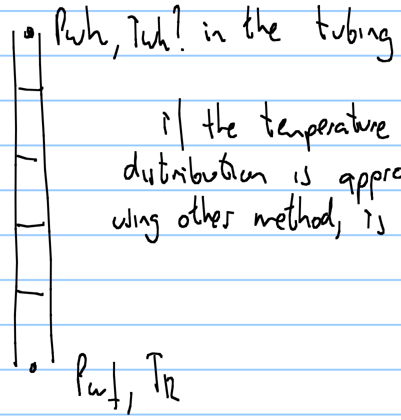
Comment about allocation: it is performed over a period of time!

↳ it involves integration of rates with time.

each point in the curve is calculated with a numerical integration (RK-4, explicit), stepwise calculation



if the temperature distribution is approximated using other method, is OK

<u>Tubing tables</u>: pre compute, for a large variation of q_o, P_{wh} the pressure drop in the tubing

$P_{wh} = P_{wh_1}$

q_o	q_g	q_w	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

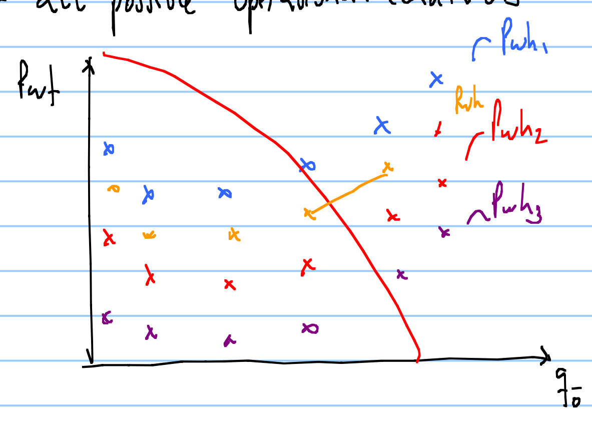
$P_{wh} = P_{wh_2}$

q_o	q_g	q_w	P_{wf}	T_{wh}
0				
50				
100				
00				
500				

$P_{wh} = P_{wh_3}$

q_o	q_g	q_w	P_{wf}	T_{wh}
0				
50				
100				
00				
500				

range chosen to cover all possible operational conditions



application case res. sim. outputs P_{wf}, q_o $\rightsquigarrow$ compute P_{wh}

from res. sim → Sm^3/d

$P_{wh} = P_{wh_1}$

q_o	q_g	q_w	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

$P_{wh} = P_{wh_2}$

q_o	q_g	q_w	P_{wf}	T_{wh}
0				
50				
100				
00				
500				

$P_{wh} = P_{wh_3}$

q_o	q_g	q_w	P_{wf}	T_{wh}
0				
50				
100				
00				
500				

$P_{wf}^* \sim$ from res sim

bilinear interpolation to find P_{wh}

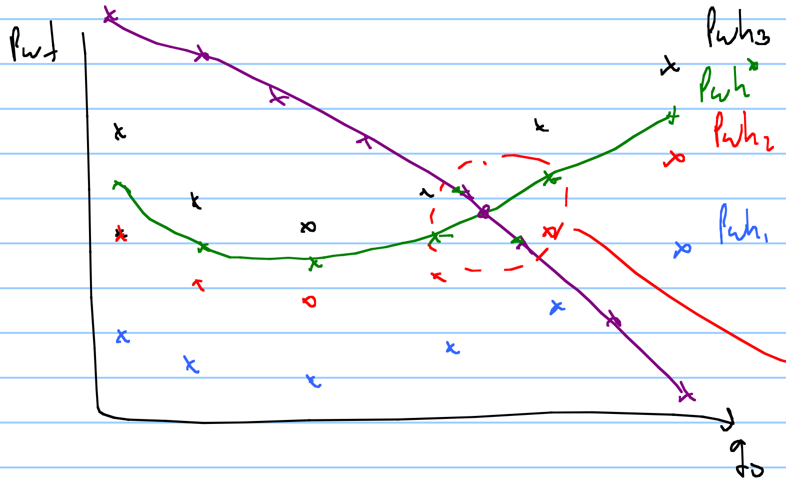
① interpolation on the rate

② interpolation on P_{wf}

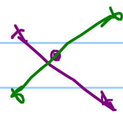
③ P_{wh}

q_1	P_{wf_1}	P_{wf_3}	P_{wf_2}
q_3	P_{wh_3}	$\boxed{}$	P_{wh}
q_2	P_{wf_1}		P_{wf_2}

find equilibrium at fixed P_{wh}.



intersection of two straight lines



P_{wh}^*

it is very important when using tubing tables to use an appropriate number of points

compare result from interpolating on the table = performing the multiphase Δp calculation designing flow table (FT)

P_{wh_1}, GOR_1, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_2}, GOR_1, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_3}, GOR_1, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_1}, GOR_2, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_2}, GOR_2, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_3}, GOR_2, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_1}, GOR_3, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_2}, GOR_3, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_3}, GOR_3, WC_1

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_1}, GOR_3, WC_2

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

P_{wh_2}, GOR_3, WC_2

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

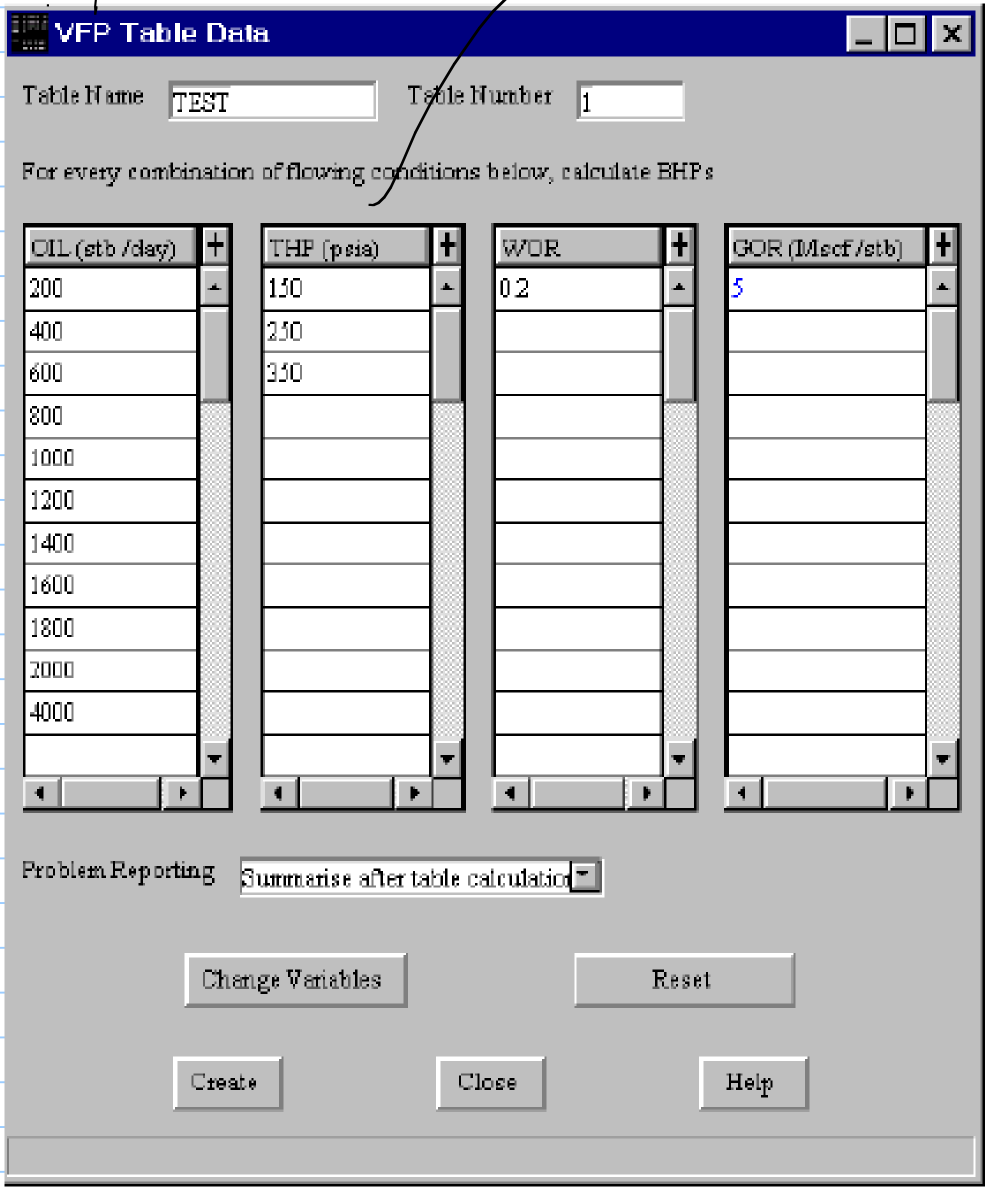
P_{wh_3}, GOR_3, WC_2

$q_{\bar{o}}$	$q_{\bar{g}}$	$q_{\bar{w}}$	P_{wf}	T_{wh}
0				
50				
100				
200				
500				

vertical flow performance

Pwh

from Sim launcher in eclipse



should take into account changes with time

- tubing tables can be generated from production simulators
  - Pipesim
  - GAP
  - wellflow

- tubing tables can also include artificial lift equipment, $q_{g\,inj}$, f_{esp}

gas injection rate

esp frequency.

flow tables are used by: reservoir simulators
production simulators ~ (network simulators). GAP

flow tables are generated assuming:
- fluid properties don't change
- well layout/completion doesn't change.

main motivation to use flow tables: table interpolation much quicker than pressure drop calculations!

