Investigation on the non-Darcy term in flow equations

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Agenda

- Darcy’s equation
- Modification of Darcy’s law
- Steps of the research
- Grouping & classing
- Sensitivity tests for oil and gas
- Behaviour of the β factor under changing PVT properties
- Summary table and how to use it

Darcy's equation

$$q_o = \frac{(P_e - P_{wf}) \times (k_o \times h)}{141.2 \times \mu_o B_o \left[ln\left(0.472 \left\{\frac{r_e}{r_w}\right\}\right)\right]}$$

$$q_g = \frac{(P_e^2 - P_{wf}^2) \times (k_g \times h)}{1.424 \times 10^3 \mu_g T z \left[ln\left(0.472 \left\{\frac{r_e}{r_w}\right\}\right)\right]}$$

→ Equation for normal fluid flow through porous medium

Neglected forces in case of low fluid velocities

Capillary force

Inertial forces

Turbulent friction force

Significant forces in case of high fluid velocities

Compression force

Gravitational force

Capillary force

Inertial forces

Turbulent friction force

Modification of Darcy's law

The equation of Forscheimer (1901)

$$-\frac{dP}{dL} = \mu\frac{v}{k} + av^2$$

The equation of Jones (1967)

For oil wells

$$P_e - P_{wf} = Aq_o^2 + Bq_o$$

$$A = \frac{2.30 \times 10^{-14} \times \beta B_o^2 \rho}{h^2 r_w}$$

$$B = \frac{141.2 \times \mu_o B_o \left[ln\left(0.472\left\{\frac{r_e}{r_w}\right\}\right)\right]}{k_o h}$$

For gas wells

$$P_e^2 - P_{wf}^2 = Aq_g^2 + Bq_g$$

$$A = \frac{3.16 \times 10^{-12} \times \beta \gamma_g T z}{h^2 r_w}$$

$$B = \frac{1.424 \times 10^3 \mu_g T z \left[ln\left(0.472\left\{\frac{r_e}{r_w}\right\}\right)\right]}{k_g h}$$

β factor: dominant role in the flow of the fluids

The β factor

- inherited from the equation of Forscheimer
- causes the differences from the Darcy equation
- literature ⟶ lot of formula for the beta factor

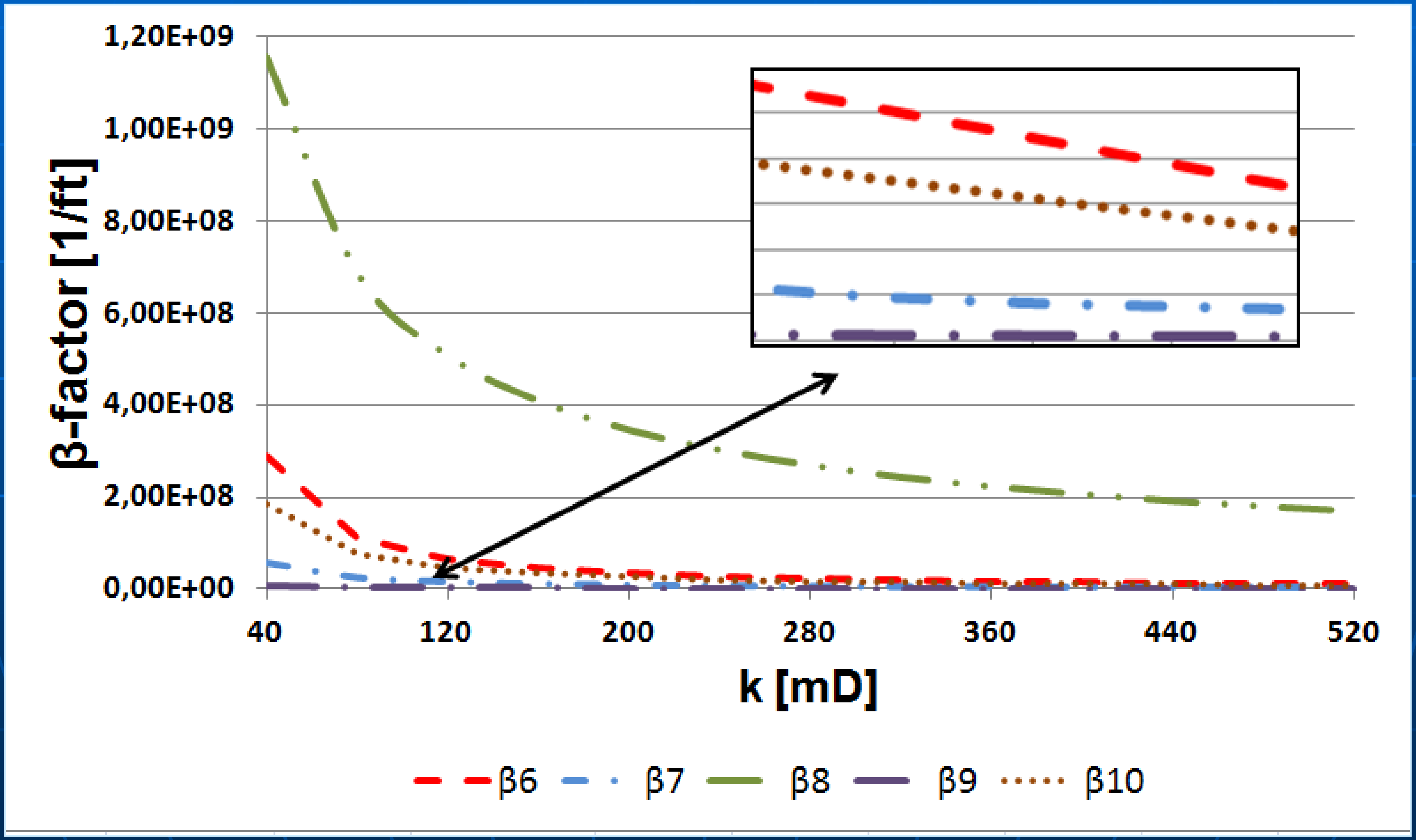
Examples for the investigated β factors

Authors	Geertsma (1974)	Pascal (1980)	Cole & Hartman (1998)
Equations	$\left(\frac{0.005}{\Phi^{5.5} k^{0.5}}\right)$	$\left(\frac{4.8 \times 10^{12}}{k^{1.176}}\right)$	$\frac{8.17 \times 10^{9} \Phi^{0.537}}{k^{1.79}}$

