Integrated Model Optimization

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Integrated Model Optimization

- Two-day seminar (Jan. 29-30, 2009 ?).
- All CIO participants welcome.
- No fee?
- Lectures, simple Excel problems.
- Introduction to *Pipe-It*.

Seminar Contents

- Traditional Modeling.
- Model Integration.
- Optimization.

Model

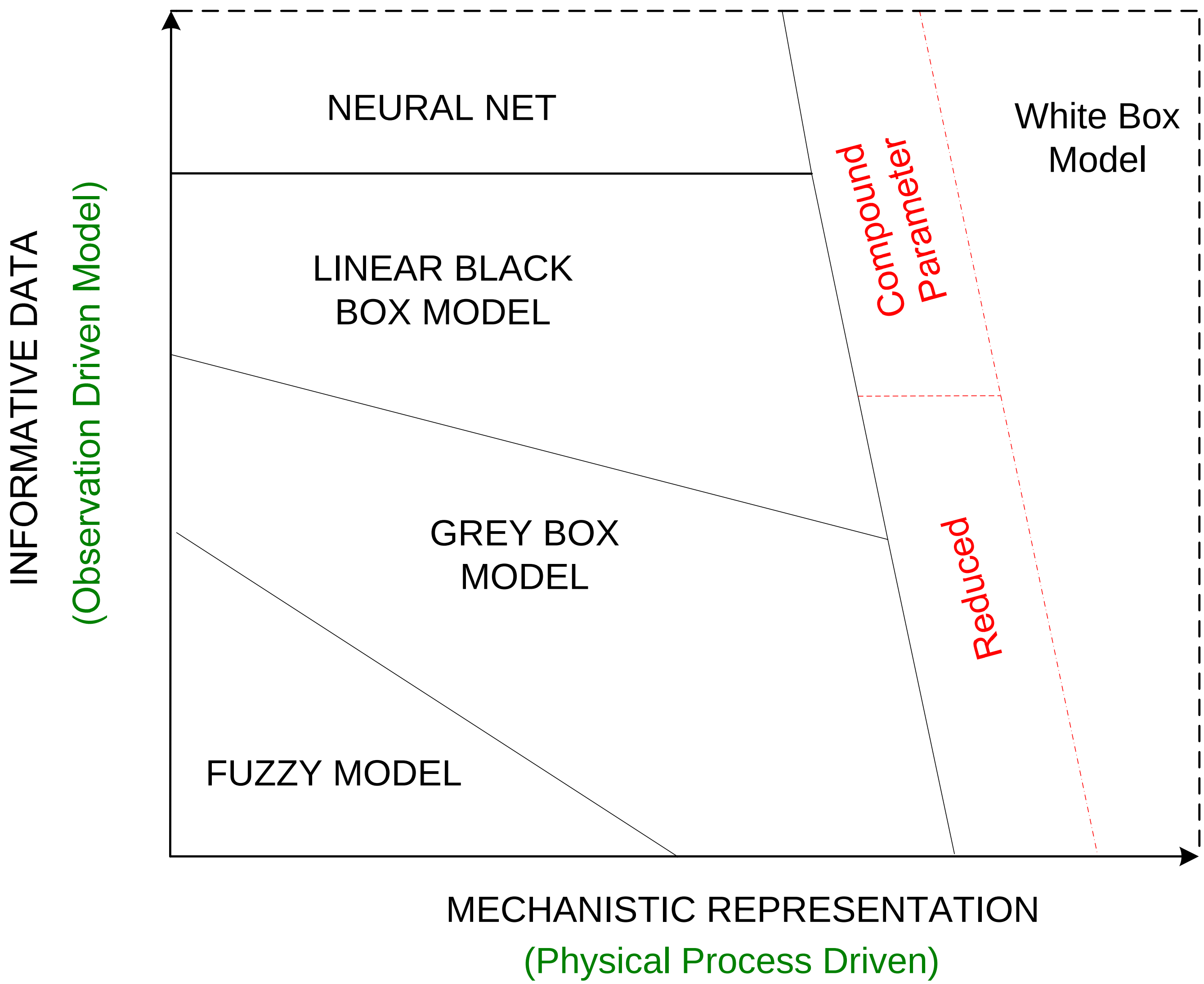
- A mathematical representation of a physical process.
  - Mathematical formulation and IT implementation.
  - Model parameters defining a specific case.

- “Simulator” might be a better term.
  - Simulator might be confused with “reservoir simulator” terminology…?
  - Model being the particular input data to a simulator for a particular case.