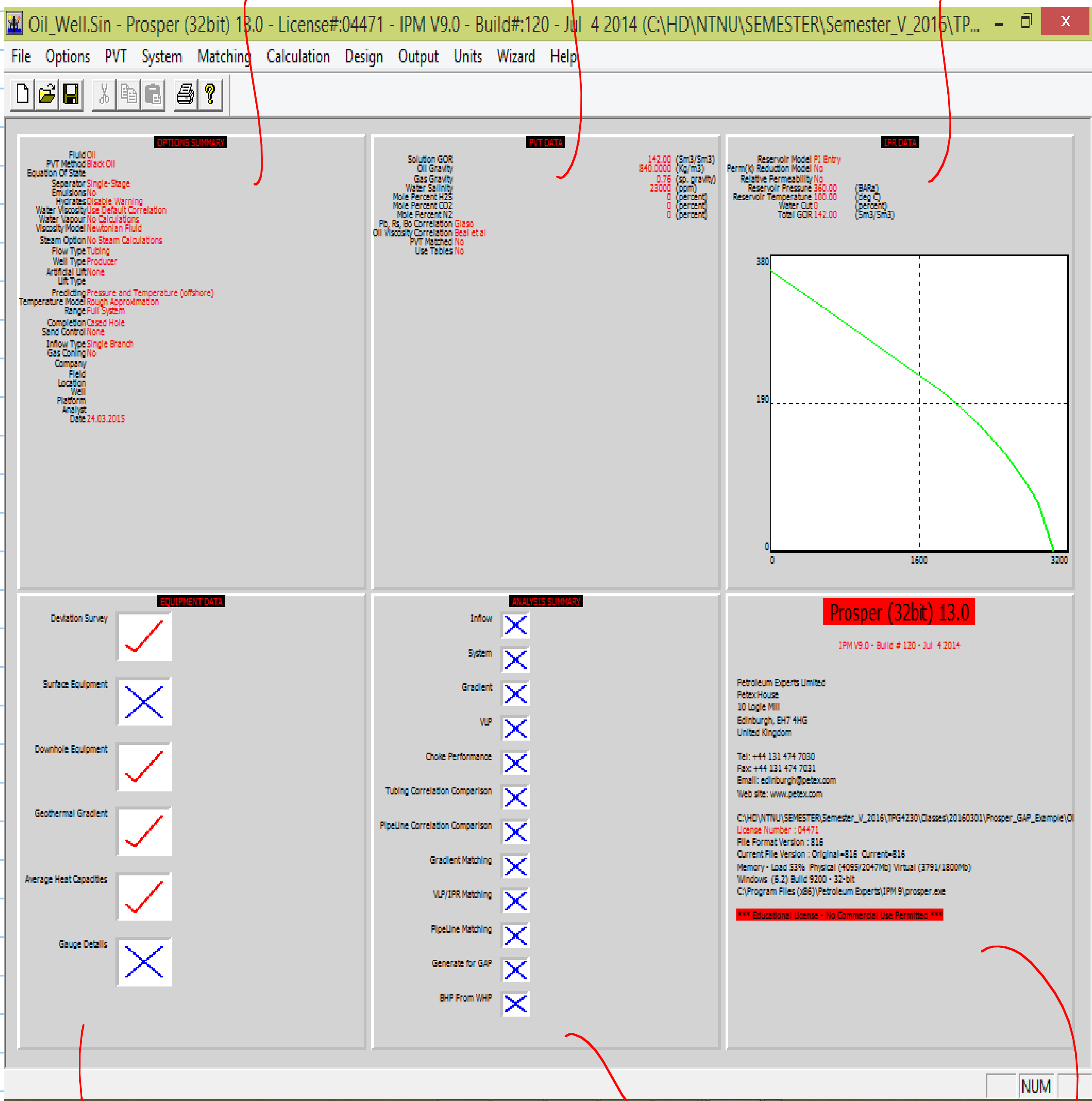
Prosper (PETEX, petroleum experts) → single well hydraulics

Oil_Well	Tpd	→ tubing table in gap format
Oil_Well	Sin	→ user input data
Oil_Well	Pvt	→ fluid properties
Oil_Well	Out	→ main file
Oil_Well	Anl	→ analysis file: results of the simulations

