DIAGNOSTICO Y MODELAMIENTO BASICO DE DAÑO DE FORMACIÓN

MESA TEMÁTICA DE INNNOVACIÓN Y TECNOLOGÍA
MESA DE TRABAJO EN DAÑO DE FORMACIÓN

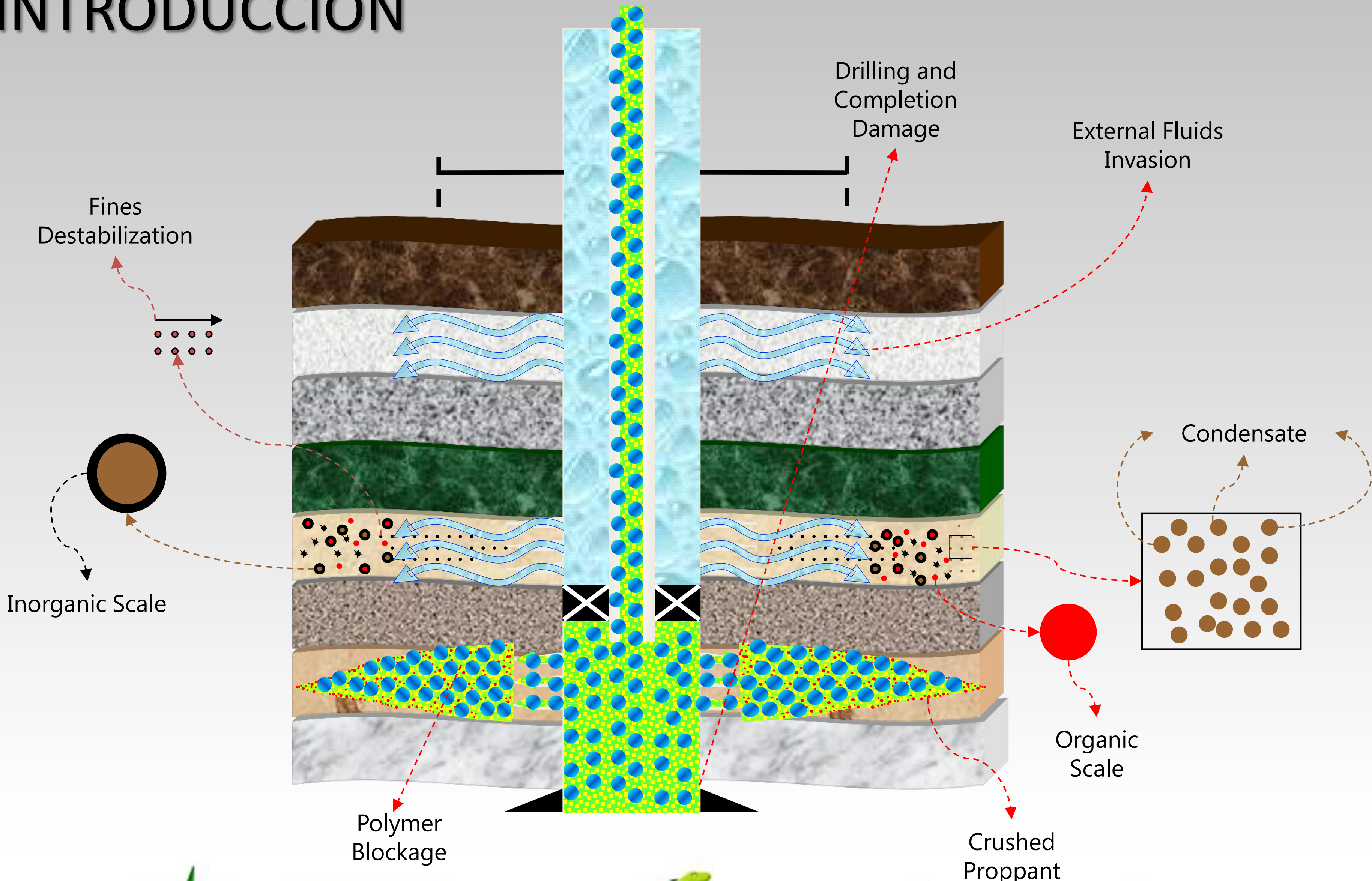
Curso Programado en Asocio con Grupos de Investigación en Hidrocarburos y Química Aplicada de la Universidad Nacional de Colombia y la Universidad Industrial de Santander

Con el Apoyo Financiero de la VP de Innovación y Tecnología de Ecopetrol

Diciembre 1 y 2 de 2016

Mesa Temática de Innovación y Tecnología

INTRODUCCIÓN



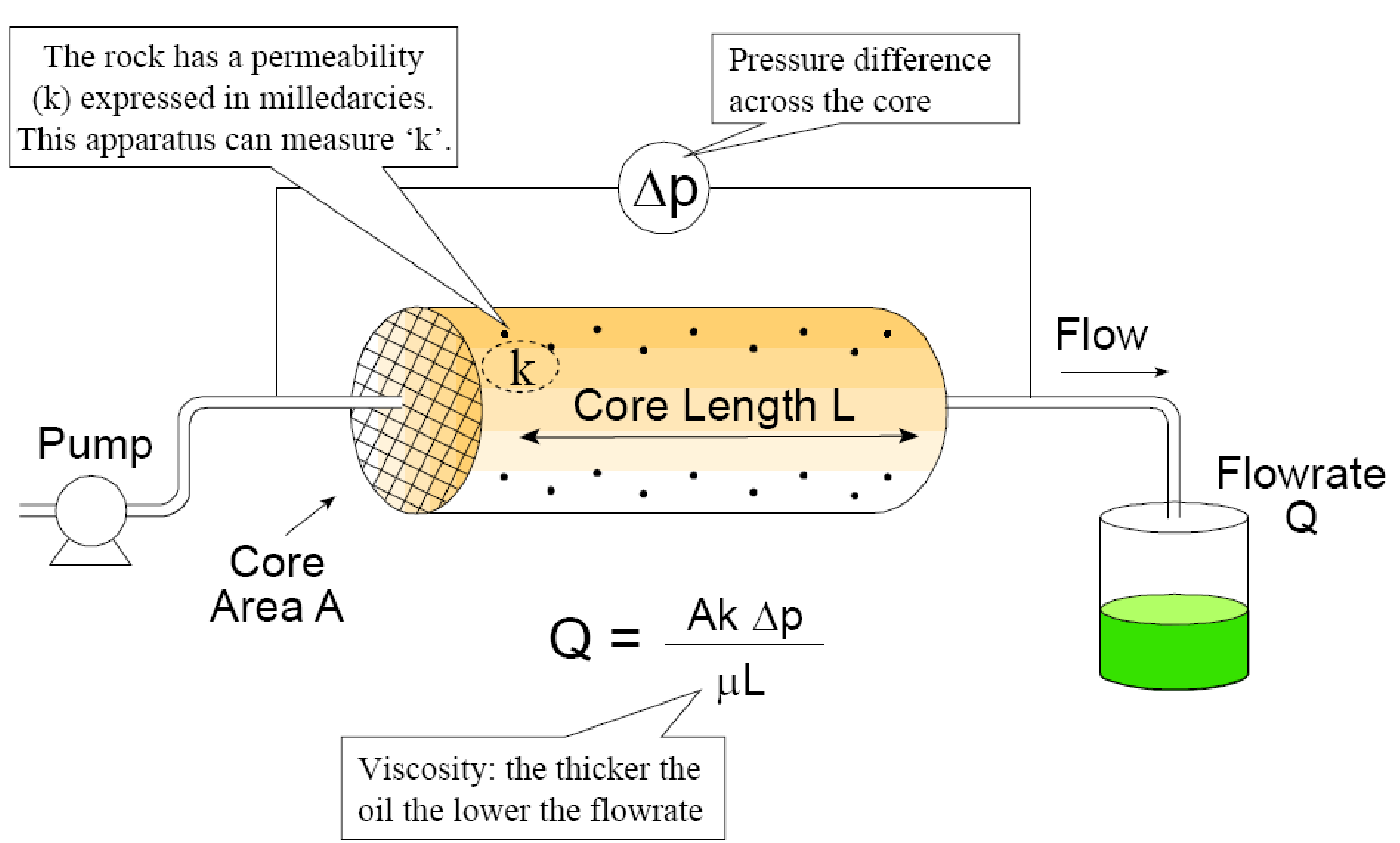
Skin Factor | Concept

Anything causing a distortion of the flow lines from the perfectly normal to the well direction, or a restriction to flow, results in a positive skin