Traditional Modeling

- Model Types.
  - Theoretical.
  - Empirical.
  - Equation-based.
  - Graphical.
  - Integer.
  - Mixed Integer.
  - Tabular (e.g. piece-wise linear).
  - Map of model types.

Map of Model Types



Traditional Modeling

- Theoretical.
  - Based on physical laws.
    - Transport.
    - Conservation.
    - Equilibrium
- Empirical
  - Arps rate-decline equation.
  - Standing PVT correlations.

Traditional Modeling

- Model Issues.
  - Direct Solution.
  - Iterative Solution.
  - Multi-level Iterative.
  - Model Parameters.
  - Parameter Estimation.
  - Parameter Tuning / Modification.

Model Integration

- Direct Coupling.
- Tight Coupling.
- Loose Coupling.
- Sequential.
- Parallel.
- Connectivity.
- Nesting, Branching, Looping.

Optimization

- Objective (Target, Goal).
  - Minimize, Maximize, Feasible.
  - Weight factors.
  - Scaling.
- Parameters.
- Constraints.
- Global vs Local.
- Nested.
- Derivatives based.
- Non-derivatives based.
- Soft “fuzzy” optimization (Bjarne ?).

Introductory Issues

What are we talking about?

Computational

- Having to do with numbers.
- Number crunching.
- Algorithms and numerical methods.
- Convergence and tolerance.
- Computer programs – software.
- Computer platforms.
- Computers

- Hard numbers, not “soft integration”.

Integration

- Linking together separate elements of a system.

Holistic

- The value of a system of many elements is far greater than the sum of the values from each element alone.

Holistic

A wide-reaching term, designating views in which the individual elements of a system are determined by their relations to all other elements of that system. Being highly relational, holistic theories do not see the sum of the parts as adding up to the whole. In addition to the individual parts of a system, there are "emergent," or "arising," properties that add to or transform the individual parts. As such, holistic theories claim that no element of a system can exist apart from the system in which it is a part. Holistic theories can be found in philosophical, religious, social, or scientific

Computational Integration – What?

- Linking numbers representing different parts of a system.
- Linking software used by different parts of a system.
- Linking numerical methods used by different parts of a system.
- Linking computers used by different parts of a system.

Computational Integration – Why?

- To study the cause-and-effect of “controllable numbers” on “other calculated numbers”.

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  - "controllable number" = (e.g.) number of wells.

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- To study the cause-and-effect of “controllable numbers” on “other calculated numbers”.
  - “controllable number” = (e.g.) number of wells.
  - “other calculated numbers” = (e.g.)
    - Recoveries and revenues.
    - Flowline dimensions and costs.
    - Number of platforms and costs.
    - Net present value.

Optimization – How?

- Numerical Optimization.
  - Use automated solvers to change "controllable numbers" within limits to maximize one of the "other calculated numbers".

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  - Use automated solvers to change “controllable numbers” within limits to maximize one of the “other calculated numbers”.

- Sensitivity & Uncertainty Analysis.
  - Statistical.
  - Change “controllable numbers” in a systematic manner to study impact on a collection of key “other calculated numbers”.

Integrated Optimization – How?

- Computers.

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- Number-handshaking – *Translators*.

Integrated Optimization – How?

- Computers.
- Build “number-carrying” pipeline layout.
- User interface – *GUI*.
- Links to all “numbers” – *R/W Linker*.
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- Model-orchestrating software – *Runner*.

Integrated Optimization – How?

- Computers.
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- User interface – *GUI*.
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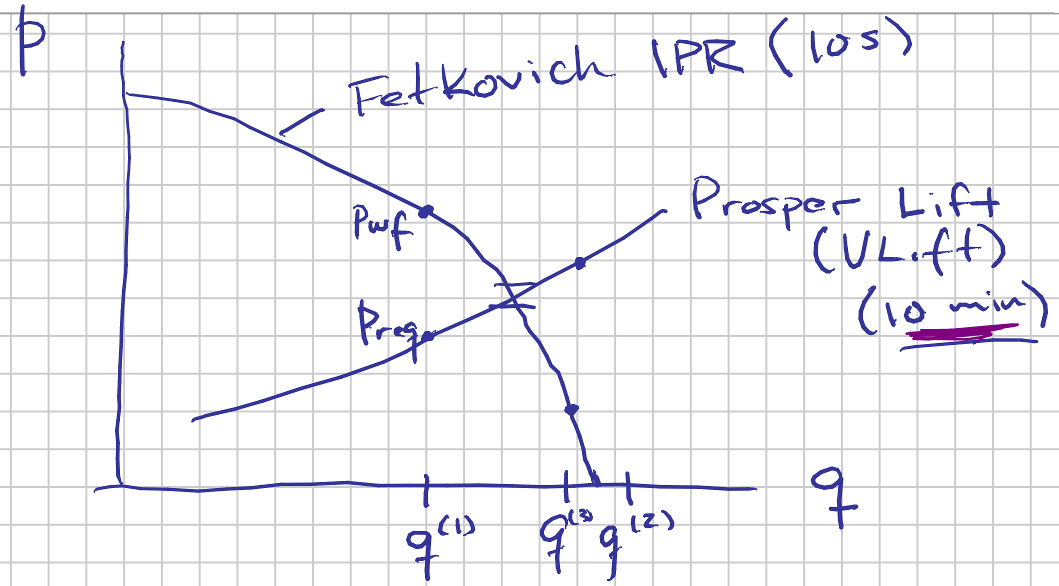
- Model-orchestrating software – *Runner*.
- Optimization – *Solvers*.