general info

fluid properties

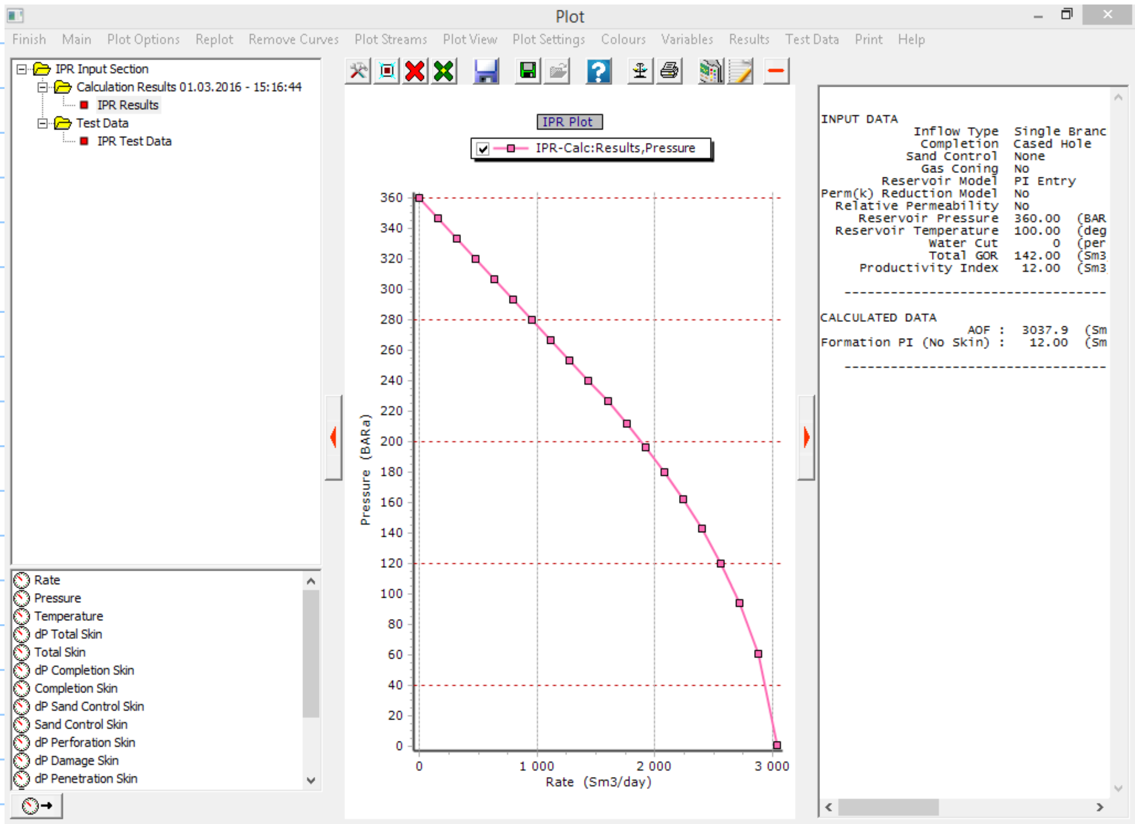
IPR

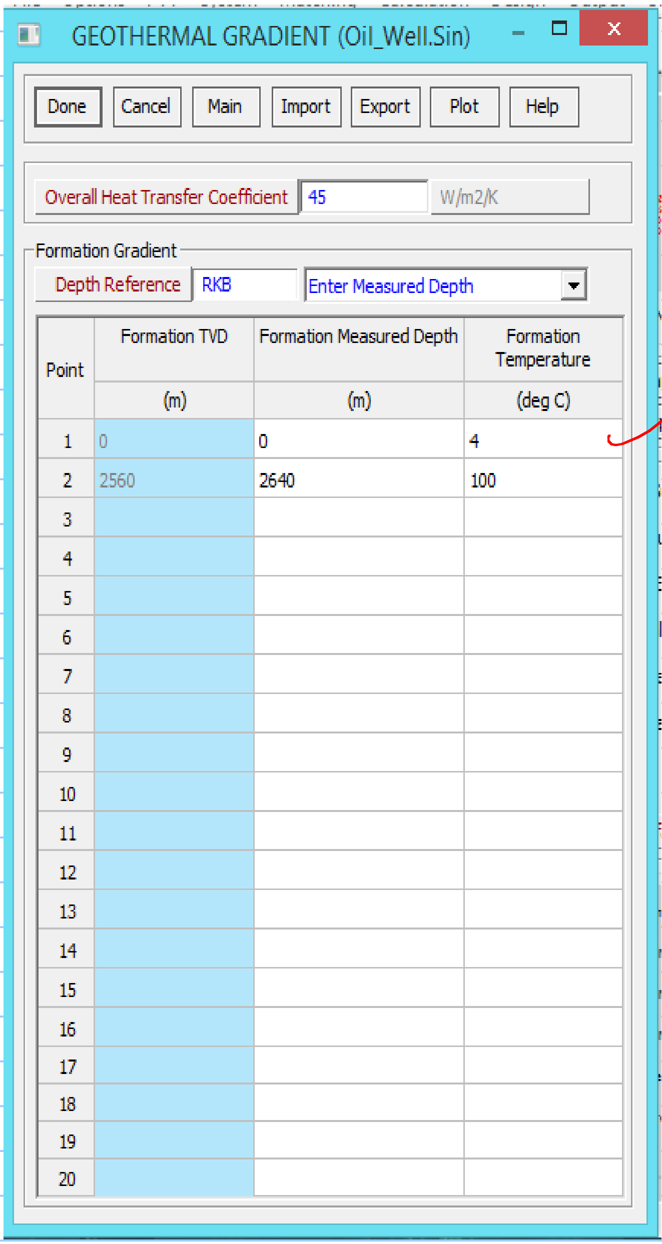


well layout and lifting equipment

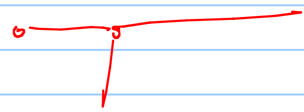
analysis and calculations

license info.

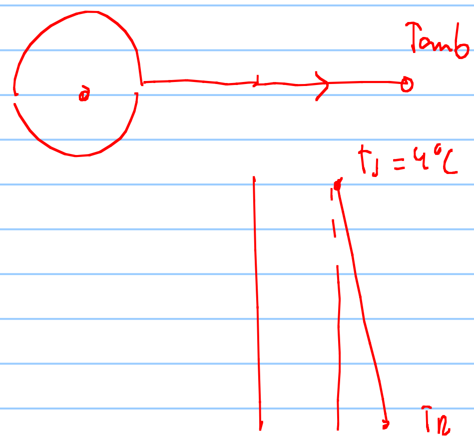


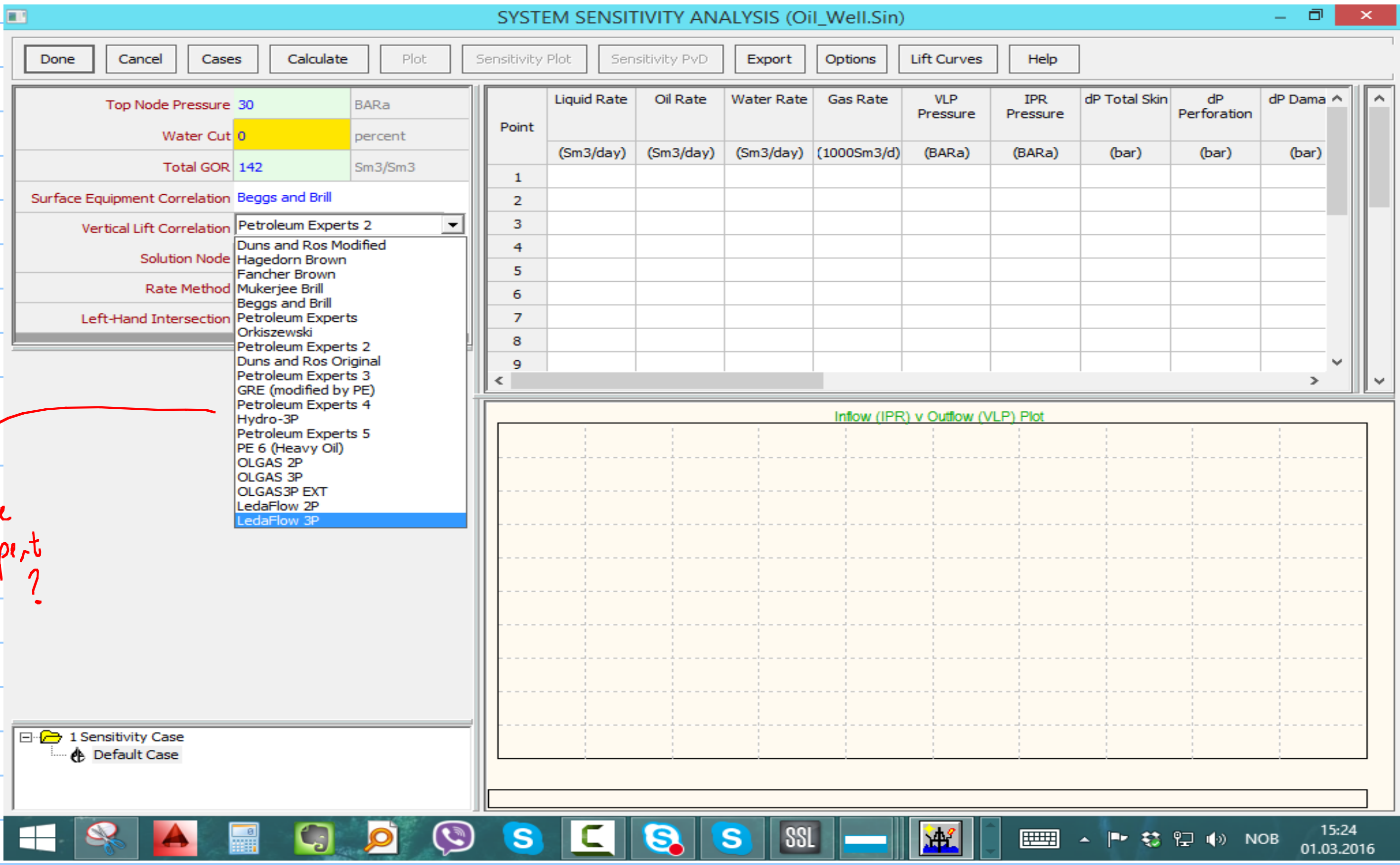


Point	Formation TVD (m)	Formation Measured Depth (m)	Formation Temperature (deg C)
1	0	0	4
2	2560	2640	100
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			