The steps of our investigation

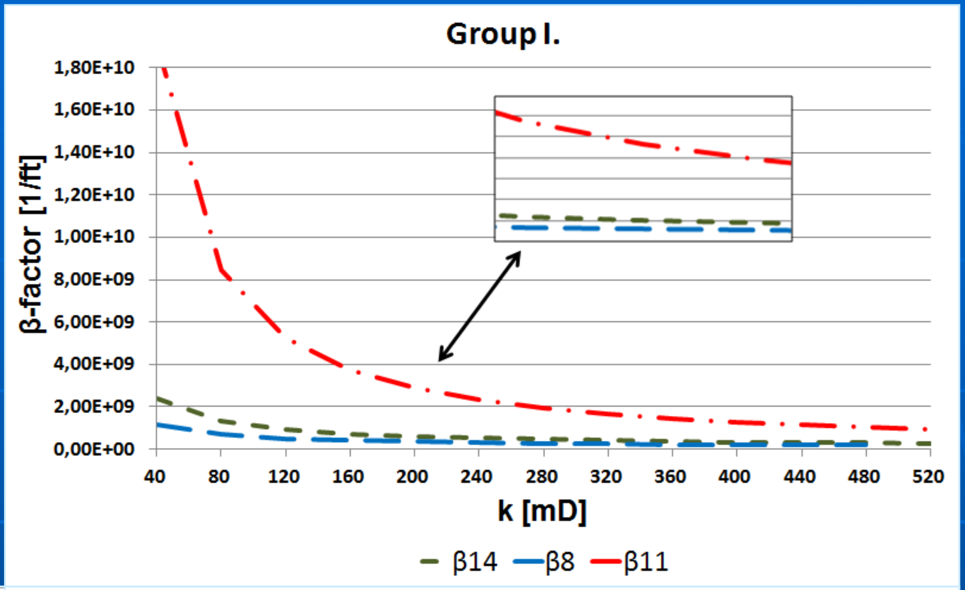
I. Grouping & classing based on similar trends of the curves
II. Sensitivity analysis for oil and gas wells – individual properties
III. Sensitivity analysis for oil and gas wells – based on depth

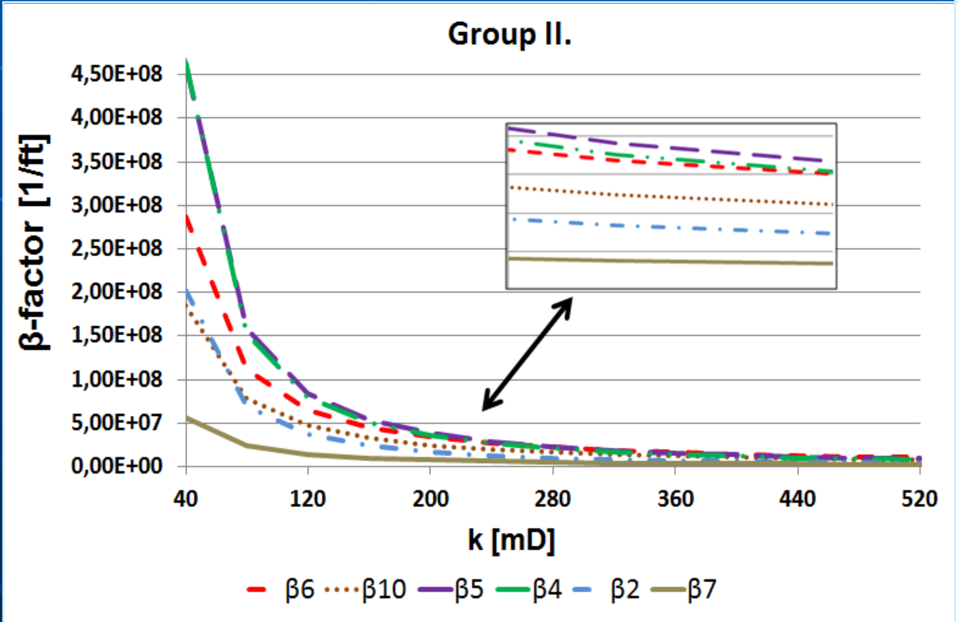
Significant differences between the 20 β equations

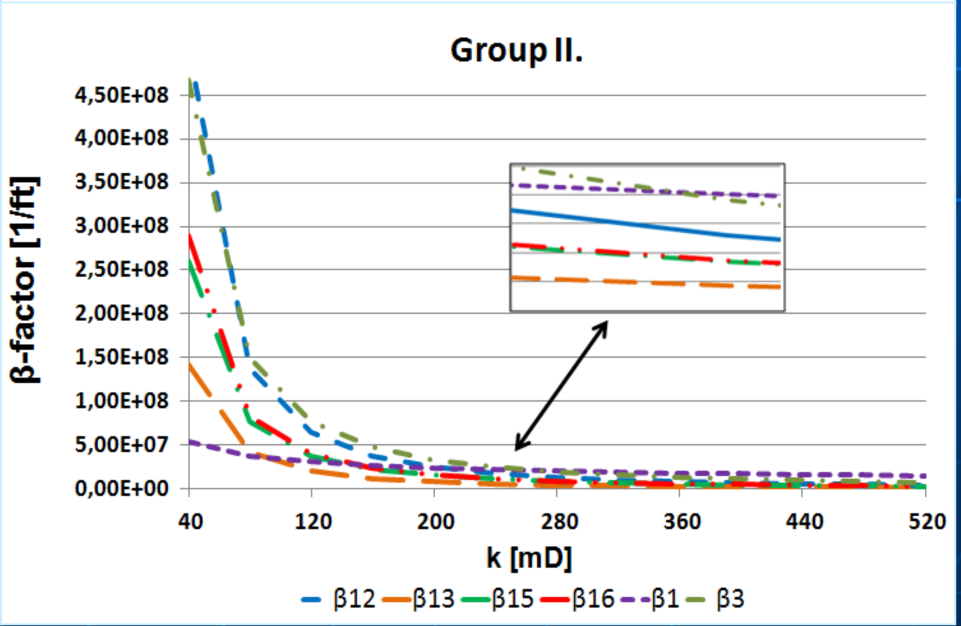


4 Groups

- Group I.
- Group II.