Note Title 1/29/2009



Goal Seek: $\Delta p = p_{wf}^{(q)} - p_{req}^{(q)}$

$\Delta p \to 0 \ (\epsilon)$

$\Delta p(q)$

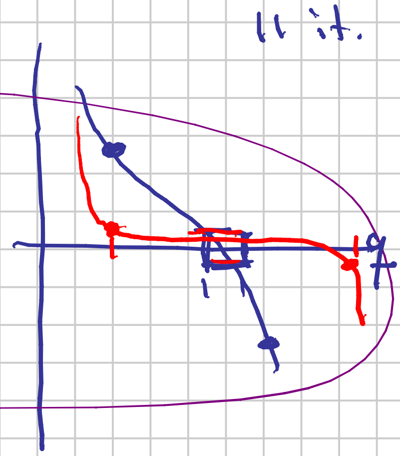
10^{-10}

↓

1 bbl/D

1 psi

Δp



$q_w \pm 1$ bbl/D

10^{-6}

q_w 10 wells ⇒ $f(V)$

Network of 10 wells

GAS FIELD

Rate Equation (R+T)

$$B\,q_{gw}^{2} + A\,q_{gw} - \left(P_c^2 - P_t^2\right) = 0$$

P_c → $P_{ci}(1-RF_{12})$

P_t ← $P_{tmin} = P_{sp}$

Direct Solution IPR + VL

- $B\,q_{gw}^2$: Tubing (ΔP_T)
- $A\,q_{gw}$: Reservoir ΔP_R
- $(P_c^2 - P_t^2)$: Total ΔP

$$B \propto \frac{1}{d_T^{2.6}} \qquad A \propto \frac{8+s}{kh}$$

Field Gas Contract

G_p at end plateau $= G \cdot t_p \cdot 0.04$ (RF/yr)

Simple Mat. Balance:

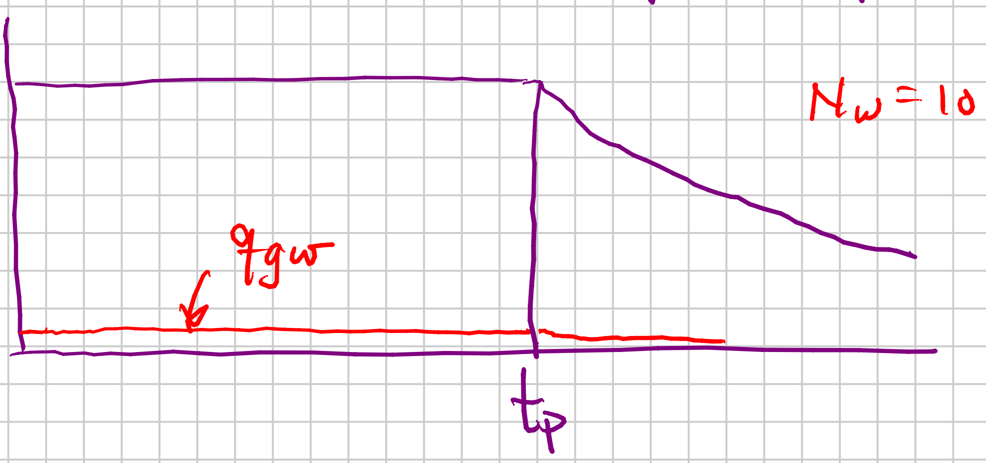
$$P_c = P_{ci}\left(1 - \frac{G_p}{G}\right)$$