ambient temperature used for heat transfer calculations

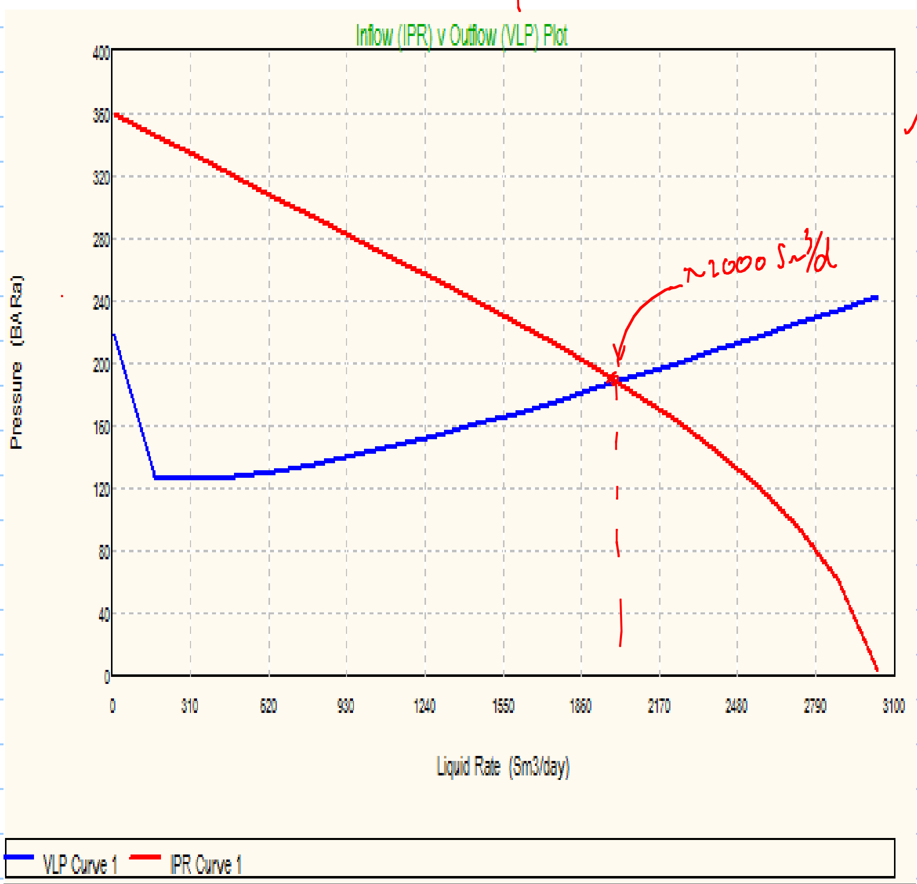




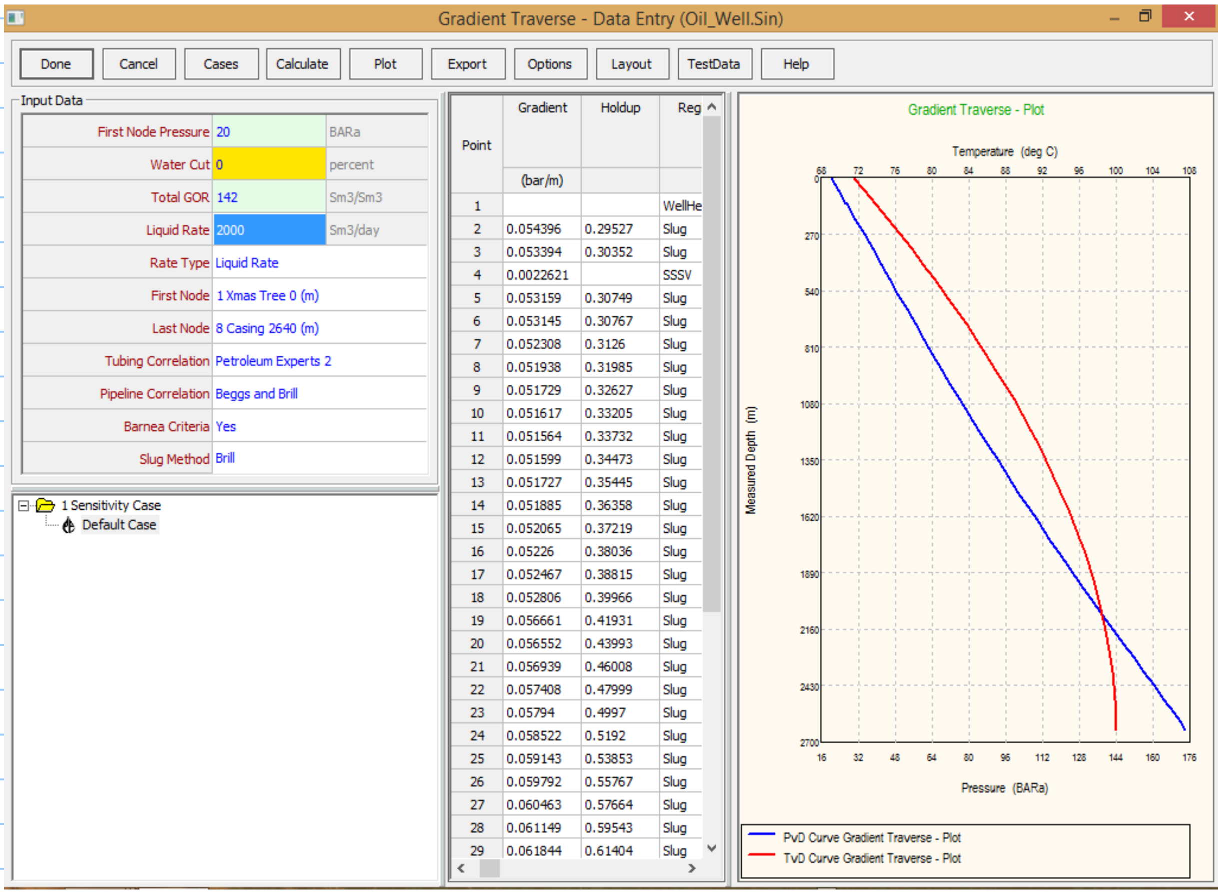
which multiphase flow expert to use ?

vertical lift performance

equilibrium at bottom-hole



"gradient"



Point	Gradient (bar/m)	Holdup	Reg
1			WellHe
2	0.054396	0.29527	Slug
3	0.053394	0.30352	Slug
4	0.0022621		SSSV
5	0.053159	0.30749	Slug
6	0.053145	0.30767	Slug
7	0.052308	0.3126	Slug
8	0.051938	0.31985	Slug
9	0.051729	0.32627	Slug
10	0.051617	0.33205	Slug
11	0.051564	0.33732	Slug
12	0.051599	0.34473	Slug
13	0.051727	0.35445	Slug
14	0.051885	0.36358	Slug
15	0.052065	0.37219	Slug
16	0.05226	0.38036	Slug
17	0.052467	0.38815	Slug
18	0.052806	0.39966	Slug
19	0.056661	0.41931	Slug
20	0.056552	0.43993	Slug
21	0.056939	0.46008	Slug
22	0.057408	0.47999	Slug
23	0.05794	0.4997	Slug
24	0.058522	0.5192	Slug
25	0.059143	0.53853	Slug
26	0.059792	0.55767	Slug
27	0.060463	0.57664	Slug
28	0.061149	0.59543	Slug
29	0.061844	0.61404	Slug

$$q = J(P_R - P_{wf})$$

undersaturated oil + water

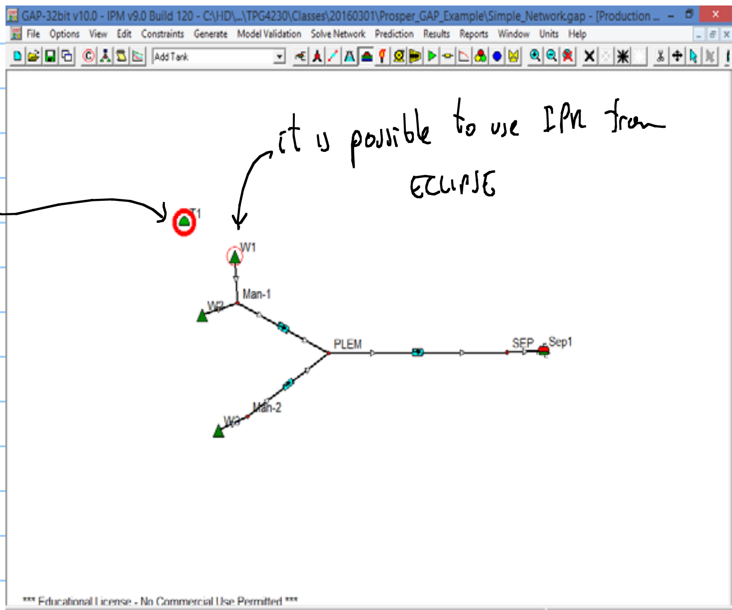
J is for total liquid.