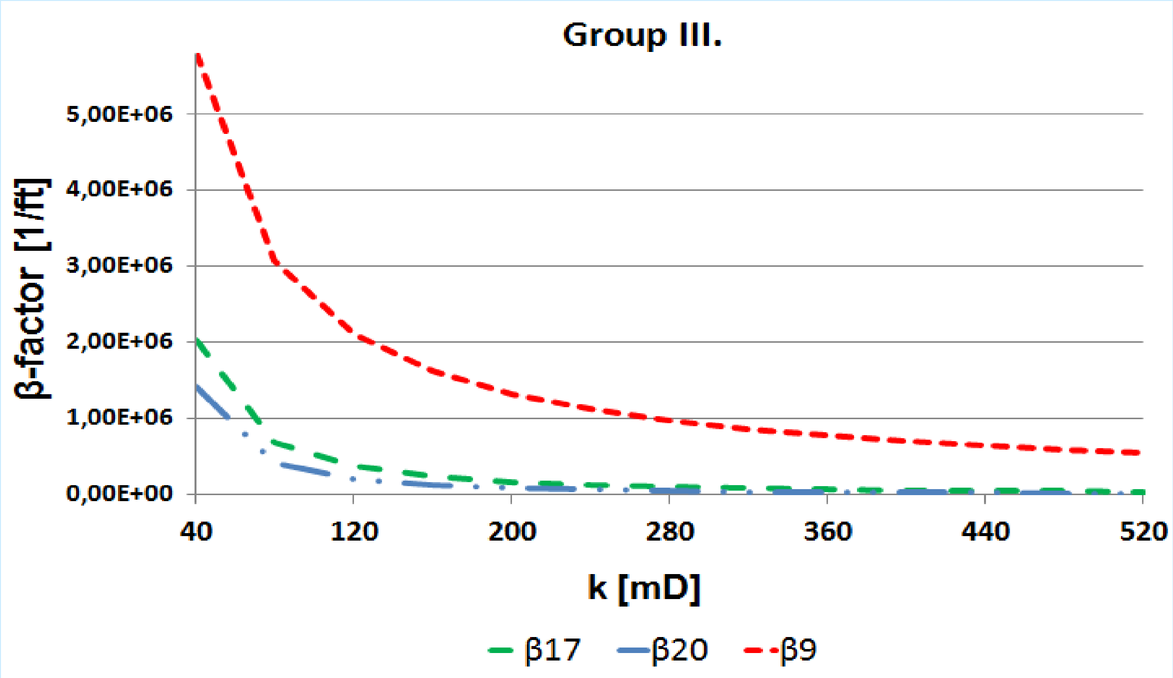


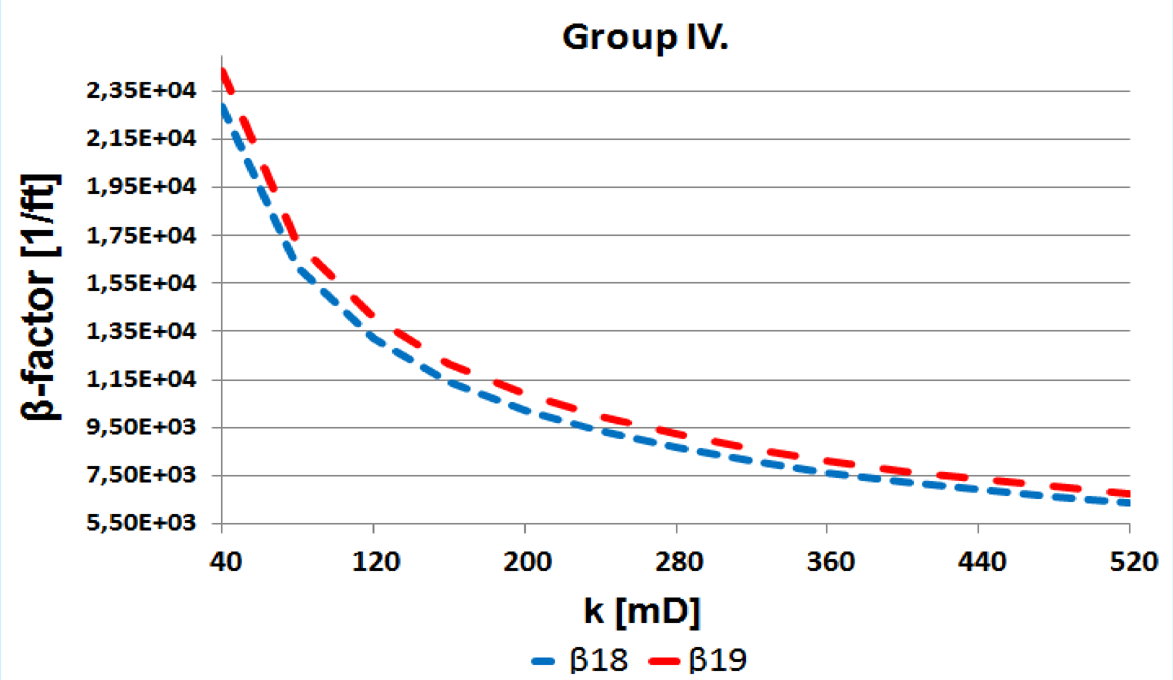


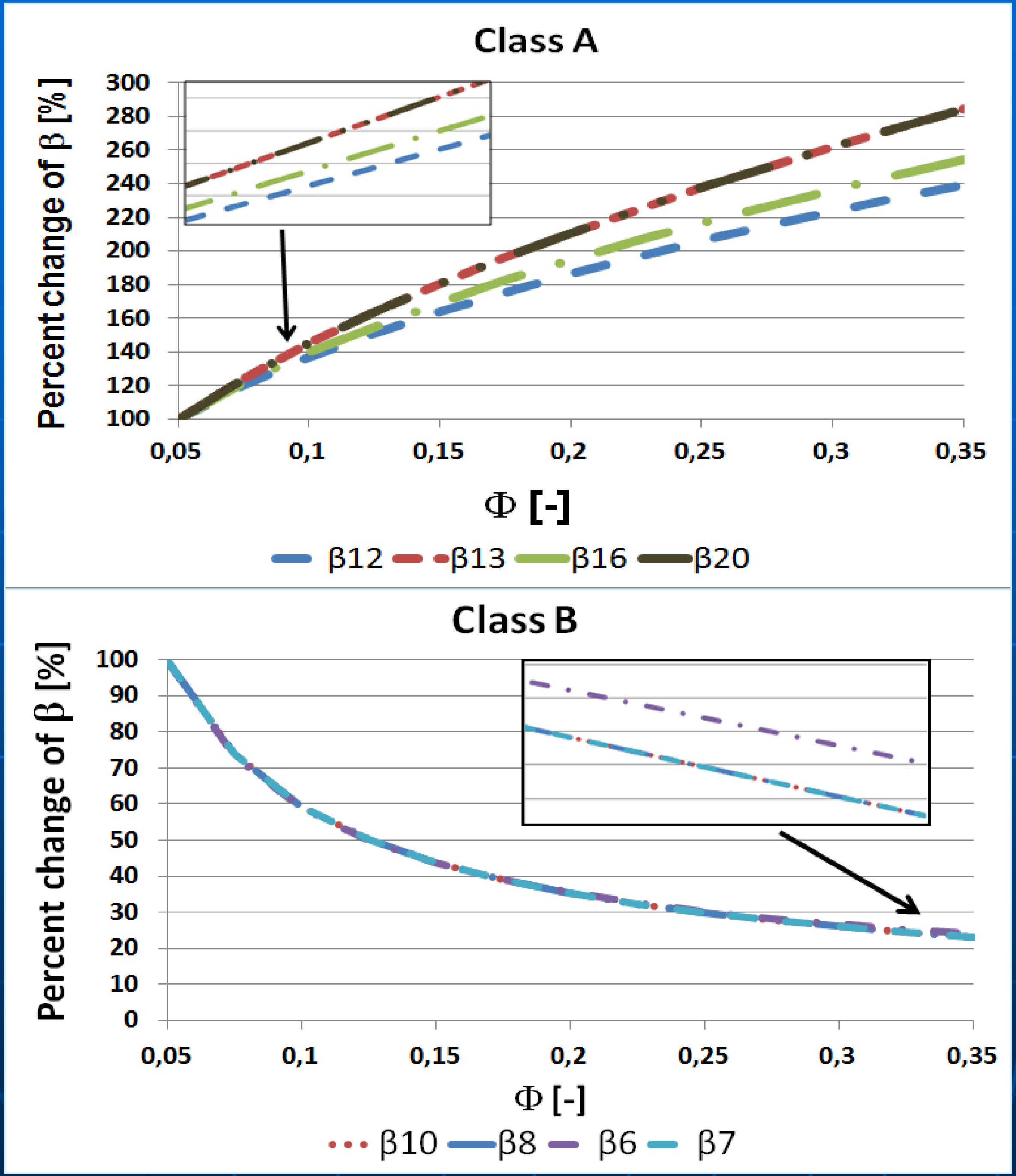


4 Groups

- Group III.
- Group IV.