- Damage to the near wellbore reservoir permeability
- Partial completion (distortion of lines of flow to the wellbore)
- Geometry and number of perforations (distortion of lines of flow to the wellbore)
- Perforation (crushed zone) damage
- Phase changes (relative permeability reduction to the main fluid)
- Turbulence (rate dependant effects)

Skin Factor | Concept (2)

Linear Flow



$$Q = \frac{Ak\,\Delta p}{\mu L}$$

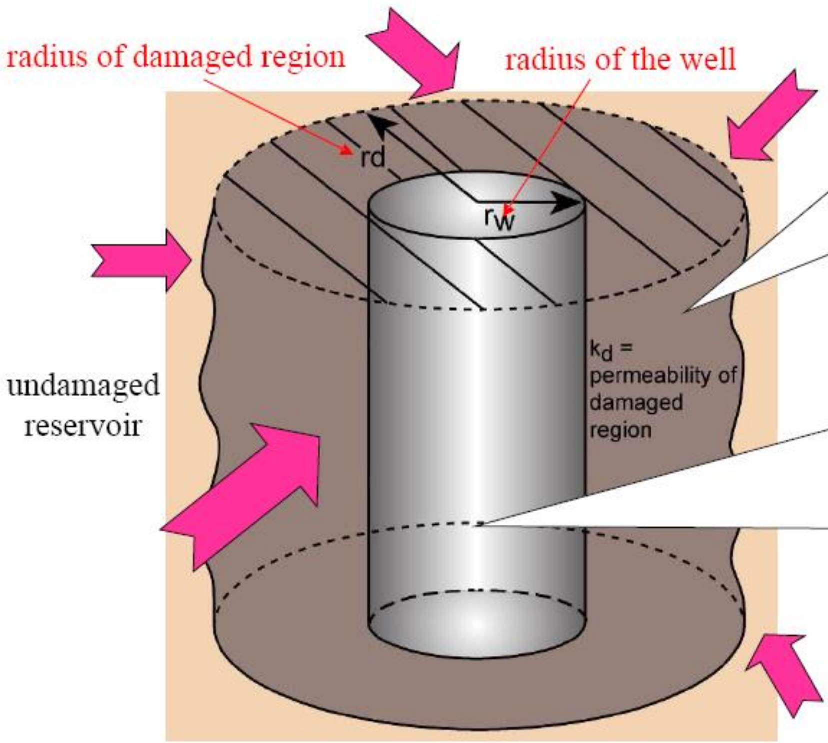
Skin Factor | Concept (3)

$$q_o = \frac{7.08 \times 10^{-3} \; k_o h (P_r - P_{wf})}{\mu_o B_o \left(\left(\ln \frac{r_e}{r_w} \right) - 0.75 + S \right)}$$

How do we measure "Skin":?

Radial Flow

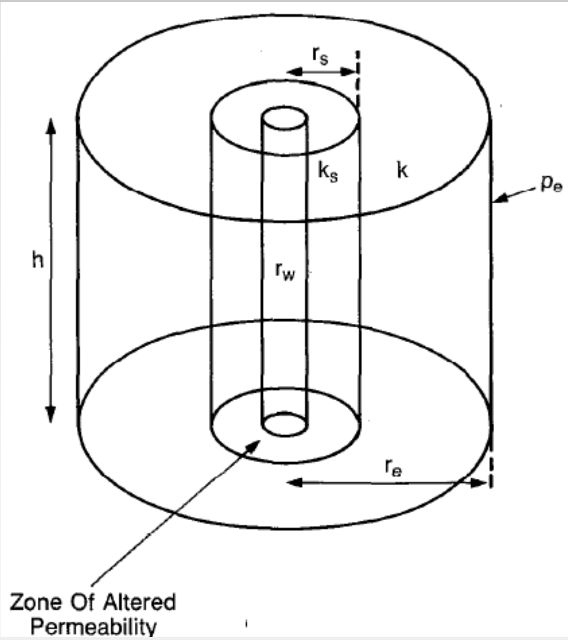
Q = flowrate in stock tank (bbls/day)
K = permeability (md)
H = vertical height of reservoir (ft)
Pr = Average reservoir pressure (psi)
Pw = Bottom hole flowing pressure (psi)
B = Formation volume factor. (Reservoir bbls/stock tank bbls)
μ = viscosity (cP)
re = drainage radius of reservoir (ft)
rw = wellbore radius (open hole) (ft)
S = Skin – a dimensionless number. 0 in undamaged wells.

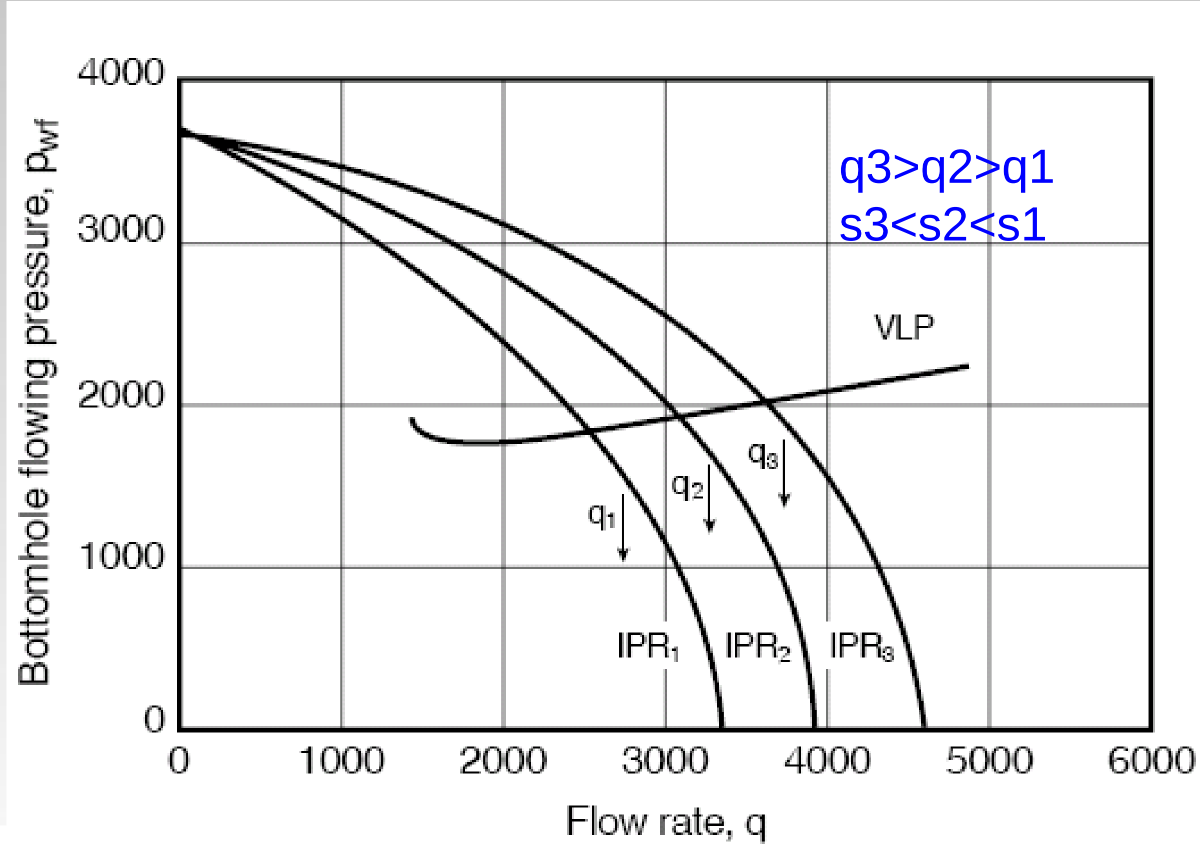


This damaged zone will cause a decrease in the well productivity. However, be aware that a well with no damage zone can have a lower than expected productivity if it is cased and then badly perforated.