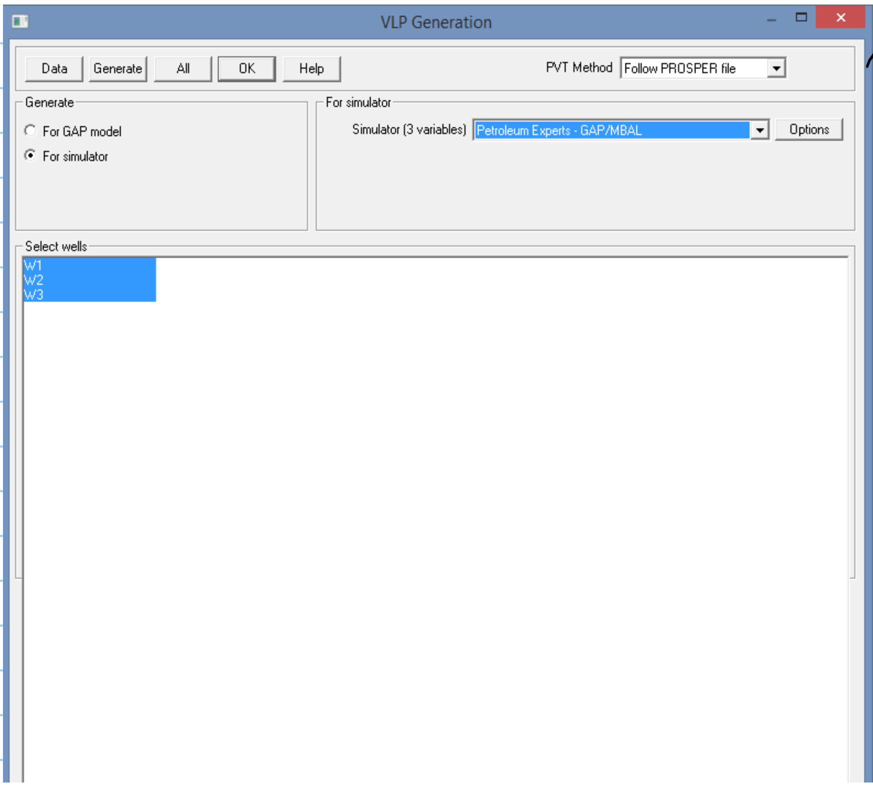
Simple_Network gap

tank model representing reservoir

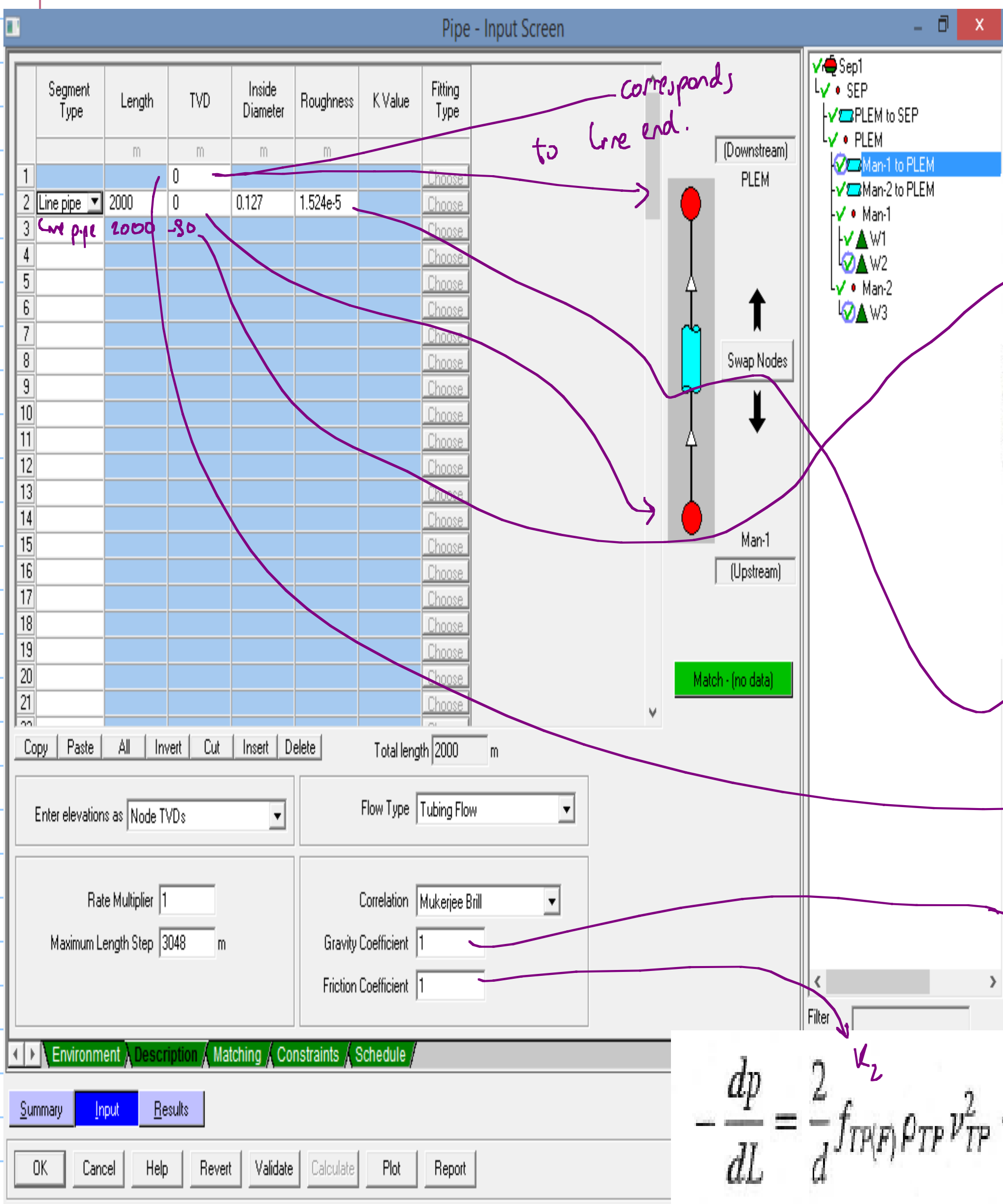
MBAL

it is possible to use IPR from ECLIPSE



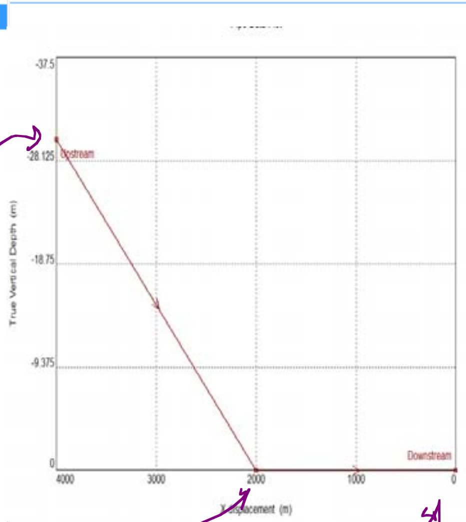


batch generation of tubing tables from GAP



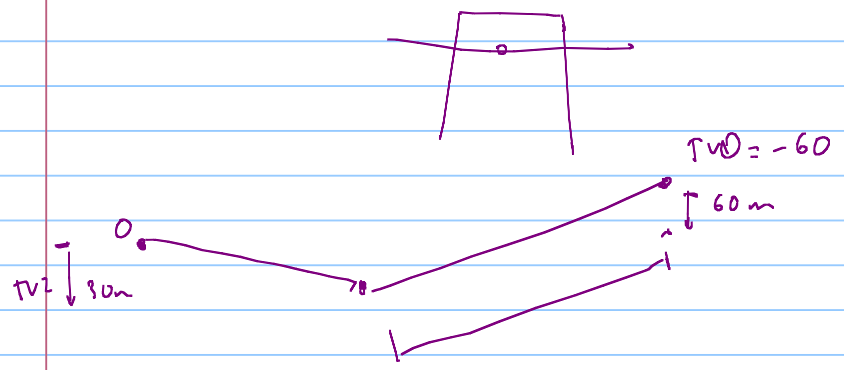
Line pipe 2000 -90

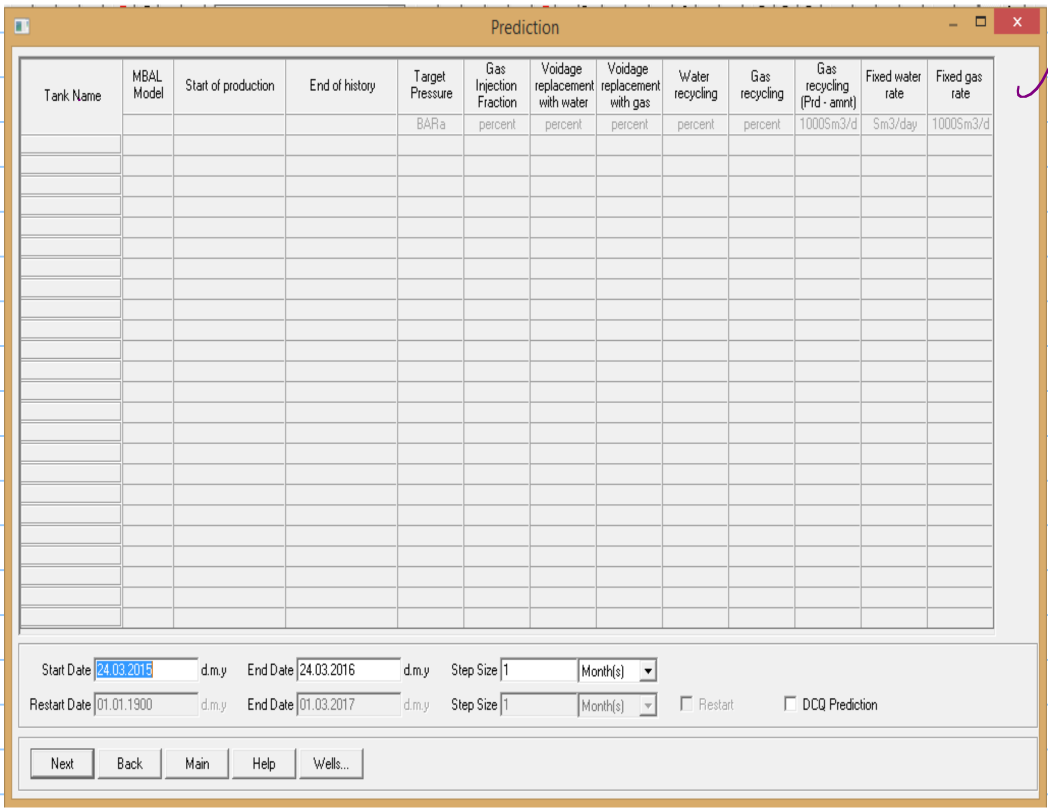
corresponds to line end.



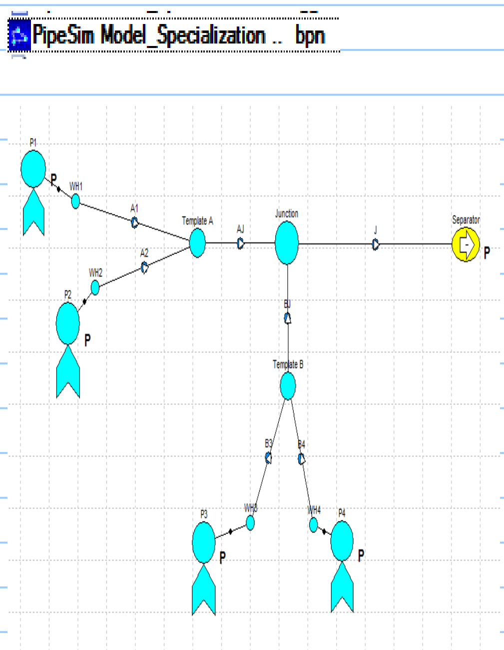