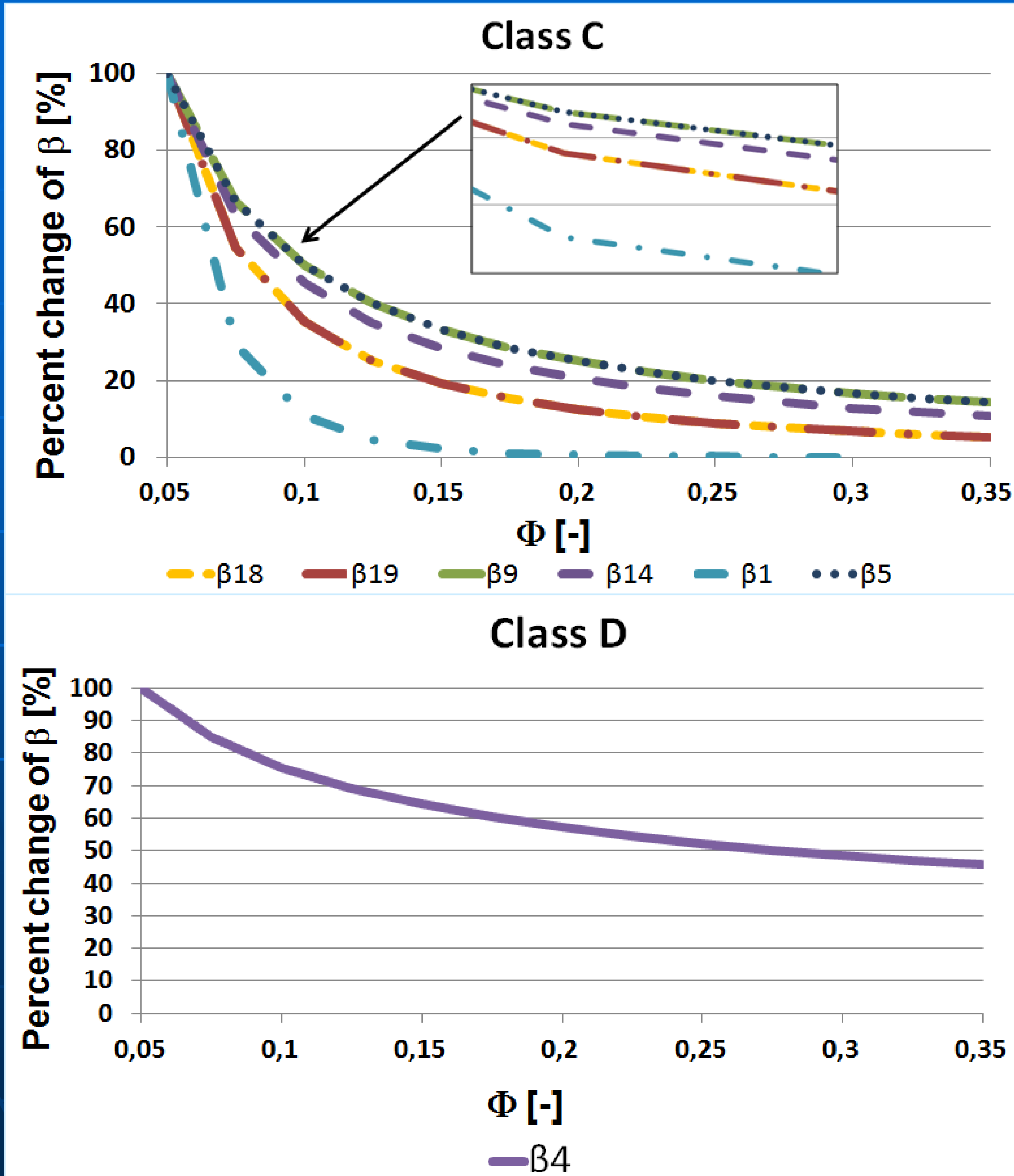






5 Classes

- Class A
- Class B



5 Classes

- Class C
- Class D

+ Class E

Sensitivity analyzes

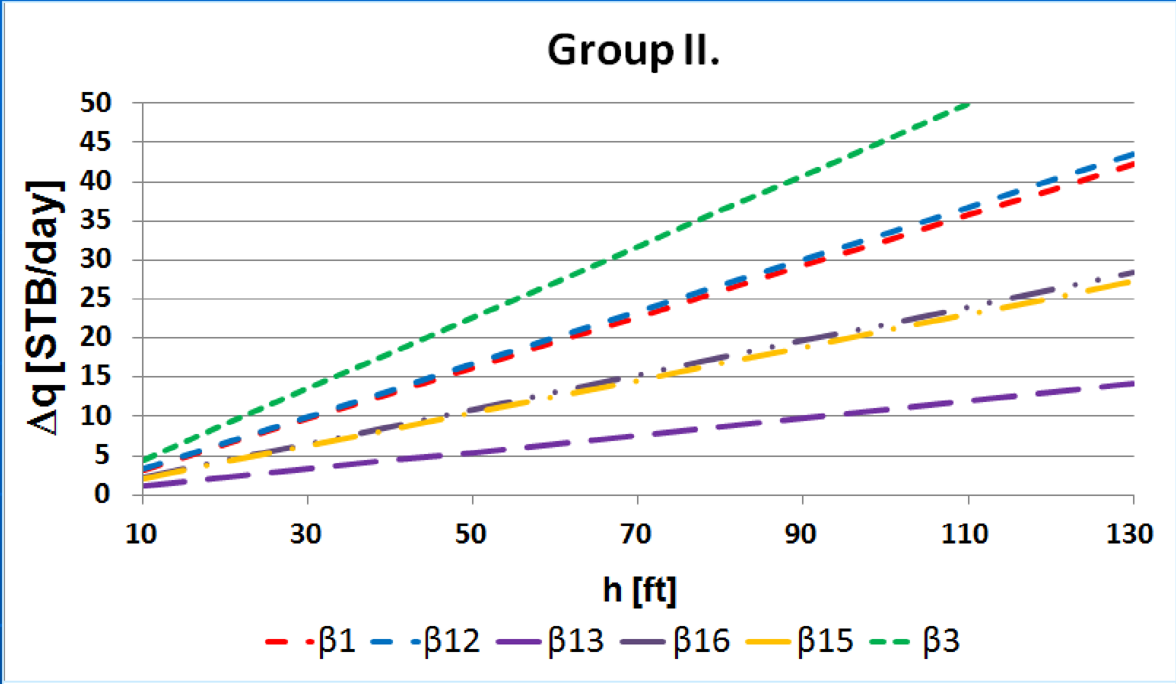
<u>In case of oil:</u>