RADIAL FLOW
Imagine the drainage area of this well. Oil that is one thousand feet away has plenty of room to travel through the reservoir to the wellbore. BUT as it gets closer and closer there is less and less room. The near wellbore region therefore becomes crucial: damage this and you severely impair the wells productivity.

Formation Damage | Relationship w/ Well Performance





$$q_o = \frac{7.08 \times 10^{-3}\, k_o\, h\, (\bar{p}_r - p_{wf})}{\mu_o B_o \left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s_t + Dq_o \right]}$$

Positive values of Skin cause deviations from optimal well response

Skin Factor | Measurement

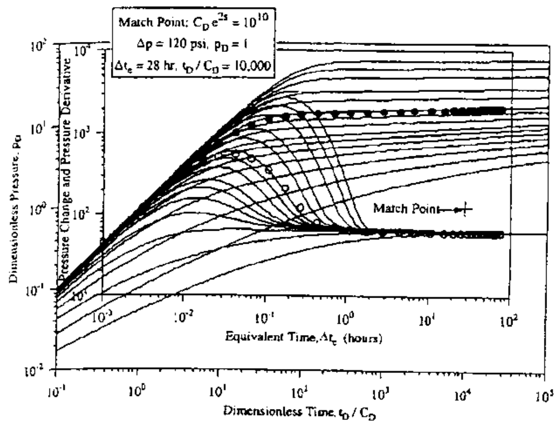


Fig. 4.18—Type-curve match by use of the Bourdet *et al.*[10] pressure-derivative model, Example 4.4.

6. The effective permeability to oil is computed with the pressure match point:

$$k = \frac{141.2 qB\mu}{h}\left(\frac{p_D}{\Delta p}\right)_{MP}$$

$$= \frac{(141.2)(600)(1.1)(1.0)}{(78)}\left(\frac{1}{120}\right)$$

$$= 9.96 \text{ md.}$$

7. The dimensionless wellbore-storage coefficient is computed with the time match point:

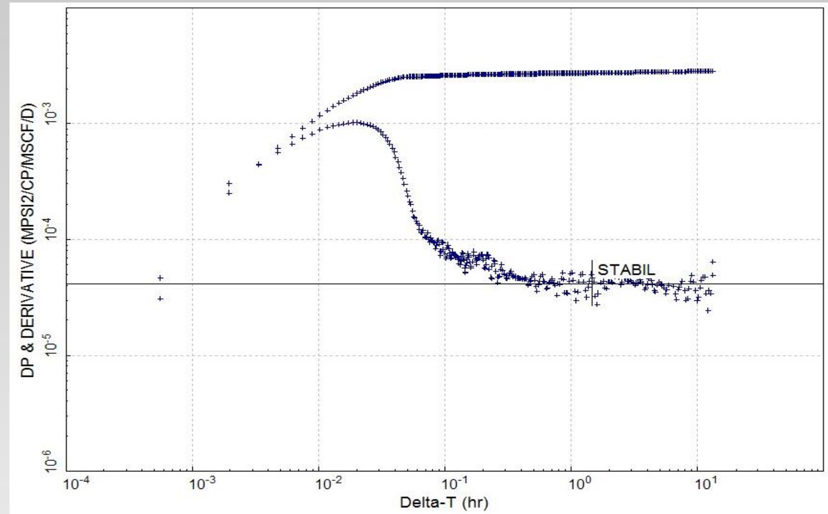
$$C_D = \frac{0.0002637k}{\phi h c_t r_w^2}\left(\frac{\Delta t_e}{t_D/C_D}\right)_{MP}$$

$$= \frac{(0.0002637)(10.0)}{(0.2)(1.0)(1.61 \times 10^{-5})(0.365)^2}\left(\frac{28}{100}\right)$$

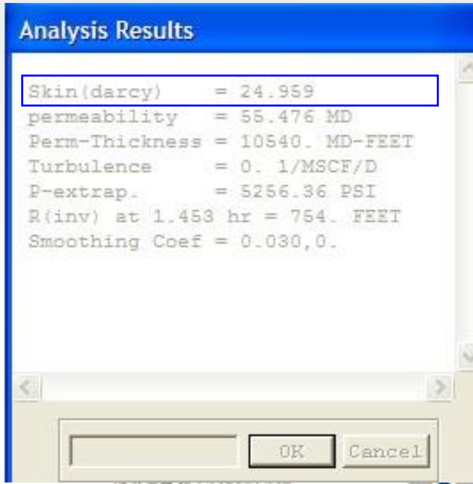
$$= 17.21.$$

8. Calculate the skin factor, s, with C_D from Step 7 and $C_D e^{2s}$ from Step 5.

$$s = 0.5 \ln\left(\frac{C_D e^{2s}}{C_D}\right) = 0.5 \ln\left(\frac{10^{10}}{17.2}\right) = 10.1.$$



Cusiana BA-G13 Fall-off#1



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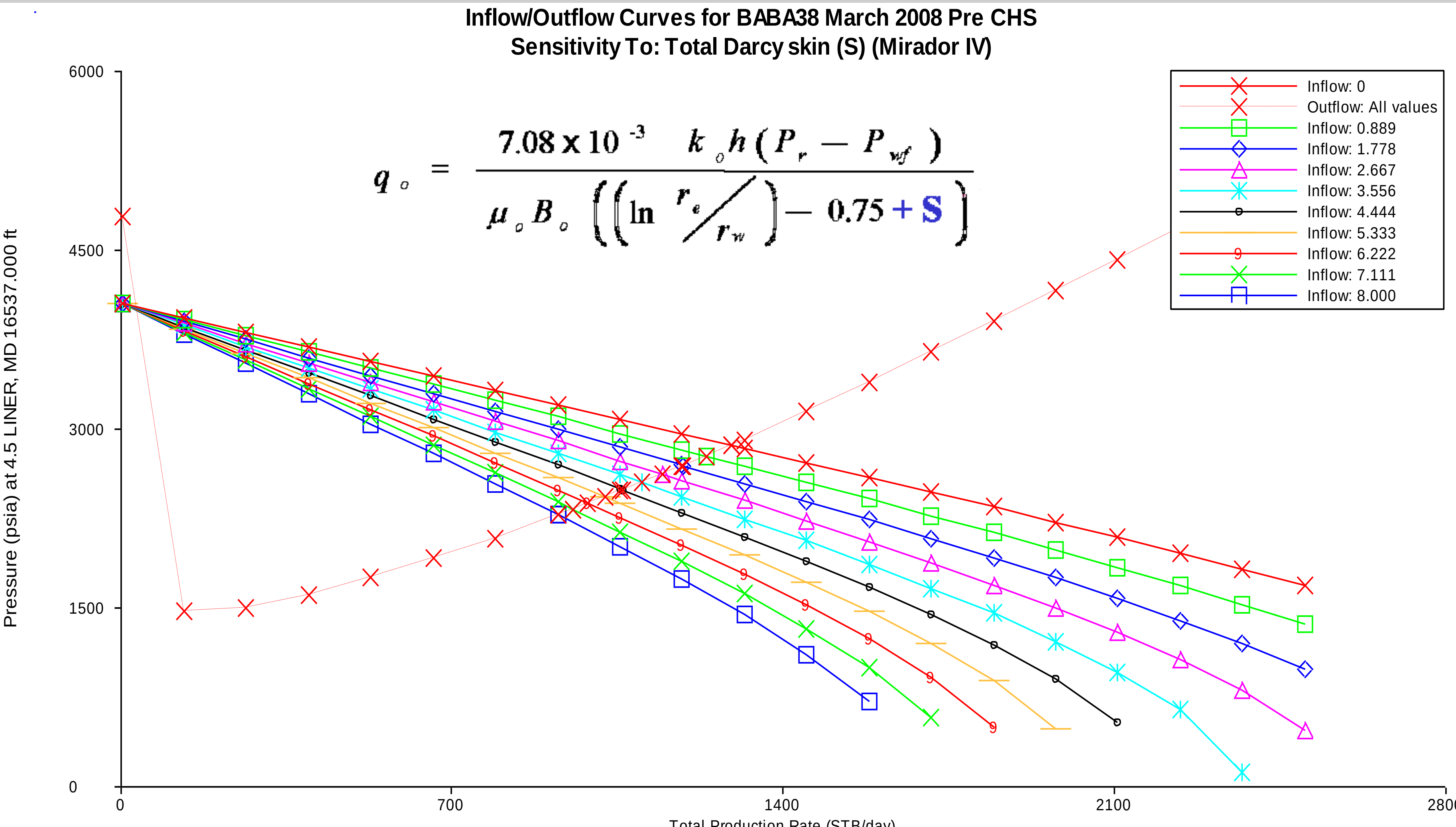
Skin Factor | Impact on Well Productivity



Skin Factor | Impact on Well Productivity (2)

- A negative skin factor means that well is stimulated (fractured, acidized, etc)
- A positive skin factor means that well is damaged
- Note that skin can be positive to infinite, but negative to about -6, possibly -7.