K_2 K_1

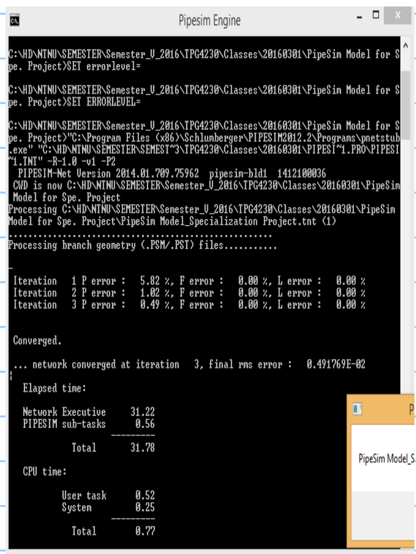
$$-\frac{dp}{dL} = \frac{2}{d} f_{TP(F)} \rho_{TP} v_{TP}^2 + \rho_{TP}\, g \sin\theta + \rho_{TP} v_{TP} \frac{dv_{TP}}{dL},$$



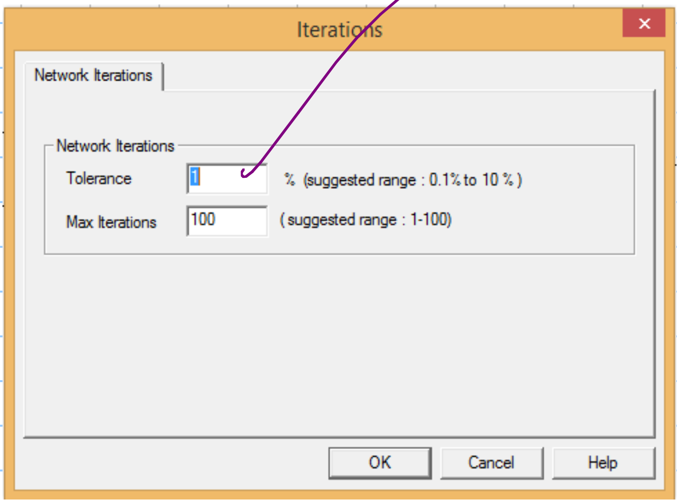


running GAP with MBAL: similar to what we have done in excel.



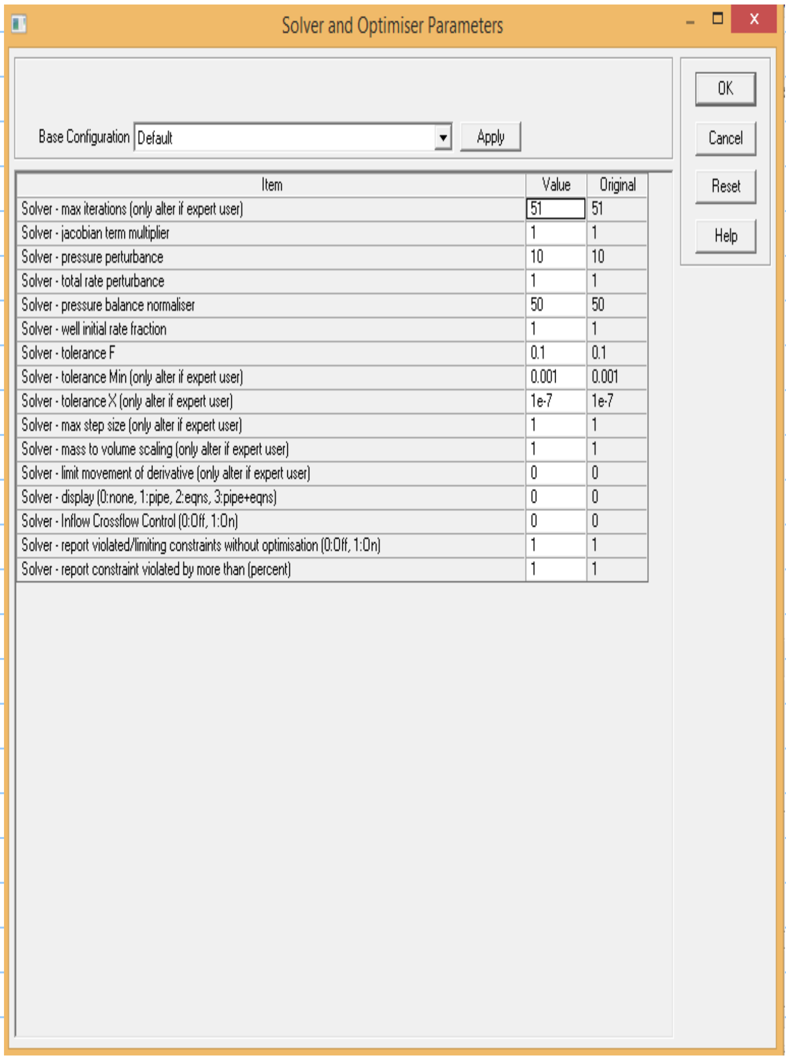


tolerance ~ we use different tolerances until the results stop changing.