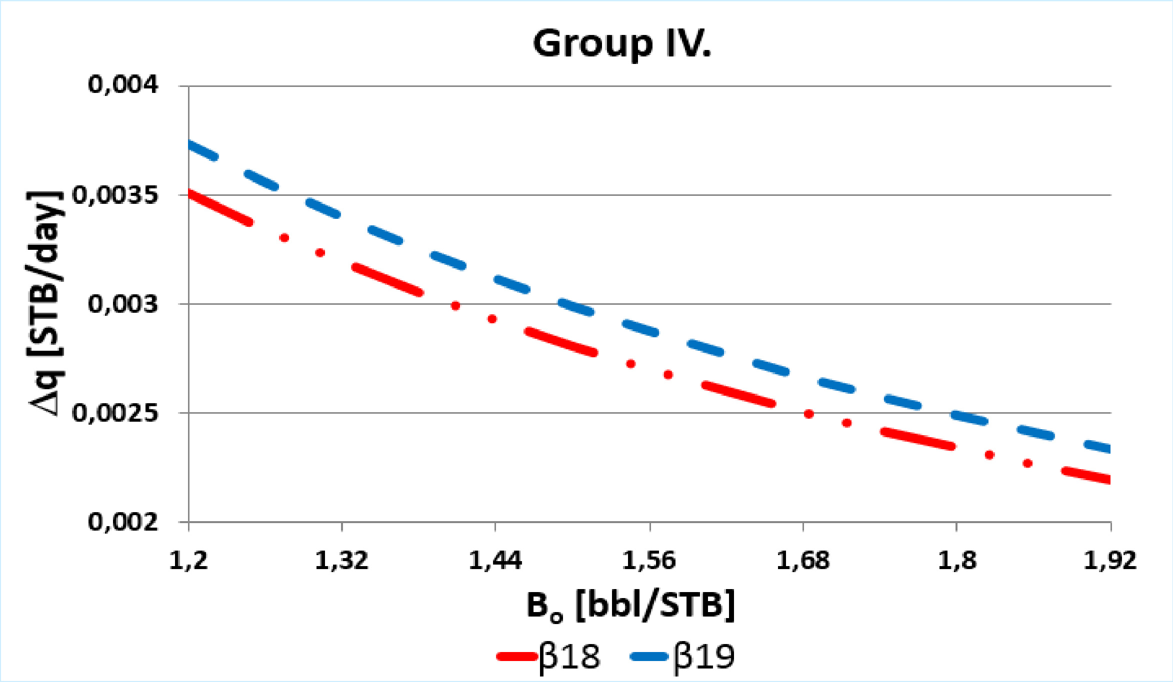
- Permeability(k)
- Viscosity(μ)
- Formation volume factor(Bo)
- Reservoir thickness(h)

<u>In case of gas:</u>

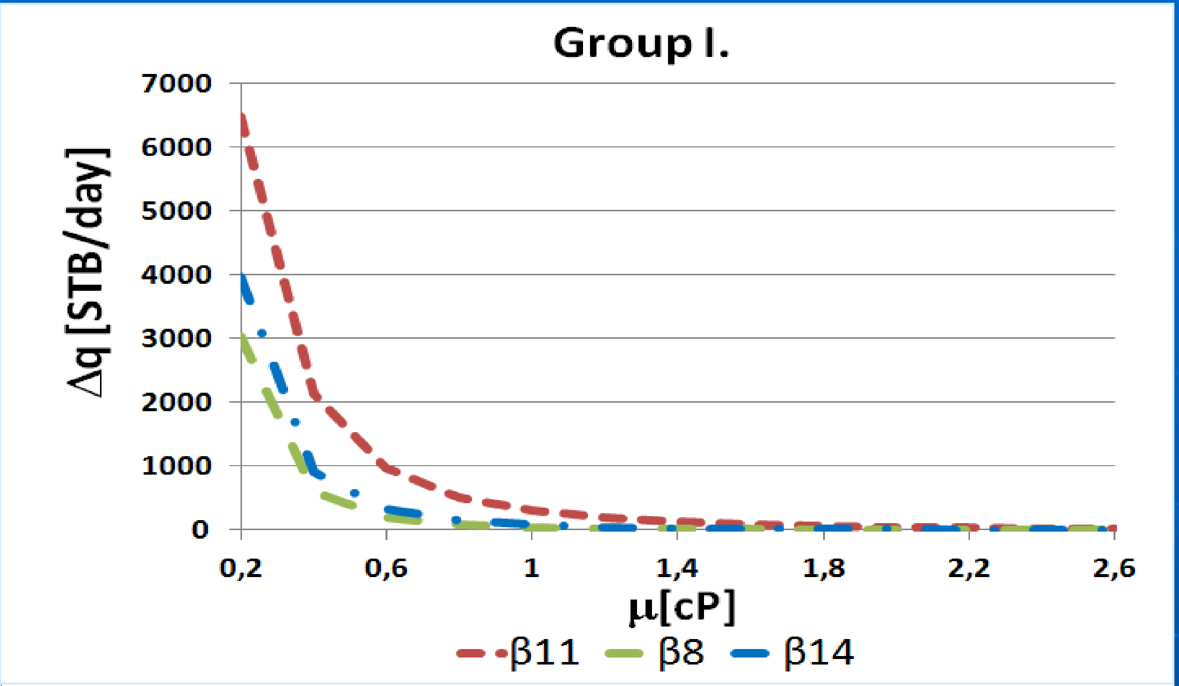
- Permeability(k)
- Viscosity(μ)