Situation	Typical Skin Factor
Badly damaged or partially completed well	+20 to +500
Damaged well (during drilling or well intervention)	+2 to +20
Good initial completion - vertical/unstimulated	+2 to -1
Lightly acidised	0 to -2
Typical deviated well	-0.5 to -3
Natural fractures or small propped frac	-3 to -5
Large frac in low permeability formation	-5 to -6.5

In the Radial Flow Equation productivity is affected by:

1. reservoir pressure
2. bottomhole flowing pressure
3. drainage radius
4. wellbore radius
5. THE SKIN FACTOR!

The optimum "skin" factor is generally the lowest possible

Formation Damage Theory

Formation Damage

A reduction of permeability around a wellbore, which is the consequence of drilling, completion, intervention, injection, attempted stimulation, or production of that well

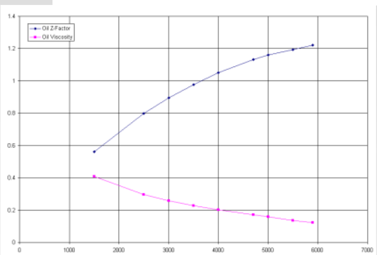
Can be classified according to the mechanism of K reduction

PROCESS TYPE	PHYSICAL PORE SIZE REDUCTION	RELATIVE PERMEABILITY REDUCTION
FLUID-ROCK INTERACTIONS	Fines Migration Clay Swelling Solids Invasion Adsorption/Precipitation of large molecules (e.g. polymers)	Wettability change due to surfactant adsorption
FLUID-FLUID INTERACTIONS	Scale Formation Emulsion Formation Sludge Formation	Fluid saturation change and fluid block
PRESSURE/ TEMPERATURE CHANGE	Scale Formation Wax Formation Asphaltene Formation	Gas breakout Condensate banking Water coning
MECHANICAL PROCESSES	Stress-induced permeability change Perforation plugging	

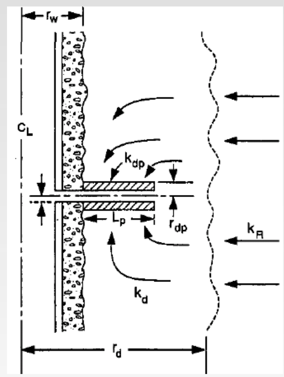
Formation Damage | Relationship w/ Well Performance (4)

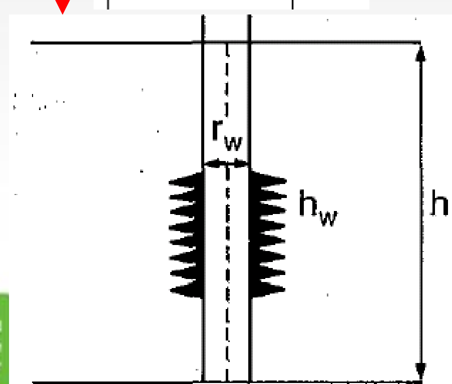
And....

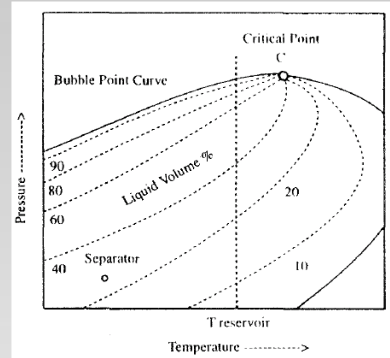
$$q_o = \frac{7.08 \times 10^{-3}\, k_o\, h\, (\bar{p}_r - p_{wf})}{\mu_o B_o \left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s_t + Dq_o\right]}$$

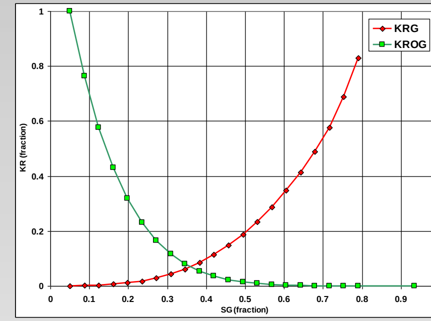


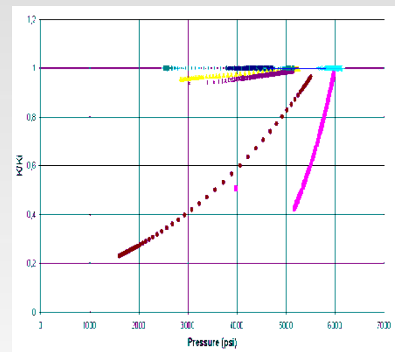
SYSTEM	X
	$\frac{r_e}{r_w}$
	$\frac{0.571A^{1/2}}{r_w}$
	$\frac{0.565A^{1/2}}{r_w}$
	$\frac{0.604A^{1/2}}{r_w}$
60	$\frac{0.610A^{1/2}}{r_w}$
1/3	$\frac{0.678A^{1/2}}{r_w}$
2 1	$\frac{0.668A^{1/2}}{r_w}$
4 1	$\frac{1.368A^{1/2}}{r_w}$
5 1	$\frac{2.066A^{1/2}}{r_w}$
	$\frac{0.884A^{1/2}}{r_w}$
	$\frac{1.485A^{1/2}}{r_w}$

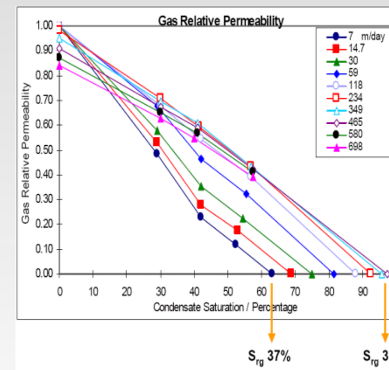


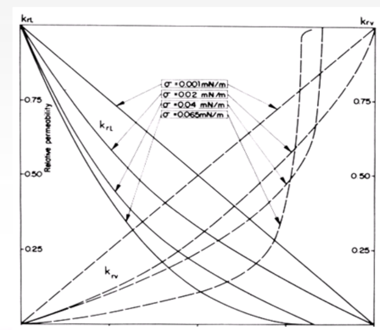


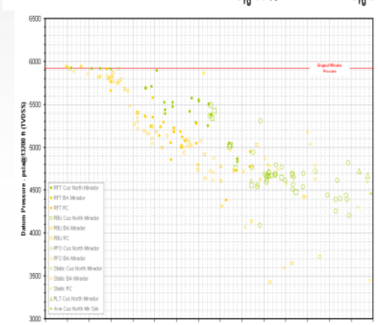












Formation Damage | Relationship with Well Performance

$$q_o = \frac{7.08 \times 10^{-3}\, k_o\, h\, (\bar{p}_r - p_{wf})}{\mu_o B_o \left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s_t + Dq_o \right]}$$