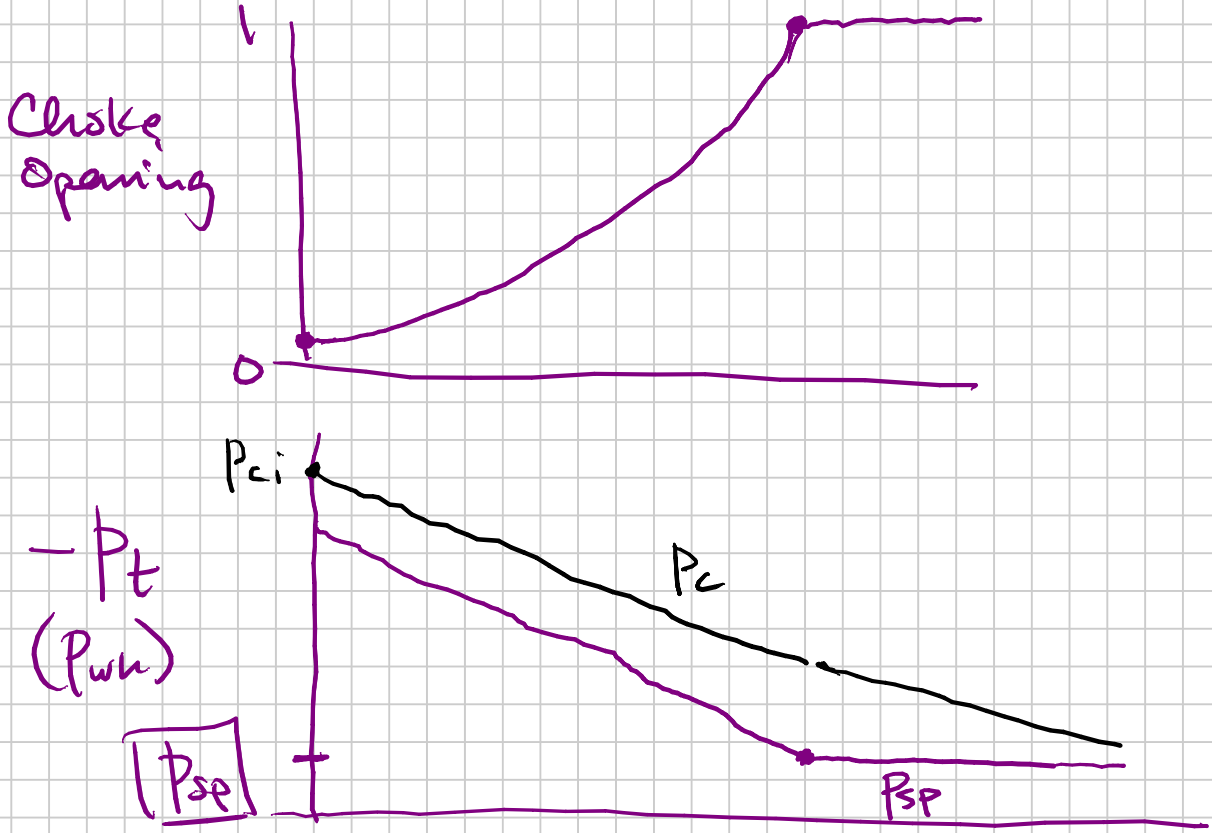
Avg Press Res.

1st order model

What happens at end of the plateau?

$q_{gF} = q_{gw} \times N_w$





$$q_{gw}^* @ t_p = f(\underline{RF} @ t_p, \underline{P_{tmin}})$$

$$q_{gF} @ t_p = \underbrace{0.04\,\bar{G}}/365$$

$$N_w = \frac{q_{gF}}{q_{gw}^*}$$

$$A = \frac{\ln \frac{r_e}{r_w} + S}{Kh} = \frac{8/\sqrt{N_w} + S}{Kh}$$

$$r_e = \sqrt{\frac{A_F}{\pi N_w}} = c \frac{1}{\sqrt{N_w}}$$

$N_w = 10$ ~~$r_e^* \approx 3000$~~

2nd order effect – ignore

$$\ln \frac{r_e}{r_w} = \underbrace{\ln}_{8} \left\{ \frac{r_e^*}{r_w} \cdot \frac{1}{\sqrt{N_w}} \right\}$$

$$= \ln \frac{r_e^*}{r_w} - \ln \sqrt{N_w}$$

$$\ln \frac{r_e}{r_w} = 8 - \frac{1}{2} \ln \frac{N_w}{10}$$

Max. 7" tubing I.D. 6" × 25.4 $\frac{mm}{in}$ (Drilling Const)

Max Wells 30 (Economic Const)

G_{min} required to develop this field?

