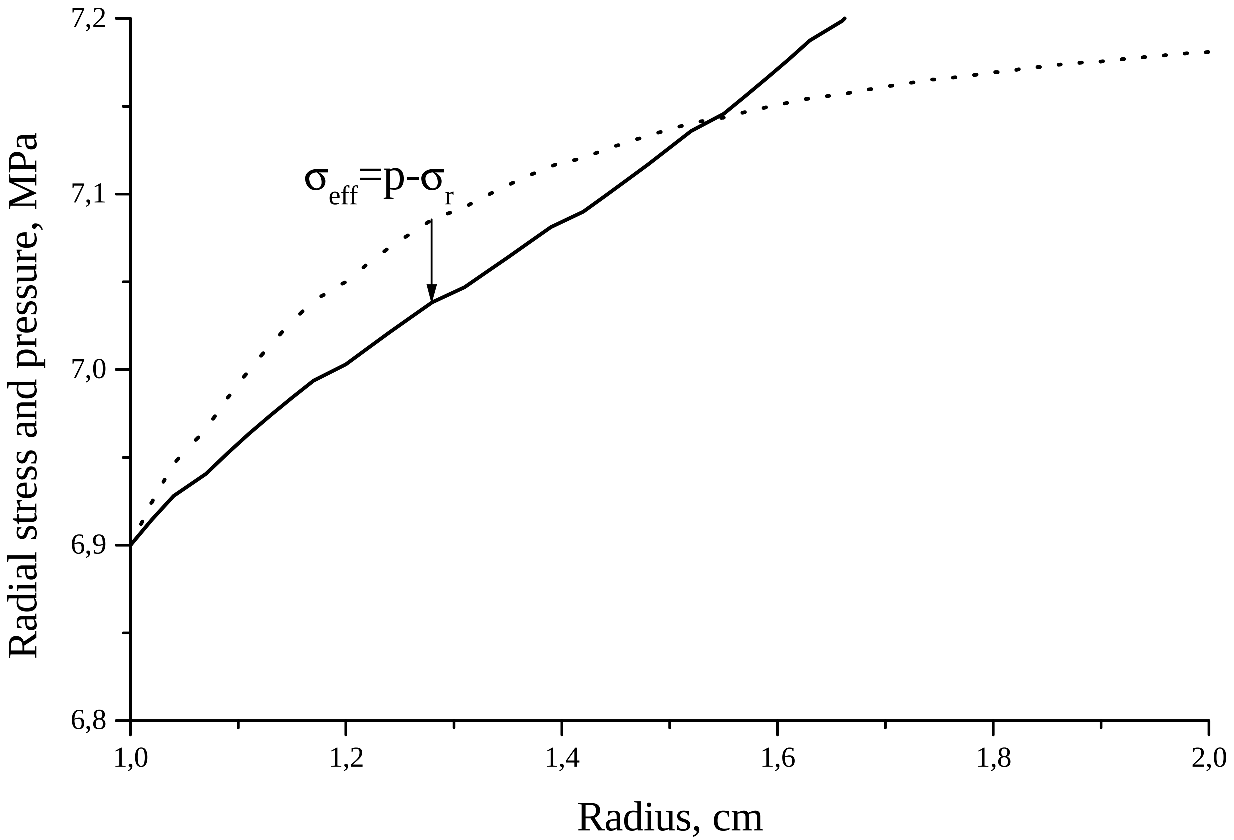
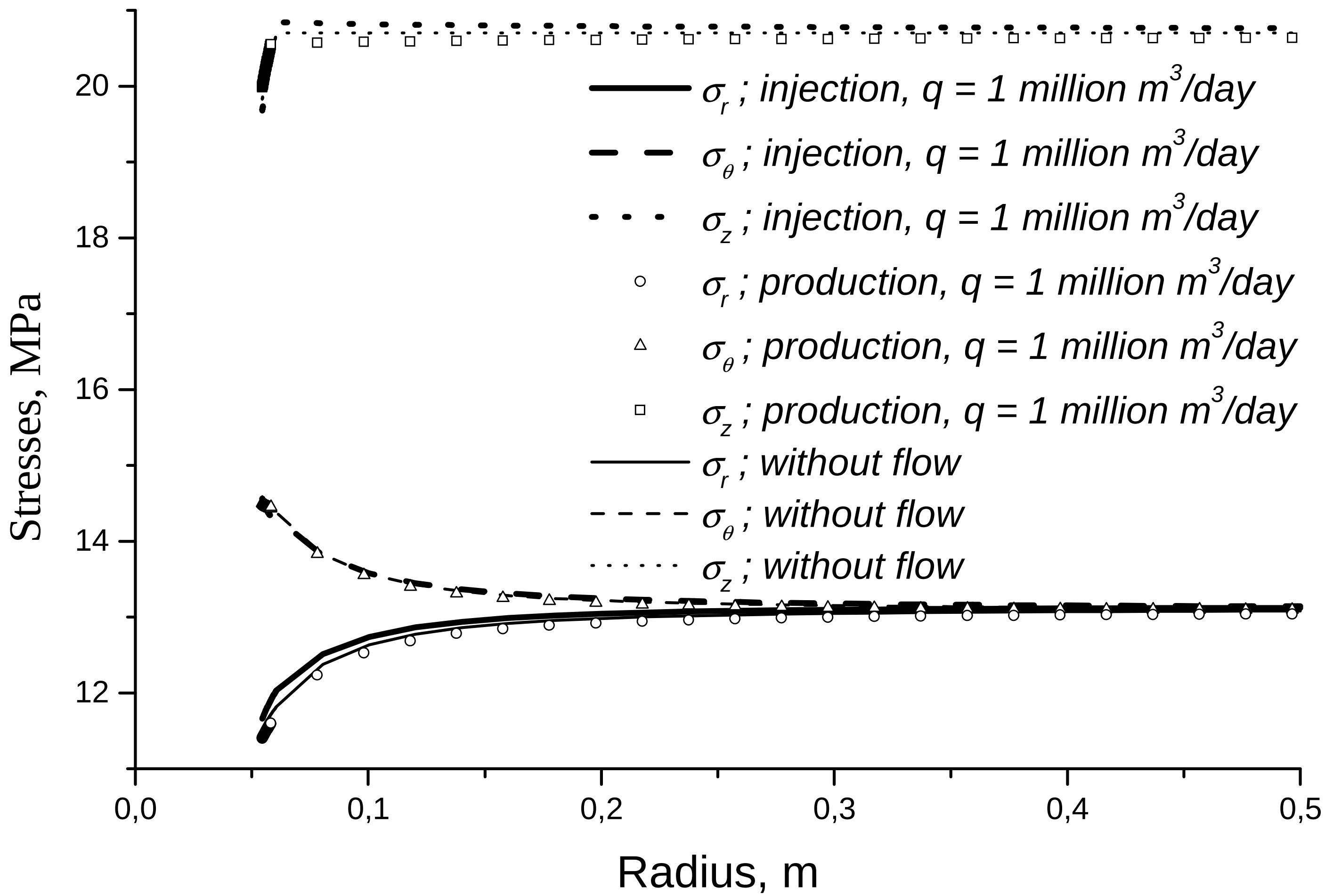