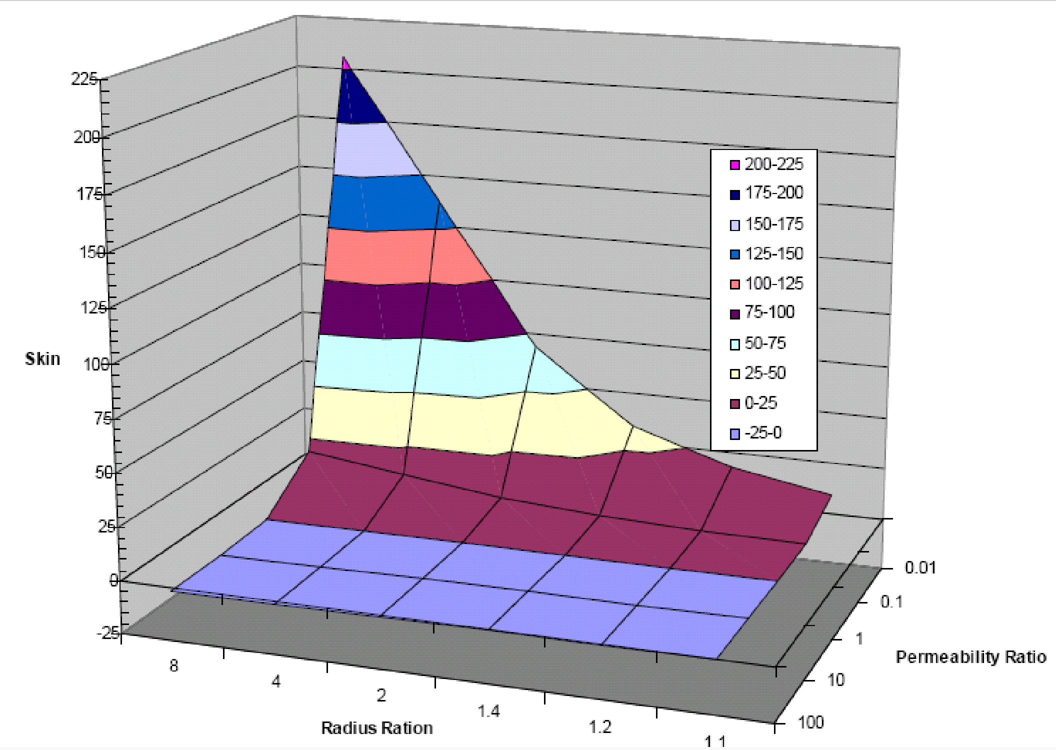
where,

q_o = oil flow rate into the well, stb/D,
B_o = formation volume factor of oil, bbl/stb,
μ_o = viscosity of oil, cp,
k_o = permeability of the formation to oil, , md,
h = net thickness of the formation, ft,
$\bar{p}_r$ = average reservoir pressure, psia,
p_{wf} = bottomhole flowing pressure, psia,
r_e = radius of drainage, ft,
= $\sqrt{\frac{A}{\pi}}$ where A is area of circular drainage in sq ft ,
r_w = wellbore radius (ft) ,
s_t = total skin,
Dq_o = pseudo skin due to turbulence. In oil wells, this term is insignificant especially for low permeability reservoirs.

$$q_g = \frac{7.03 \times 10^{-4}\, k_g\, h\, (\bar{p}_r^2 - p_{wf}^2)}{\bar{\mu}_g \bar{z}\, \bar{T} \left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s_t + Dq_g \right]}$$

where,

q_g = gas flow rate, Mscf/D,
k_g = permeability to gas, md,
$\bar{z}$ = gas deviation factor determined at average temperature and average pressure, fraction
$\bar{T}$ = average reservoir temperature, (deg. Rankine),
$\bar{\mu}_g$ = gas viscosity, cp



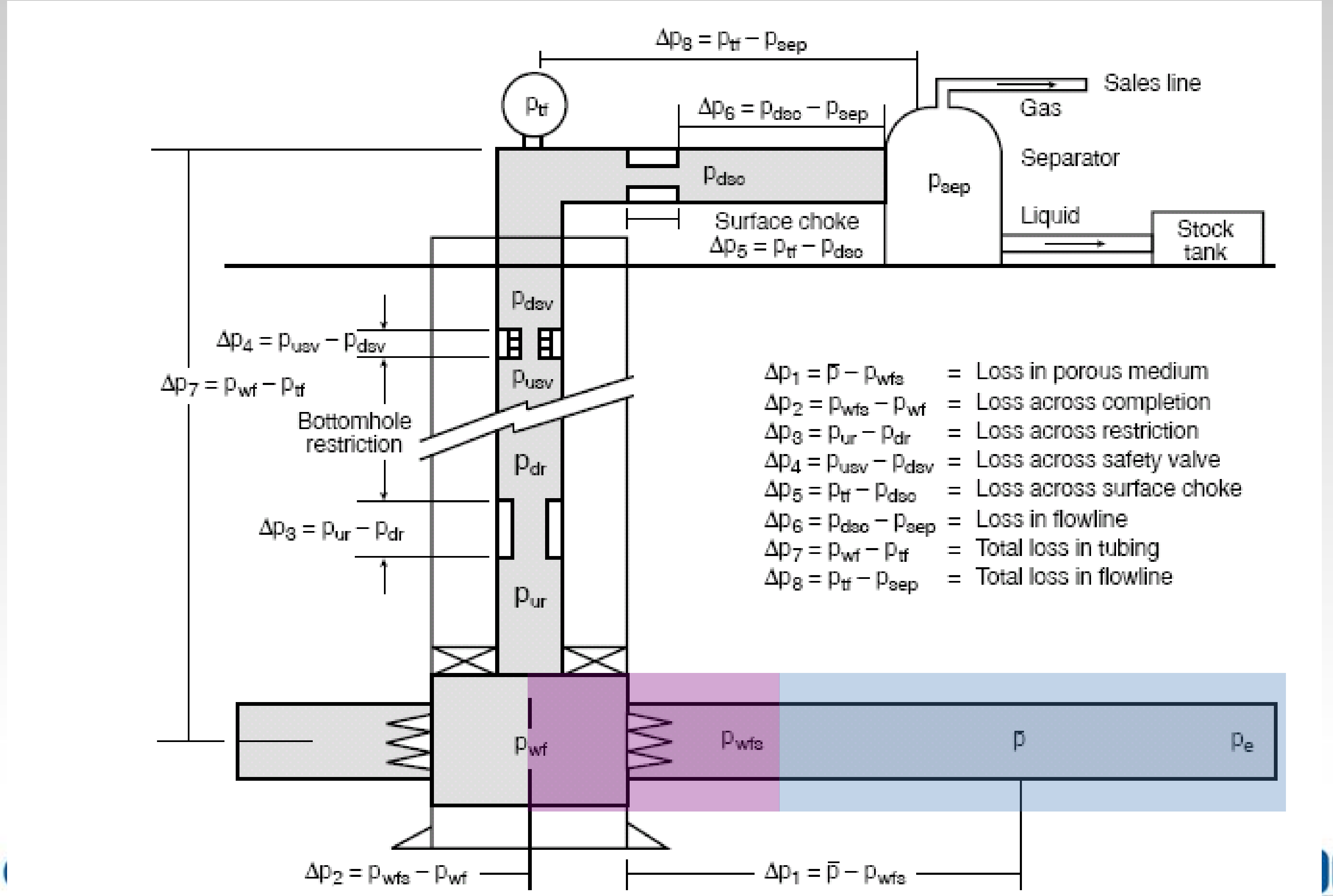
$$s_t = s_d + s_p + s_{pp} + s_{turb} + s_o + s_s + \ldots\ldots,$$

s_t = total skin effect,
s_d = skin effect due to formation damage
s_{pp} = skin effect due to partial penetration
s_p = skin effect due to perforation
s_{turb} = Dq, skin effect due to turbulence or rate dependent skin
s_o = skin effect due to slanting of well
s_s = skin effect due to stimulation