$$G_{min} = \frac{6.04 \cdot 10^{11}}{} \text{ Sm}^3$$

Variable G

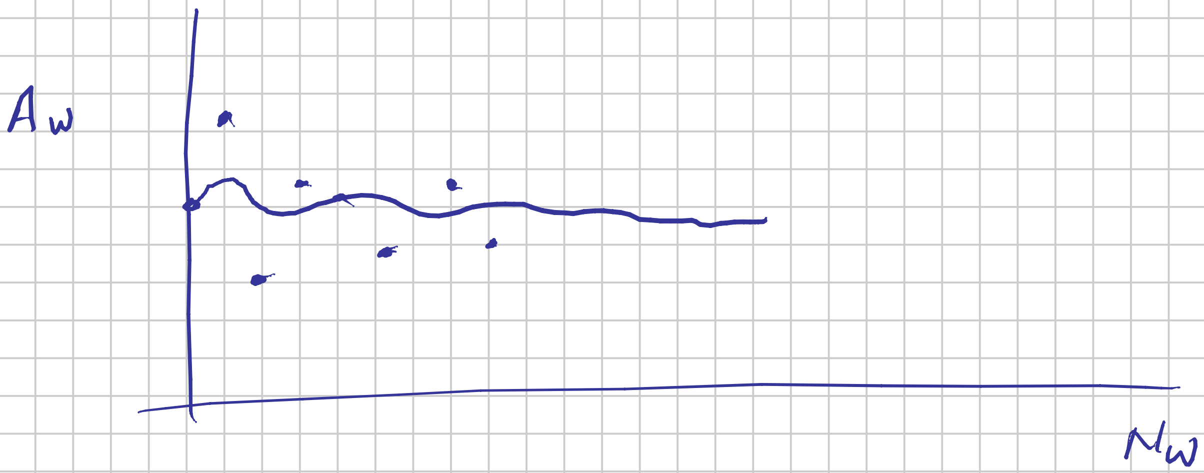
Set $d_T = 150$ mm

Obj Target = $N_w = 30$

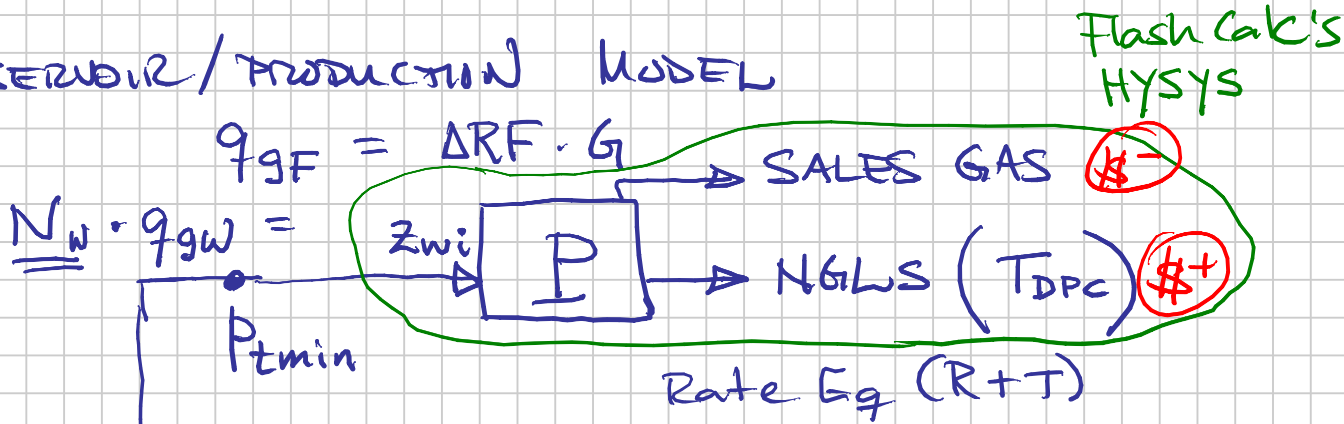
$$q_{gF} = 5 \cdot 10^7 \text{ Sm}^3/d$$