↓ TOL more iterations

↑ TOL less iterations


Solver and Optimiser Parameters

Base Configuration Default Apply

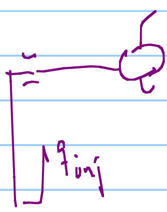
OK Cancel Reset Help

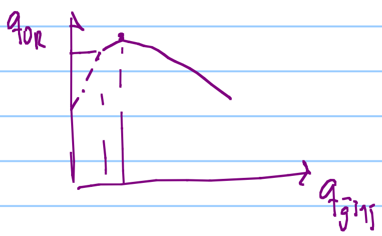
Item	Value	Original
Solver - max iterations (only alter if expert user)	51	51
Solver - jacobian term multiplier	1	1
Solver - pressure perturbance	10	10
Solver - total rate perturbance	1	1
Solver - pressure balance normaliser	50	50
Solver - well initial rate fraction	1	1
Solver - tolerance F	0.1	0.1
Solver - tolerance Min (only alter if expert user)	0.001	0.001
Solver - tolerance X (only alter if expert user)	1e-7	1e-7
Solver - max step size (only alter if expert user)	1	1
Solver - mass to volume scaling (only alter if expert user)	1	1
Solver - limit movement of derivative (only alter if expert user)	0	0
Solver - display (0:none, 1:pipe, 2:eqns, 3:pipe+eqns)	0	0
Solver - Inflow Crossflow Control (0:Off, 1:On)	0	0
Solver - report violated/limiting constraints without optimisation (0:Off, 1:On)	1	1
Solver - report constraint violated by more than (percent)	1	1

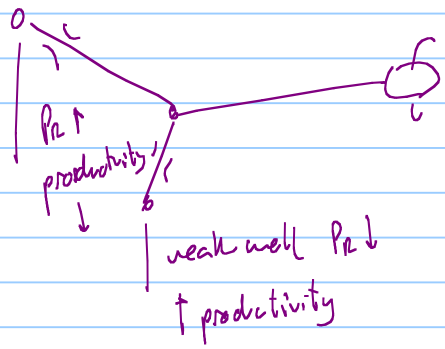
IAM integrated asset modeling

to integrate reservoir + production modes ~> Resolve (petex)

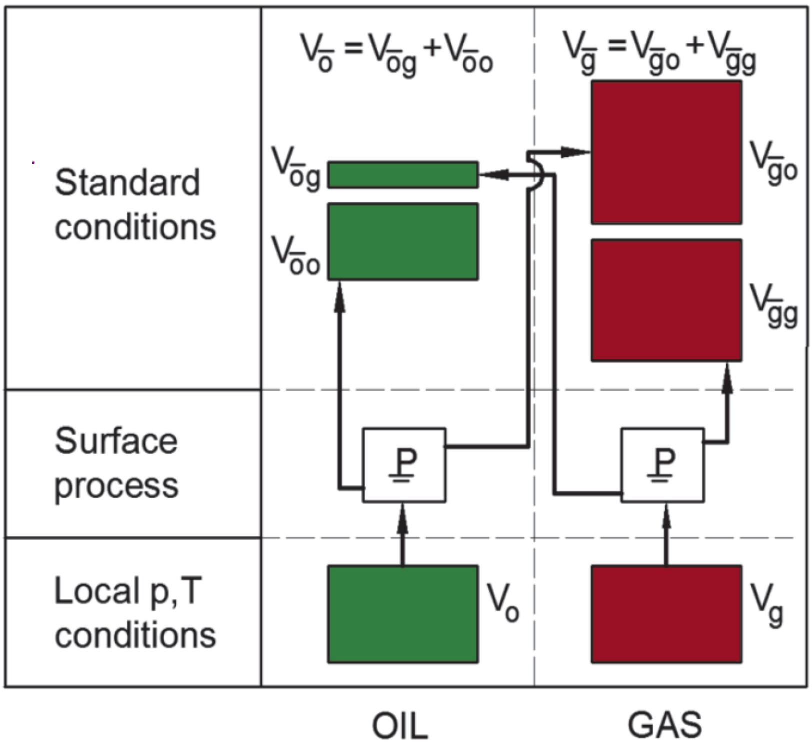
↳ IAM Avocet (Schlumberger) eclipse, pipesim







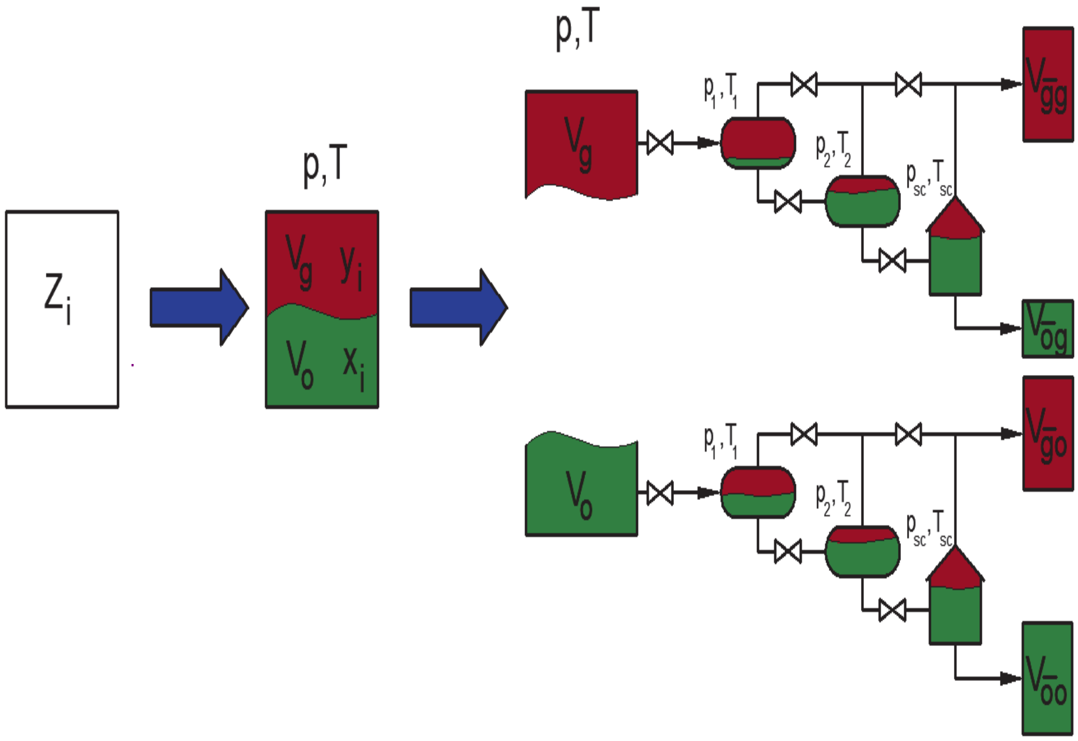
BO Approach: (2 components oil and gas)



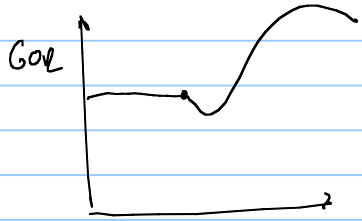
BO Variable	Definition
Oil Volume Factor	$B_o(p,T) = \frac{V_o(p,T)}{V_{\bar{o}o}}$
Gas Volume Factor	$B_g(p,T) = \frac{V_g(p,T)}{V_{\bar{g}g}}$
Solution Gas Oil Ratio	$R_s(p,T) = \frac{V_{\bar{g}o}}{V_{\bar{o}o}}$
Solution Oil Gas ratio	$r_s(p,T) = \frac{V_{\bar{o}g}}{V_{\bar{g}g}}$

where do i get these properties from?