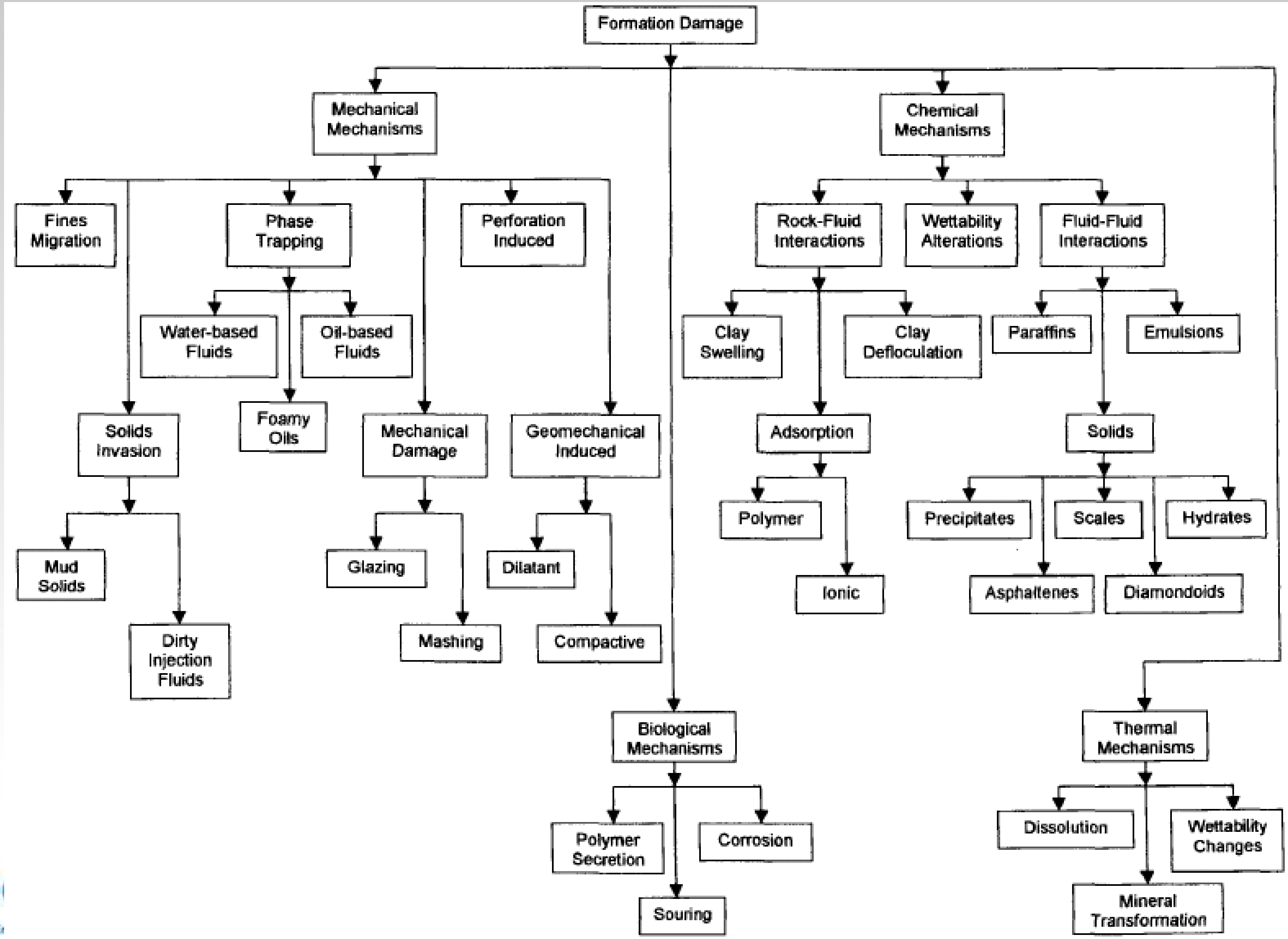
S=((Ki/Kd)-1)*Ln(rd/rw)

S: equivalent Skin
Ki: initial permeability
Kd: damaged permeability
rw: wellbore radius
rd: damaged radius

Formation Damage | Relationship w/ Well Performance (2)



Formation Damage | Causes



Uncertainty

Ecuación Convencional

$$q_o = \frac{7.08 * 10^{-3} * Ko * h\,[P - Pwf]}{\mu_{o(p)} * \ \beta_{o(p)} \ \left[\ln\left[\frac{r_e}{r_w}\right] - 0.75 + S_t\right]}$$

Input Determinístico & Estático

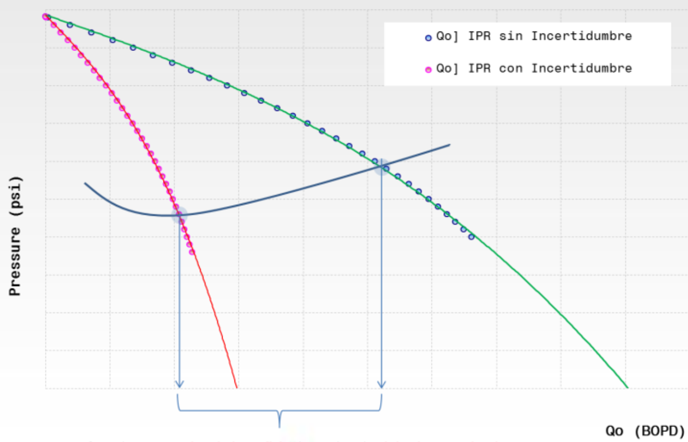
Valores fijos de:
Kabs, Kr, Pyto, r_e , y PVT

Ecuación Modificada

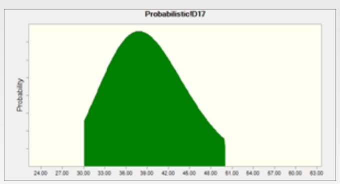
$$q_o = \frac{7.08 * 10^{-3} * Ki\, e^{\gamma(P-Pi)} Kro_{(Sw)} * Kro_{(Sg)} * h\,[P - Pwf]}{\mu_{o(p,GOR)} * \ \beta_{o(p,GOR)} \ \left[\ln\left[\frac{r_e}{r_w}\right] - 0.75 + S_t\right]}$$

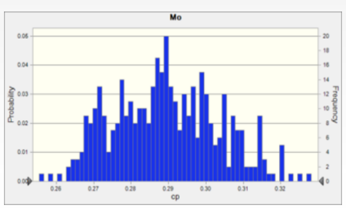
Input Probabilístico & Dinámico

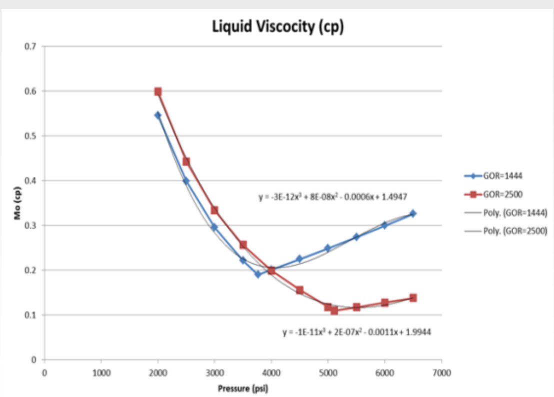
Distribuciones de:
Kabs, Pyto, r_e , no, nw, ng
PVT variable con GOR
Método de Monte Carlo



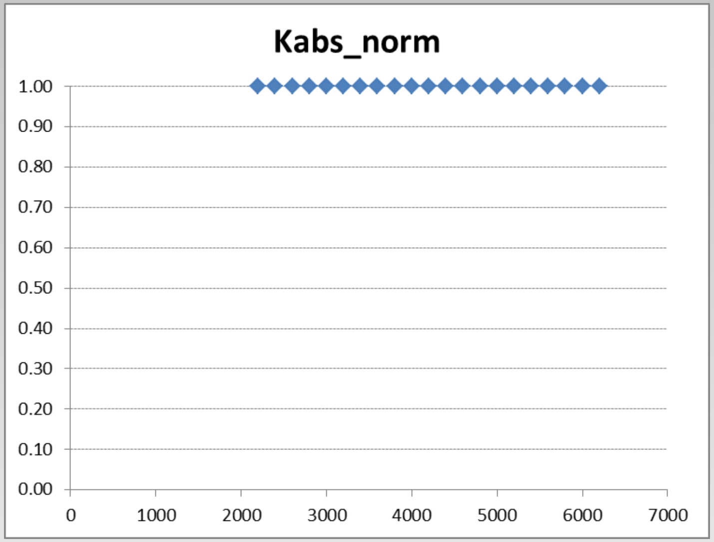
Se afecta la **expectativa de beneficio** dependiendo **del valor S evaluado**