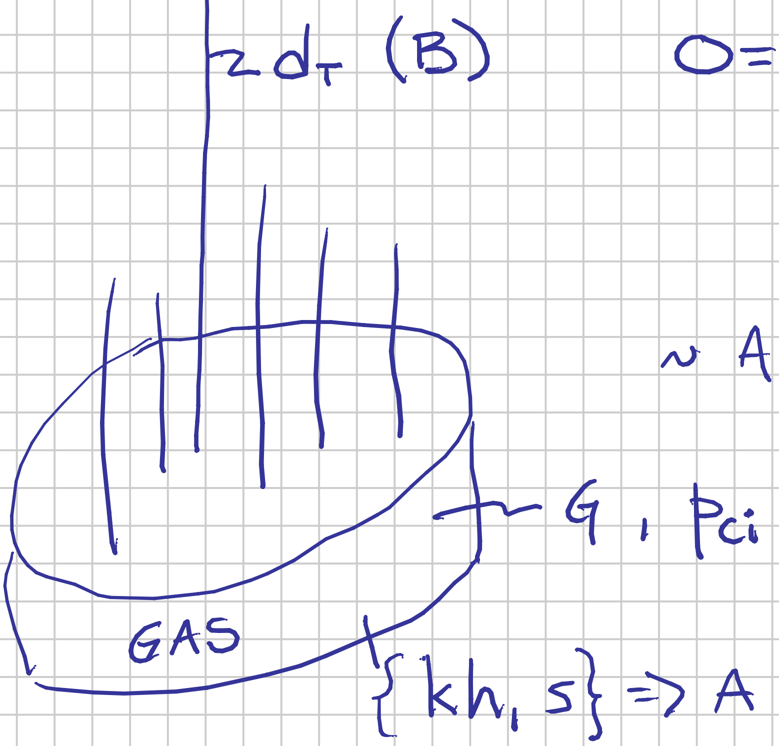
$$G = \frac{q_{gF}}{\%/yr}$$

max %/yr = 5



RESERVOIR / PRODUCTION MODEL

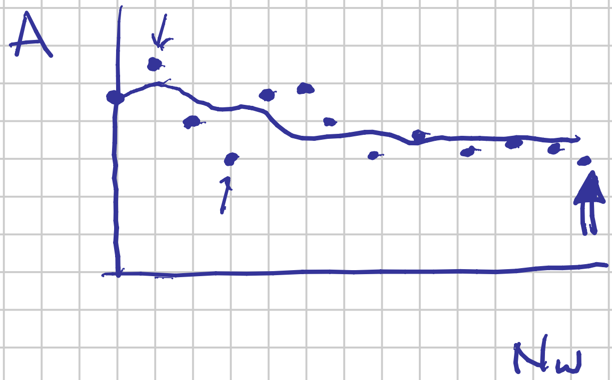


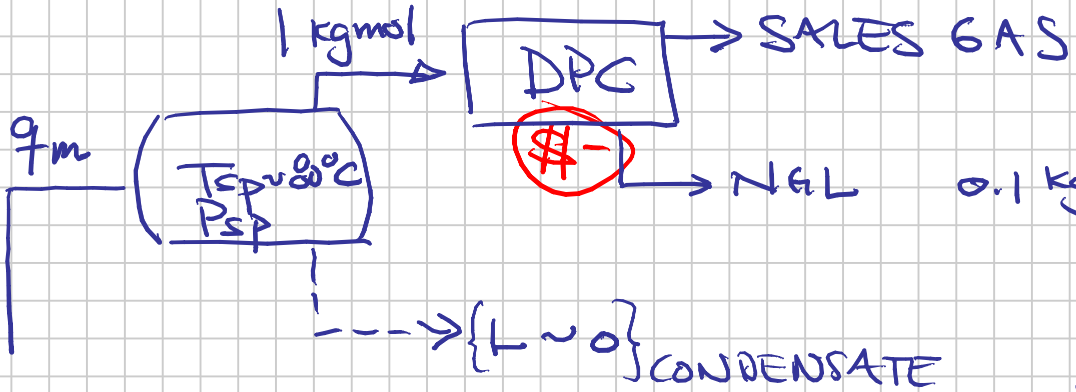


$$0 = B q_{gw}^2 + A q_{gw} - (P_c^2 - P_t^2)$$

$$P_c = P_{ci}(1 - RF)$$

~ All wells identical





$0.1 \text{ kgmole} \times f_{ngl}$

0 — 1

80°C   -40°C

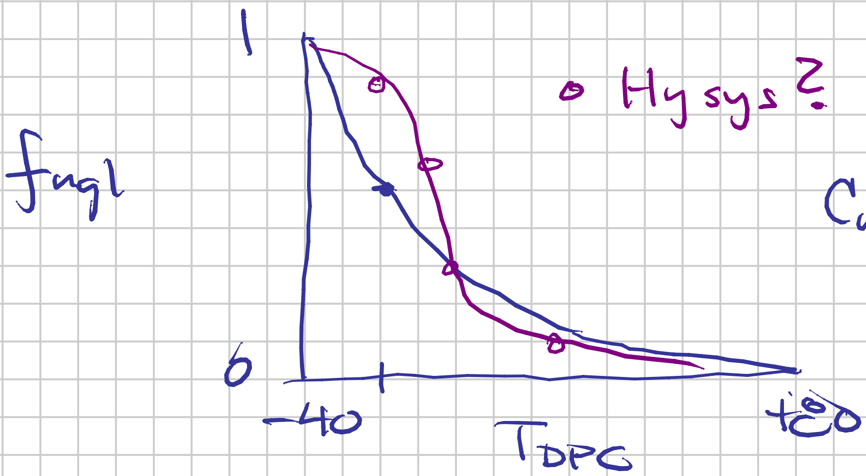
T_{DPC}

$$\underbrace{q_{gF} \cdot Z_{ngL} \cdot f_{ngL}}_{Sm^3/d}$$

$$\underset{m^3/d}{q_{NGL}} = q_{gF} \cdot Z_{ngL} \cdot f_{ngL} \cdot C_{ngl}$$

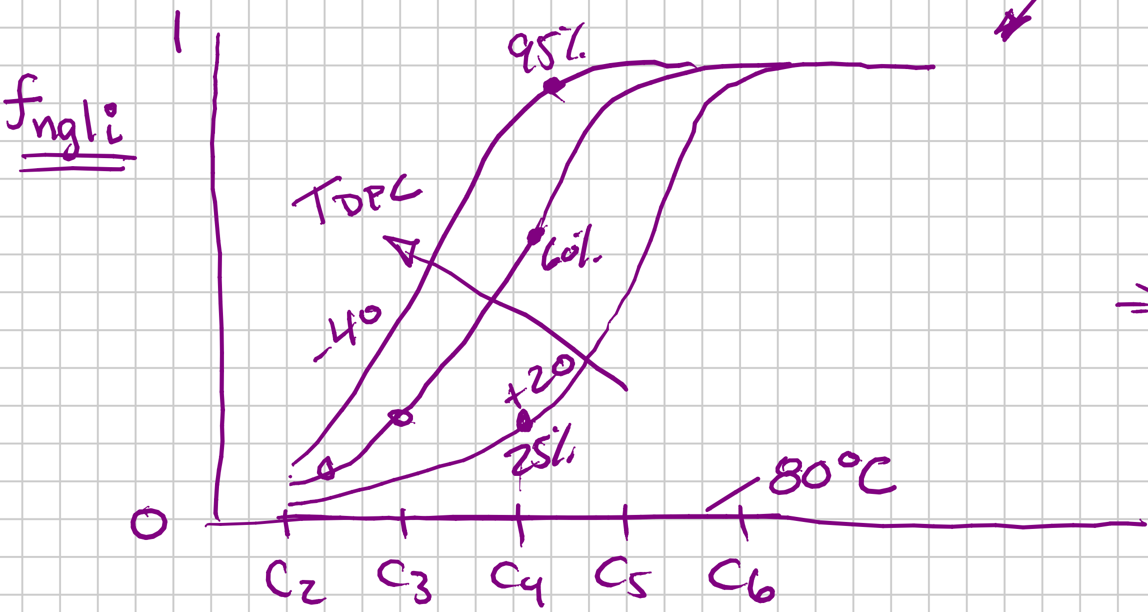
$$f_{ngl} = (1 - T_n)^n$$

$$T_n \equiv \frac{T_{DPC} - T_{DPC\,min}}{T_{DPC\,max} - T_{DPC\,min}}$$



$$C_{ngl} = \frac{(M/\rho)_{ngL}}{23.64}$$

ngl : $C_2 - C_5$



$\Rightarrow \bar{f}_{ngl}$

$i \in \{C_2 - - - C_6\}$

Economics: Through t_p

$P_{gas} = \text{const}$

$P_{ngl} = \text{const}$

$q_g = \text{const thru } t_p$

$q_{ngl} = $ —— " ——

$$\text{Total Revenues} = \sum_{i=1}^{t_p} \Big(\underbrace{q_{gi} \cdot P_g}_{R_{gi}} + \underbrace{q_{ngl} \cdot P_{ngl}}_{R_{ngli}} \Big)$$

$$= G_{pdry} P_g + N_{ngl} \cdot P_{ngl}$$

DR

$$\text{Discounted Revenue} = \sum_{i=1}^{t_p} \left(R_{gi} + R_{ngli} \right) \frac{1}{(1+DF)^{i-1/2}}$$

$$NPV = DR - C_{Infra} - C_{wells} - C_{DPC}$$

...