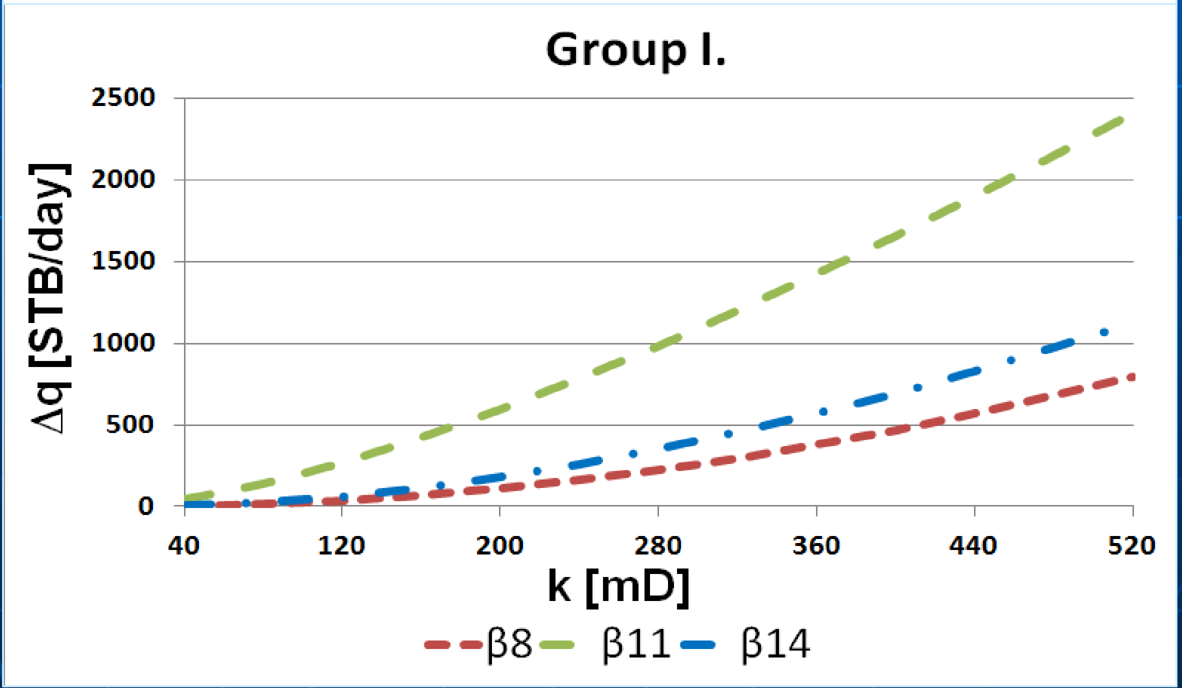
Sensitivity analyzes for OIL



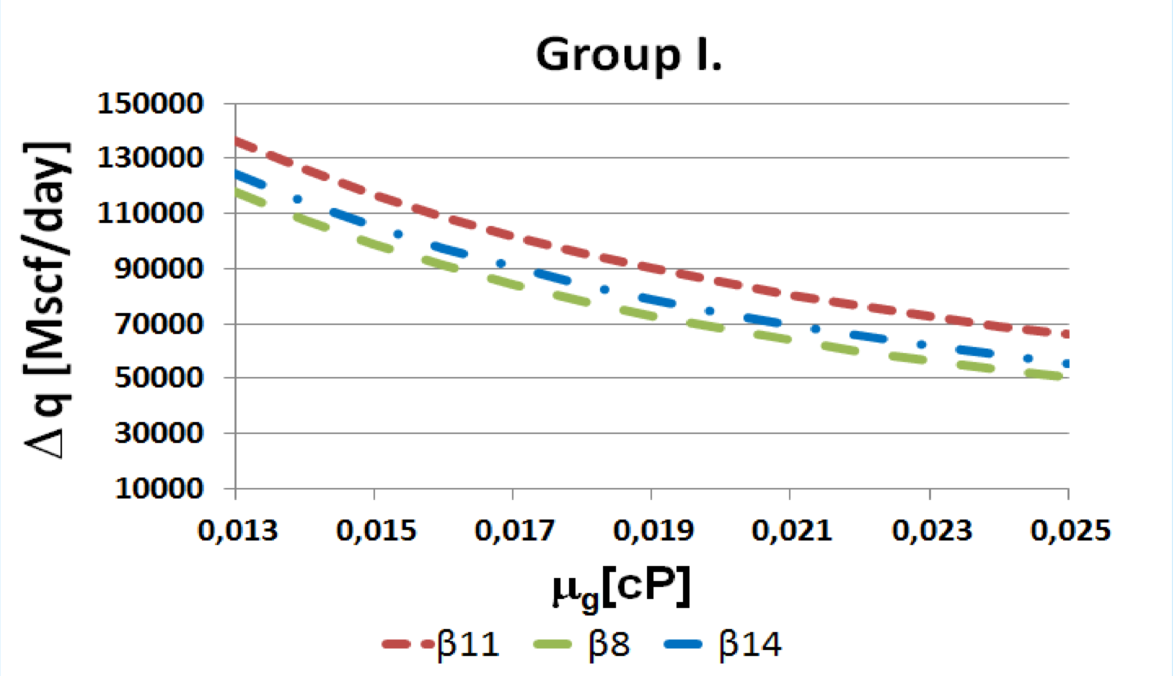


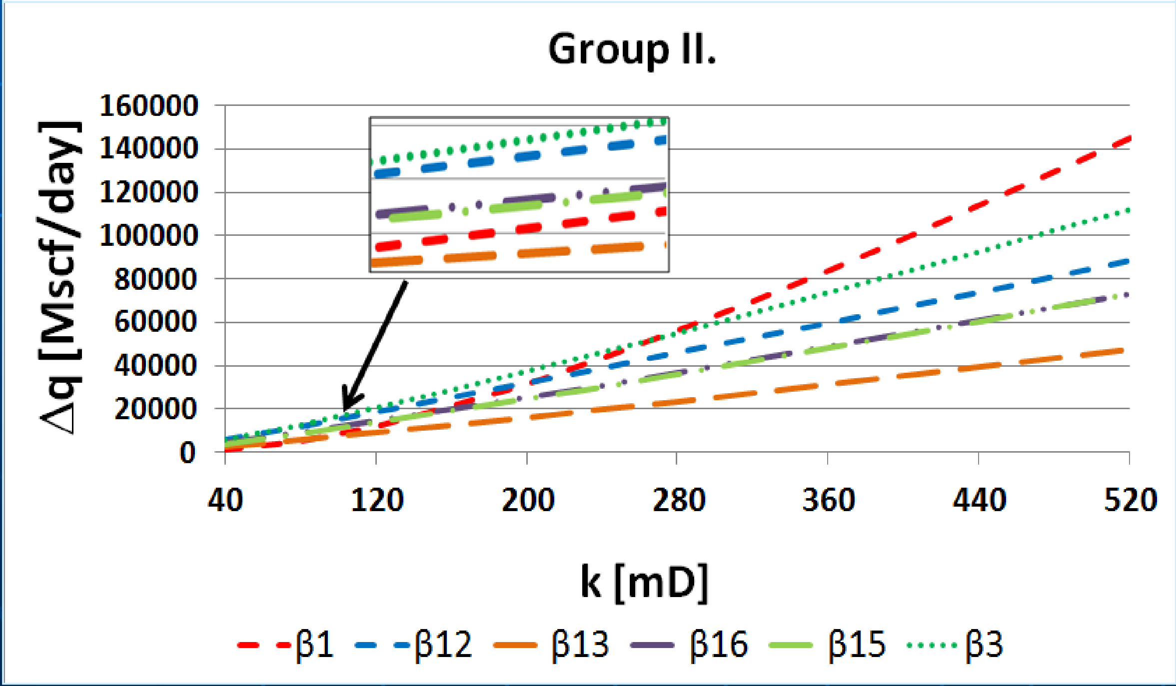
Sensitivity analyzes for OIL



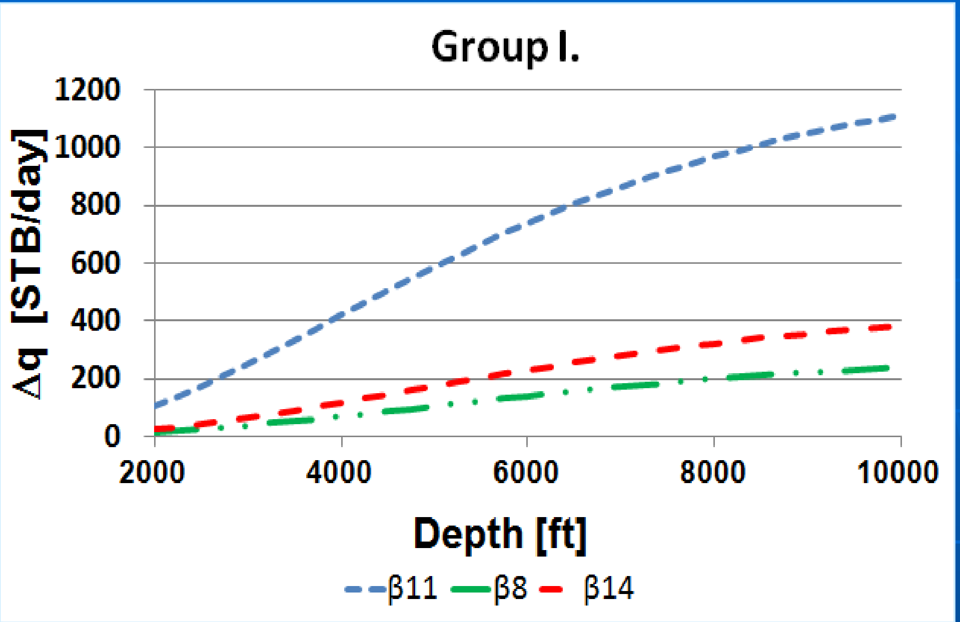