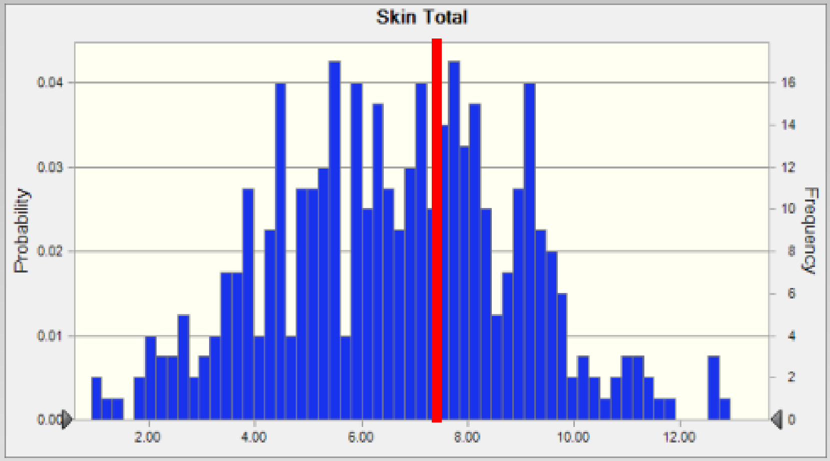




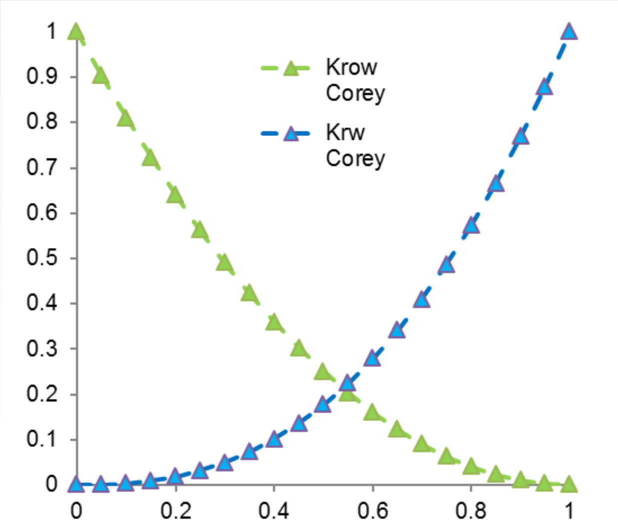


Caso No 1: Módulo de K cero, Curvas Kr Optimistas, GOR base





Statistics:	Forecast values
Trials	400
Base Case	7.53
Mean	6.68
Median	6.78
Mode	---
Standard Deviation	2.38
Variance	5.65
Skewness	0.1664
Kurtosis	3.03
Coeff. of Variability	0.3557
Minimum	0.91
Maximum	15.15
Range Width	14.24
Mean Std. Error	0.12



S = 6.78

Forecast: Skin Total (cont'd)

Percentiles:	Forecast values
0%	0.91
10%	3.65
20%	4.54
30%	5.37
40%	6.02
50%	6.78
60%	7.37
70%	7.96
80%	8.74
90%	9.48
100%	15.15

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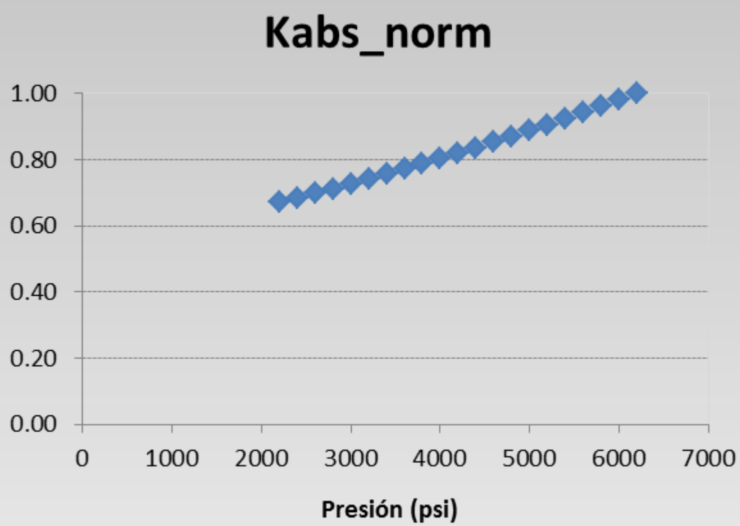
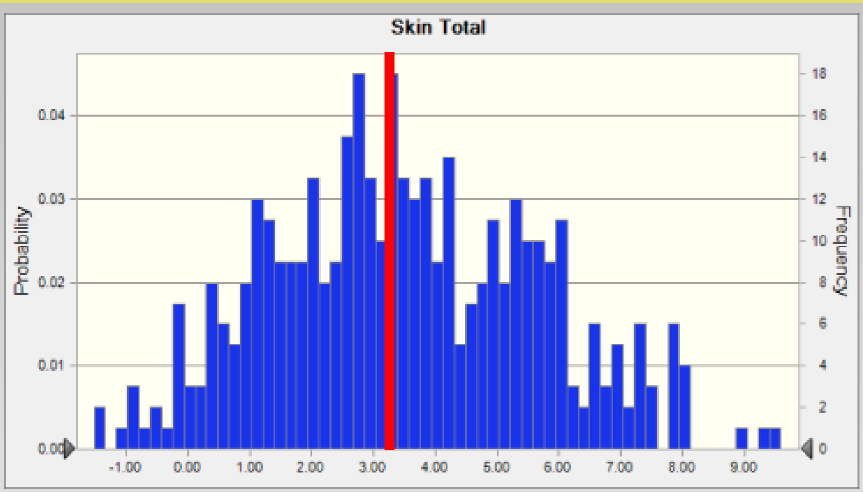
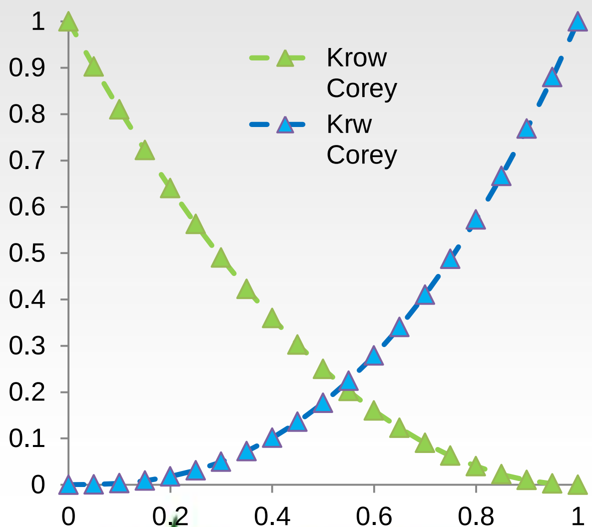
Caso No 2: Módulo de K = 1E-04, Curvas Kr Optimistas, GOR base







S = 3.73

Statistics:	Forecast values
Trials	400
Base Case	4.42
Mean	3.52
Median	3.37
Mode	---
Standard Deviation	2.17
Variance	4.71
Skewness	0.2176
Kurtosis	2.60
Coeff. of Variability	0.6173
Minimum	-1.53
Maximum	9.82
Range Width	11.34
Mean Std. Error	0.11

Forecast: Skin Total (cont'd)

Percentiles:	Forecast values
0%	-1.53
10%	0.74
20%	1.54
30%	2.26
40%	2.80
50%	3.37
60%	3.90
70%	4.75
80%	5.44
90%	6.40
100%	9.82