Illustration of the fracturing mechanism. The full curve corresponds to σ_r and the broken curve, to p (Pyatakhin and Kazaryan, 2004).

Injection of fluid into bed



Stressed-state solution at elastoplastic deformations for fluid production (scatter graph) and injection (thick curve) with q = 1 million m^3/day, and without fluid flow (thin curve); σ_r (full curve), σ_θ (broken curve), and σ_z (dotted curve).

Two-phase filtration

Forchheimer equation:

$$\frac{dp_i}{dr} = \frac{\mu_i}{k_i} u_i + \beta_i \rho_i u_i |u_i|$$

p_i, μ_i , k_i , β_i , ρ_i and u_i - pressure, viscosity, effective permeability, effective non-Darcy flow coefficient, density, and volumetric flux for the i-th phase

relative permeabilities of phases:

$$\tilde{k}_i = \frac{k_i}{k}$$

constant saturation approach (*s* - gas saturation):

$$\tilde{k}_g(s) = \begin{cases} 0 & at\, 0 < s \le 0.1 \\ [(s-0.1)/0.9]^{3.5}(4-3s) & at\, 0.1 < s < 1 \end{cases}$$

$$\tilde{k}_w(s) = \begin{cases} [(0.8-s)/0.8]^{3.5} & at\, 0 < s < 0.8 \\ 0 & at\, 0.8 \le s < 1 \end{cases}$$

50 % gas: $k_g = k / 7$

Results

- ***Well completion with stressed screen stabilizes a poorly consolidated rock in typical cases.***
- ***For UGS, the direction of flow changes because of cyclic operation and the SS maintains reservoir stability.***
- ***Even in the case of a significant permeability reduction arising from particle movement or saturation changes, the SS stabilizes the bed.***
- ***During water and gas co-production, the SS appears to sustain wall stability even at high levels of water saturation.***
- ***The SS represent effective tools for active preventing of reservoir destruction.***
- ***Super well with stressed screen allows to maximize the well deliverability independently from mechanical rock properties.***
- ***The using of the stressed screen is the way to get a super well with maximum production rate limited only by reservoir energy and throughput of pipes.***

Materials of the report are put in a basis of the application of the patent for the invention «The way of prevention of rock destruction in the reservoir near the wellbore», Joint-stock company "Gazprom" is the applicant.

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