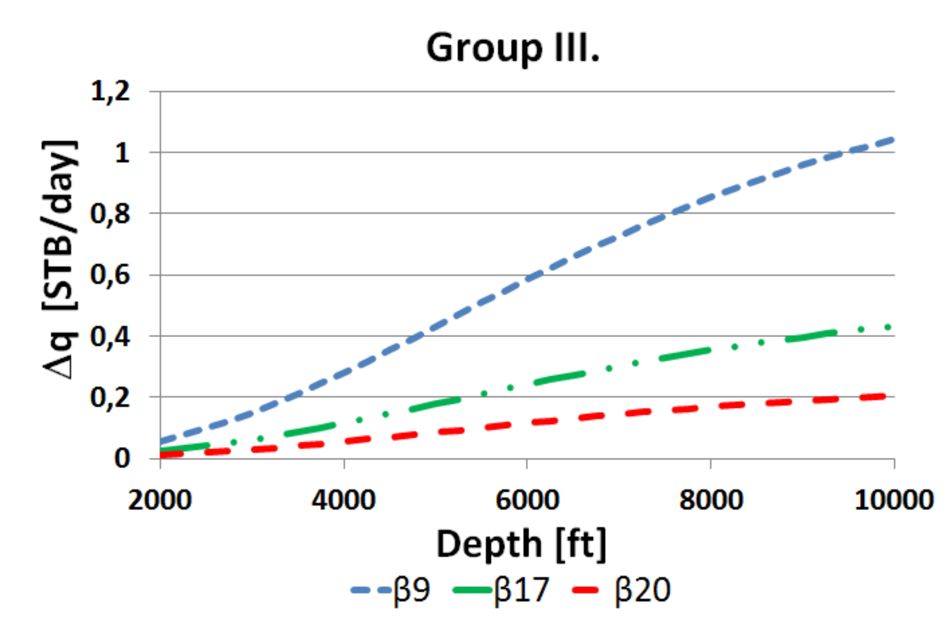
Sensitivity analyzes for GAS

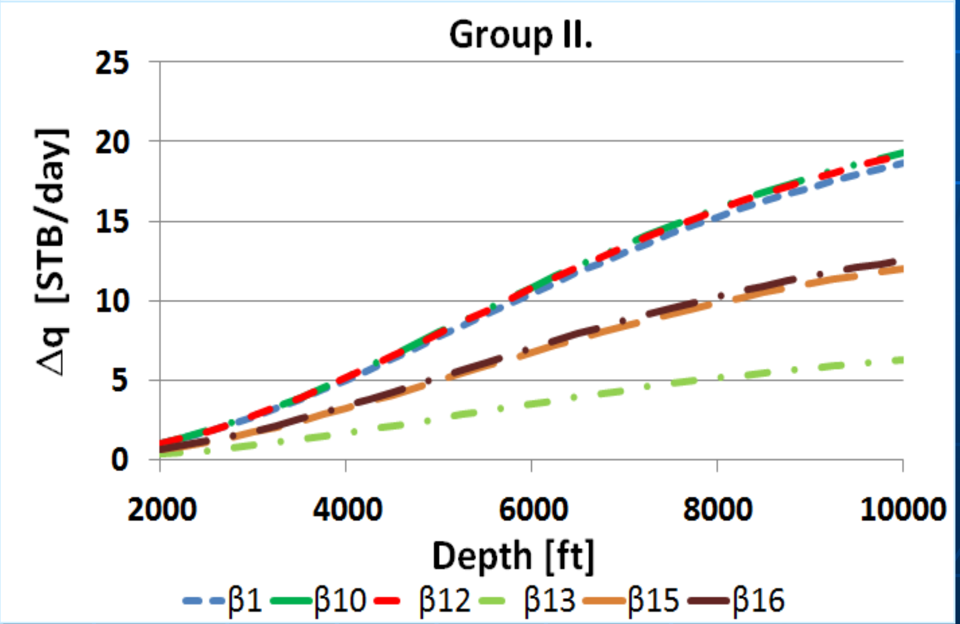




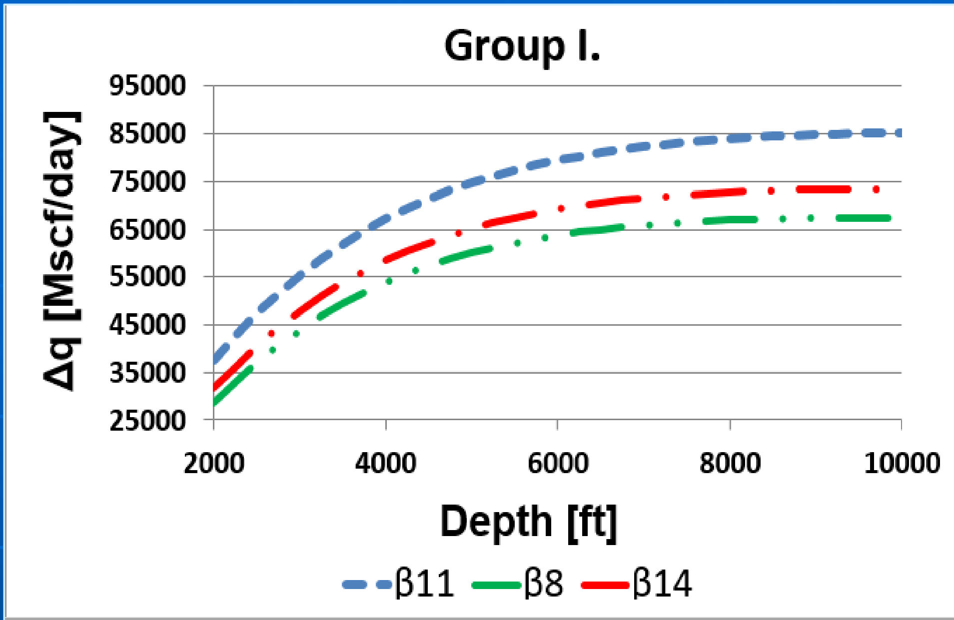
Sensitivity analyzes based on the depth for OIL