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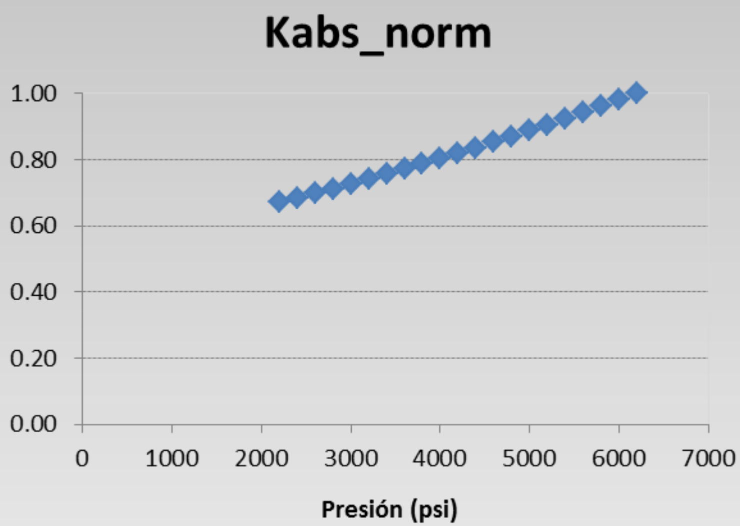
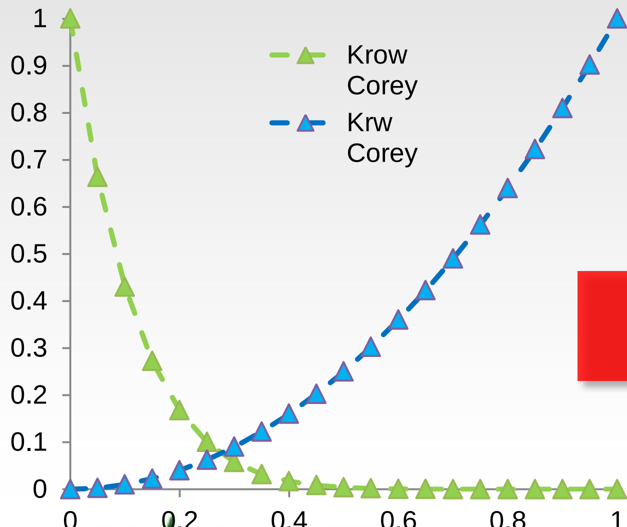
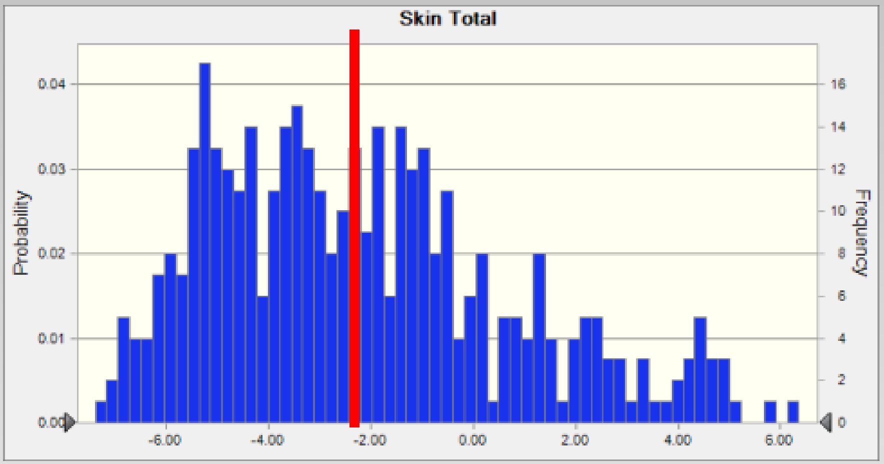
Caso No 3: Módulo de K = 1E-04, Curvas Kr Pesimistas, GOR base







Statistics:	Forecast values
Trials	400
Base Case	-1.77
Mean	-2.14
Median	-2.56
Mode	---
Standard Deviation	3.03
Variance	9.21
Skewness	0.7936
Kurtosis	3.40
Coeff. of Variability	-1.42
Minimum	-7.38
Maximum	10.24
Range Width	17.62
Mean Std. Error	0.15

S = -2.56

Forecast: Skin Total (cont'd)

Percentiles:	Forecast values
0%	-7.38
10%	-5.56
20%	-4.94
30%	-4.19
40%	-3.38
50%	-2.57
60%	-1.78
70%	-1.06
80%	0.15
90%	2.16
100%	10.24

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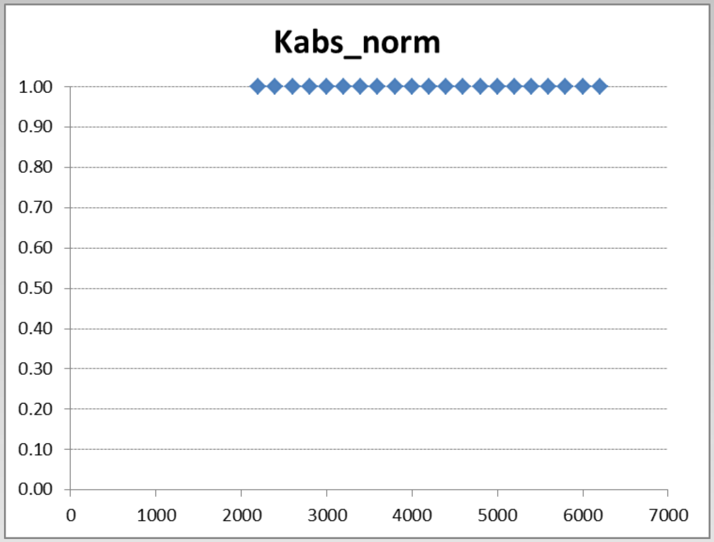
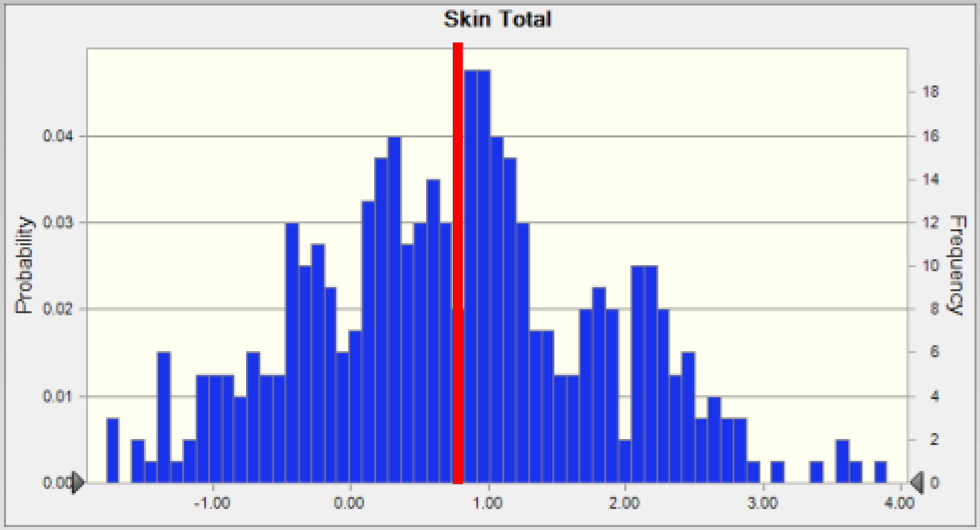
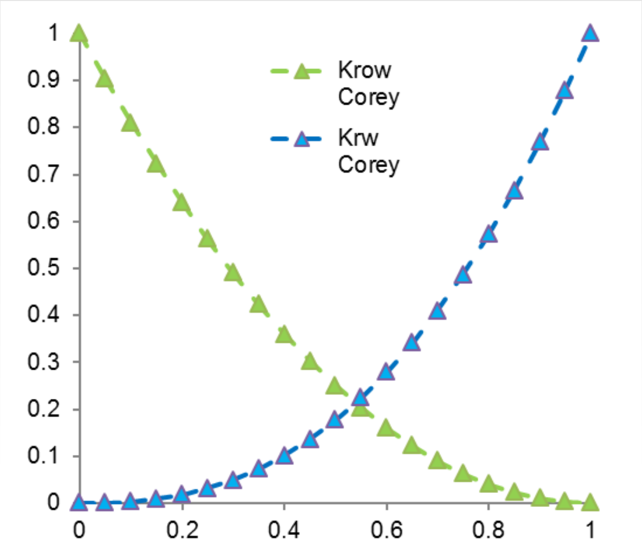
Caso No 4: Módulo de K cero, Curvas Kr Optimistas, GOR 30% por encima del base







S = 0.75

Statistics:	Forecast values
Trials	400
Base Case	0.78
Mean	0.77
Median	0.75
Mode	---
Standard Deviation	1.12
Variance	1.24
Skewness	0.2332
Kurtosis	2.88
Coeff. of Variability	1.45
Minimum	-1.78
Maximum	4.07
Range Width	5.85
Mean Std. Error	0.06

Forecast: Skin Total (cont'd)

Percentiles:	Forecast values
0%	-1.78
10%	-0.69
20%	-0.21
30%	0.18
40%	0.45
50%	0.74
60%	0.99
70%	1.23
80%	1.76
90%	2.23
100%	4.07

BIENVENIDOS