$\begin{bmatrix} q_{\bar{g}} \\ q_{\bar{o}} \\ q_{\bar{w}} \end{bmatrix} = \begin{bmatrix} \frac{1}{B_g} & \frac{R_s}{B_o} & 0 \\ \frac{r_s}{B_g} & \frac{1}{B_o} & 0 \\ 0 & 0 & \frac{1}{B_w} \end{bmatrix}_{(p,T)} \cdot \begin{bmatrix} q_g \\ q_o \\ q_w \end{bmatrix}$	$\begin{bmatrix} q_g \\ q_o \\ q_w \end{bmatrix} = \begin{bmatrix} \frac{B_g}{1-R_s \cdot r_s} & \frac{-B_g \cdot R_s}{1-R_s \cdot r_s} & 0 \\ \frac{-B_o \cdot r_s}{1-R_s \cdot r_s} & \frac{B_o}{1-R_s \cdot r_s} & 0 \\ 0 & 0 & B_w \end{bmatrix}_{(p,T)} \cdot \begin{bmatrix} q_{\bar{g}} \\ q_{\bar{o}} \\ q_{\bar{w}} \end{bmatrix}$
Standard conditions calculated from local conditions	Local conditions calculated from standard conditions

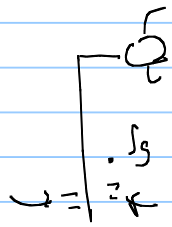


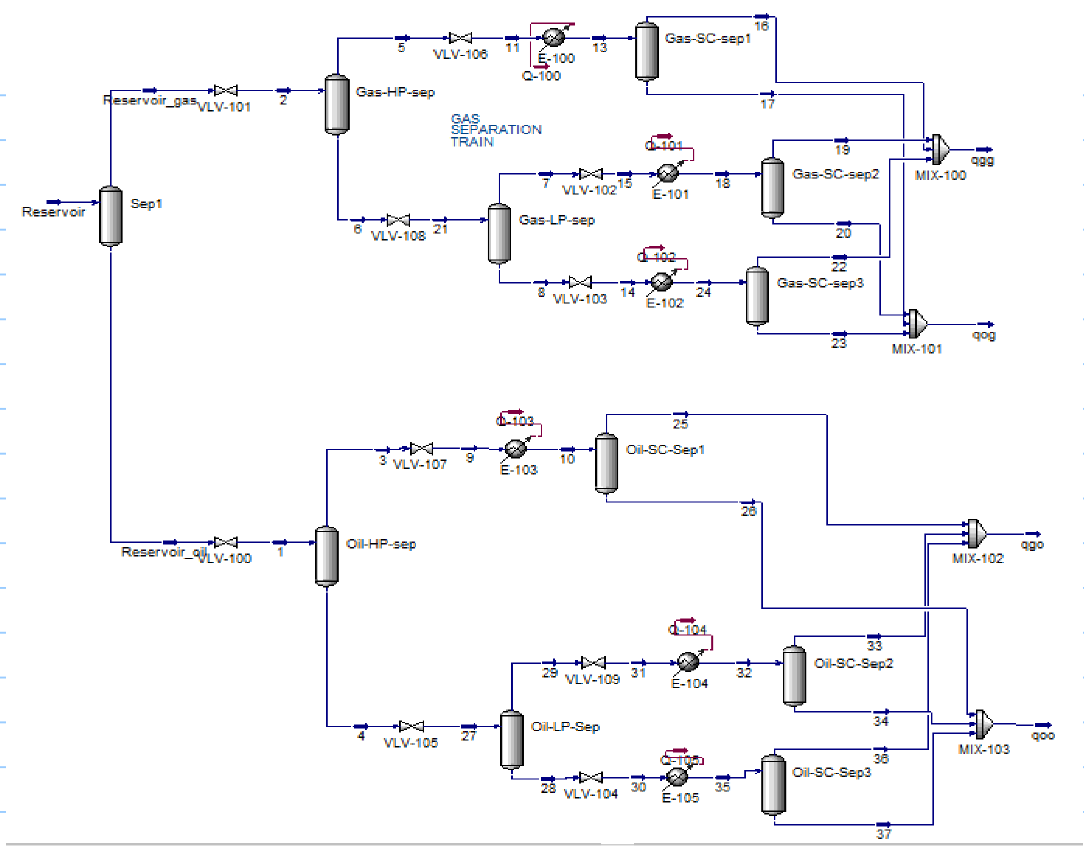
well
GOR = f(t)



→ z_i changes with time

if GOR changes then the composition changes





$T = T_1$

P	B_o	B_g	R_s	r_s
P_1	B_{o1}	B_{g1}	R_{s1}	r_{s1}
P_2	B_{o2}	B_{g2}	R_{s2}	r_{s2}
P_3	B_{o3}	B_{g3}	R_{s3}	r_{s3}
P_4	B_{o4}	B_{g4}	R_{s4}	r_{s4}

γ_{os}	M_o	M_g

$T = T_2$

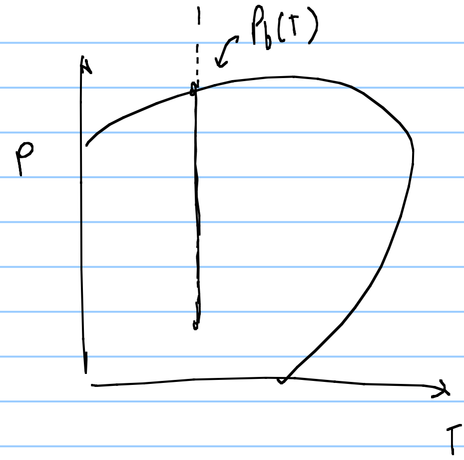
P	B_o	B_g	R_s	r_s
P_1	B_{o1}	B_{g1}	R_{s1}	r_{s1}
P_2	B_{o2}	B_{g2}	R_{s2}	r_{s2}
P_3	B_{o3}	B_{g3}	R_{s3}	r_{s3}
P_4	B_{o4}	B_{g4}	R_{s4}	r_{s4}

$T = T_3$

P	B_o	B_g	R_s	r_s
P_1	B_{o1}	B_{g1}	R_{s1}	r_{s1}
P_2	B_{o2}	B_{g2}	R_{s2}	r_{s2}
P_3	B_{o3}	B_{g3}	R_{s3}	r_{s3}
P_4	B_{o4}	B_{g4}	R_{s4}	r_{s4}

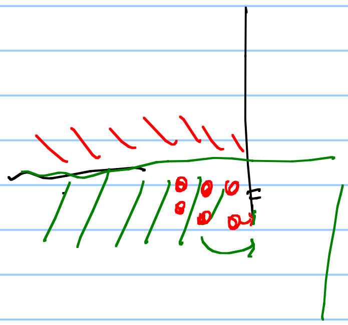
$\begin{bmatrix}\rho_{\bar{g}}\\ \rho_{\bar{o}}\\ \rho_{\bar{w}}\end{bmatrix}=\begin{bmatrix}\frac{B_g}{1-r_s\cdot R_s} & \frac{-r_s\cdot B_o}{1-r_s\cdot R_s} & 0\\ \frac{-R_s\cdot B_g}{1-r_s\cdot R_s} & \frac{B_o}{1-r_s\cdot R_s} & 0\\ 0 & 0 & B_w\end{bmatrix}_{(p,T)}\cdot\begin{bmatrix}\rho_g\\ \rho_o\\ \rho_w\end{bmatrix}$	$\begin{bmatrix}\rho_g\\ \rho_o\\ \rho_w\end{bmatrix}=\begin{bmatrix}\frac{1}{B_g} & \frac{r_s}{B_g} & 0\\ \frac{R_s}{B_o} & \frac{1}{B_o} & 0\\ 0 & 0 & \frac{1}{B_w}\end{bmatrix}_{(p,T)}\cdot\begin{bmatrix}\rho_{\bar{g}}\\ \rho_{\bar{o}}\\ \rho_{\bar{w}}\end{bmatrix}$
Standard conditions calculated from local conditions	Local conditions calculated from standard conditions

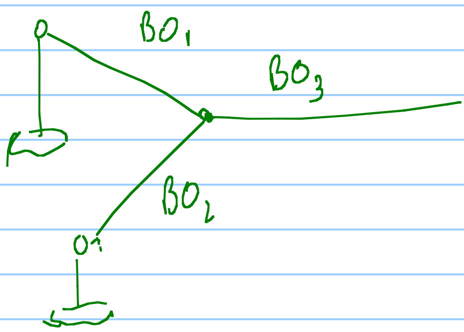
usually there is a change of trend in BO properties at the saturation pressure



Usually if changes in GOR are caused by changes of flow of reservoir oil and reservoir gas

I can use the same BO tables, just changing the saturation properties according to the GOR.





BO correlations

$\gamma_{\bar{o}}, \gamma_{\bar{g}}$

Standing

Glasø

Bubble Point Pressure

$$P_b = 18.2\left[\left(R_s/S_g\right)^{0.83}(10)^a - 1.4\right]$$

where

a = 0.00091T - 0.0125(API)

P_b = bubble point pressure, psia

R_s = solution gas to oil ratio SCF/STB

T = Temperature, °F

$$B_o = 0.9759 + \overset{k_1}{0.000120}\left[R_s\left(S_g/S_o\right)^{0.5} + 1.25T\right]^{1.2} \; k_2$$