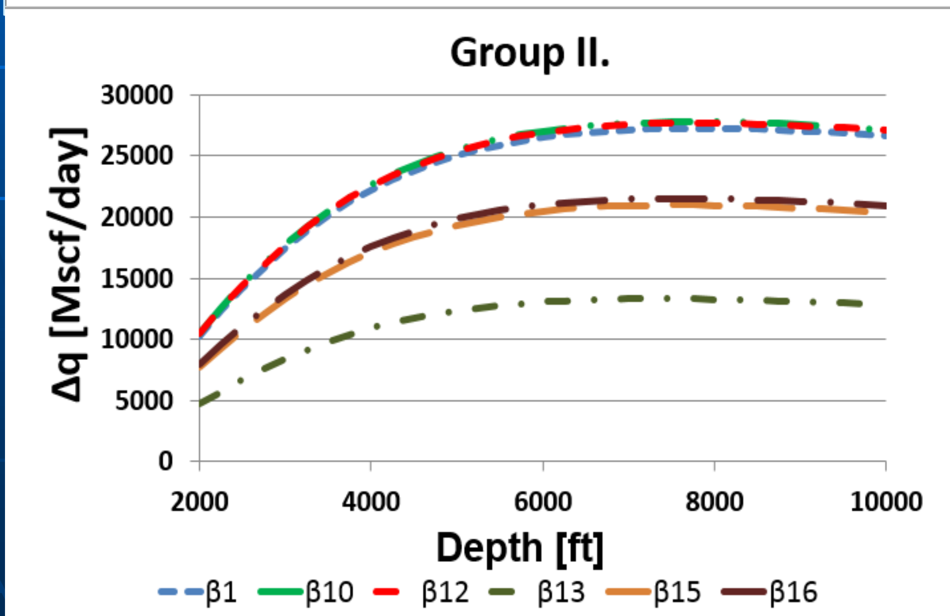


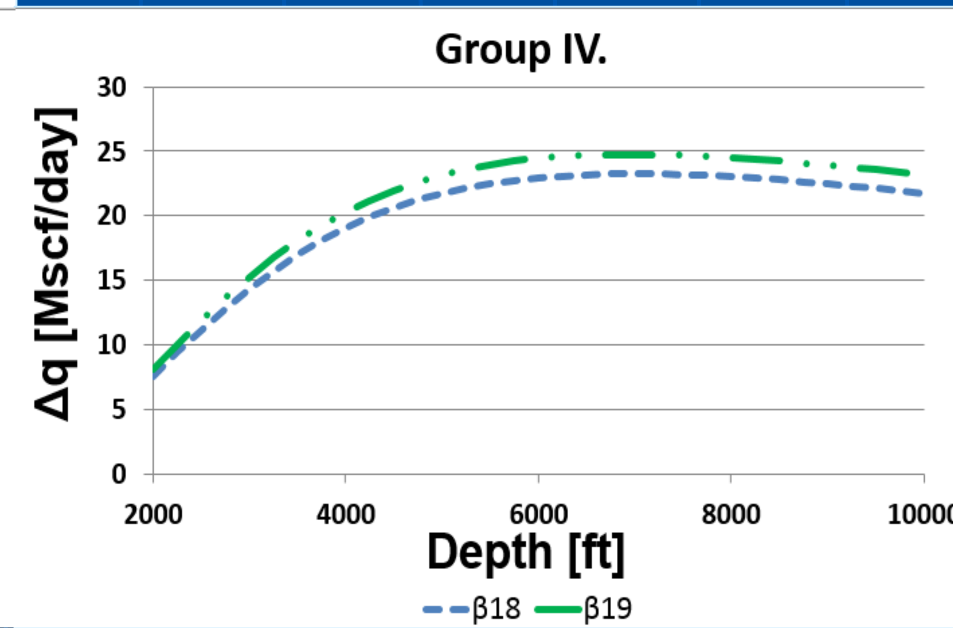




Sensitivity analyzes based on the depth for GAS







β factor	Formula	Measurement	Group	Class
β_1	$\beta_1 = \left(\frac{0.005}{\phi^{5.5} k^{0.5} \times 10^{-11}}\right) \times 30.5$	sandstone	II.	C
β_2	$\beta_2 = 6.15 \times 10^{10} (k)^{-1.55}$	sandstone limestone	II.	E
β_3	$\beta_3 = 1.98 \times 10^{11} (k)^{-1.64}$	sandstone limestone	II.	E
β_4	$\beta_4 = 7.89 \times 10^{10} (k)^{-1.60} [\phi(1 - S_w)]^{-0.404}$	sandstone limestone	II.	D
β_5	$\beta_5 = 2.11 \times 10^{10} (k)^{-1.55} [\phi(1 - S_w)]^{-1.0}$	sandstone limestone	II.	C
β_6	$\beta_6 = \frac{1}{[\phi(1 - S_w)]^2} \times e^{45 - \sqrt{407 + 81 \cdot \ln(k/(\phi(1 - S_w)))}}$	sandstone limestone	II.	B
β_7	$\beta_7 = \frac{5.5 \times 10^9}{k^{1.25} \phi^{0.75}} \times 0.305$	sandstone limestone	II.	B
β_8	$\beta_8 = \frac{5.5 \times 10^9}{k^{5/4} \phi^{3/4}}$	Wilcox- homok	I.	B
β_9	$\beta_9 = \left(\frac{5.123 \times 10^{-3}}{\phi}\left[\frac{1}{(1 - S_w)\sqrt{k \times 10^{-11}}}\right]^{1.1045}\right) \times 30.5$	sandstone	III.	C
β_{10}	$\beta_{10} = (1.82 \times 10^8 k^{-5/4} \phi^{-3/4}) \times 30.5$	sandstone limestone dolomite	II.	B
β_{11}	$\beta_{11} = \left(\frac{4.8 \times 10^{12}}{k^{1.176}}\right) \times 0.305$	Low permeability hidraulically fractured well's dates	I.	E
β_{12}	$\beta_{12} = \frac{1.07 \times 10^{12} \times \phi^{0.449}}{k^{1.88}}$	sandstone limestone	II.	A
β_{13}	$\beta_{13} = \frac{2.49 \times 10^{11} \phi^{0.537}}{k^{1.79}}$	sandstone limestone	II.	A
β_{14}	$\beta_{14} = \frac{9 \times 10^9}{k^{4/7} \times \phi^{3/7}}$	sandstone	I.	C
β_{15}	$\beta_{15} = \frac{17.2 \times 10^{10}}{k^{1.76}}$	sandstone	II.	E
β_{16}	$\beta_{16} = \frac{4.8 \times 10^{12}}{k^{1.8} \times \phi^{-0.48}}$	sandstone	II.	A
β_{17}	$\beta_{17} = \frac{2.018 \times 10^9}{k^{1.23}} \times 0.305$	limestone, crystal limestone, well-classed sandstone	III.	E
β_{18}	$\beta_{18} = \frac{1}{\phi}\sqrt{\frac{1.8 \times 10^9}{k\phi}} \times 0.305$	sandstone	IV.	C
β_{19}	$\beta_{19} = \frac{1}{\phi}\sqrt{\frac{245 \times 10^8}{12k\phi}} \times 0.305$	sandstone	IV.	C
β_{20}	$\beta_{20} = \frac{8.17 \times 10^9 \phi^{0.537}}{k^{1.79}} \times 0.305$	sandstone limestone	III.	A

Results of the research

β factor	Formula	Measurement	Group	Class
β_1	$\beta_1 = \left(\frac{0.005}{\Phi^{5.5} k^{0.5} \times 10^{-11}}\right) \times 30.5$	sandstone	II.	C
β_2	$\beta_2 = 6.15 \times 10^{10} (k)^{-1.55}$	sandstone limestone	II.	E
β_3	$\beta_3 = 1.98 \times 10^{11} (k)^{-1.64}$	sandstone limestone	II.	E

1. Choose β factors which measured cores are equal with our reservoir

2. Investigate the β factors values with changing porosity

3. Which class should be chosen from

4. Examine the magnitudes of the measured β factors

5. Which group should be chosen from

6. Decide which beta factor is the best in our conditions

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