	A	B	C	D
1	**RESERVOIR & PRODUCTION PROXY MODEL**			
2				
3				
4		Controllable	Numbers	
5				
6	Tubing diameter		300	mm
7				
8	Reservoir rate constant	A	1.00E-02	bara2/(Sm3/d)
9	Reference tubing rate const	B*	1.50E-09	bara2/(Sm3/d)2
10	Reference tubing diameter	dT*	125	mm
11	Initial gas in place	G	4.00E+11	Sm3
12	RF produced per year	RF/dt	0.06	1/yr
13	Plateau period	tp	8	yr
14	Initial pressure	pci	300	bara
15	Minimum flowing pressure	ptmin	60	bara

4		Controllable	Numbers	
5				
6	Dry gas price	Pgas	0.250	USD/Sm3
7	NGL price	Pngl	300	USD/m3
8	NPV discount factor	DF	0.1	
9	Well base cost	Cw	1.00E+08	USD
10	Well diameter factor	Fw	1.00	
11	Well diameter exponent	Ew	3.00	
12	DPC base cost	Cdpc	5.00E+08	USD
13	DPC temperature factor	Fdpc	1.00	
14	DPC temperature exponent	Edpc	2.00	
15	Infrastructure cost	Cinfra	1.00E+10	USD
16				

Fuel Model:

$q_{gas\,sales\ adj\ for\ fuel} = q_{gsales} \times \left[1 - 0.1\, f_{fuel}\right]$

$f_{fuel} = 1 - T_n$

$f_{fuel} = 0$ 80°C

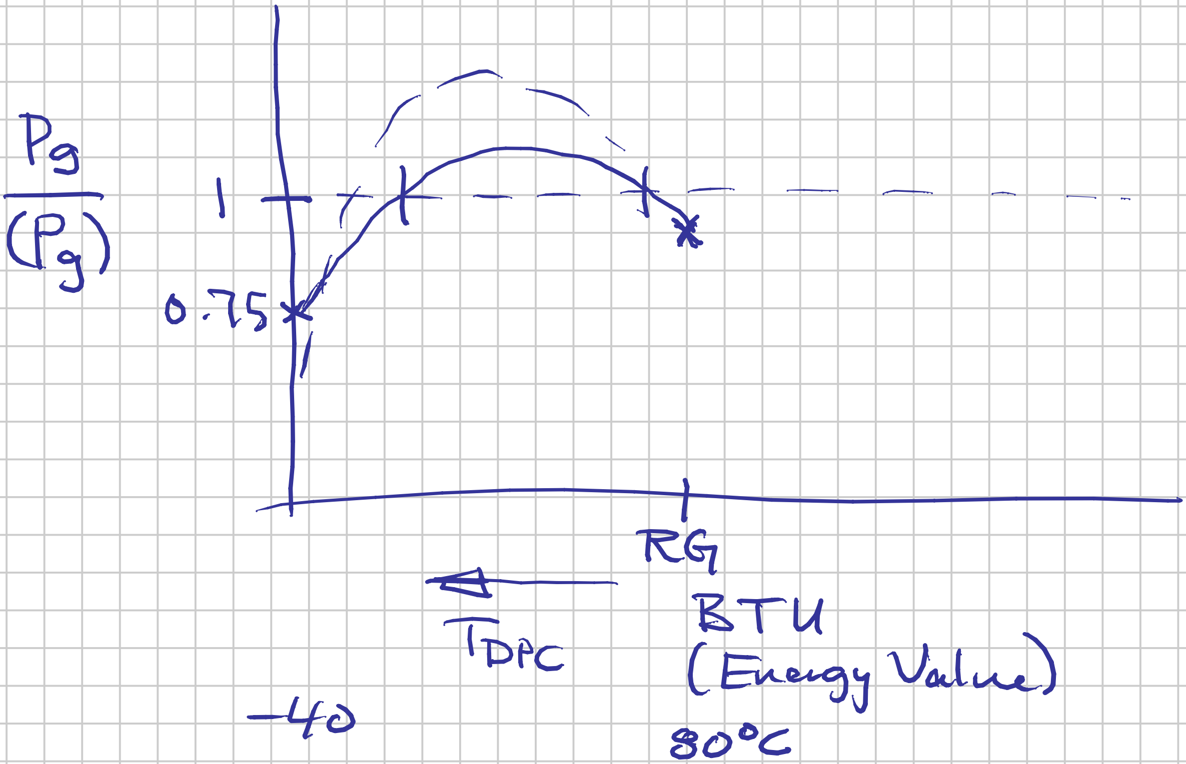
1 −40°C

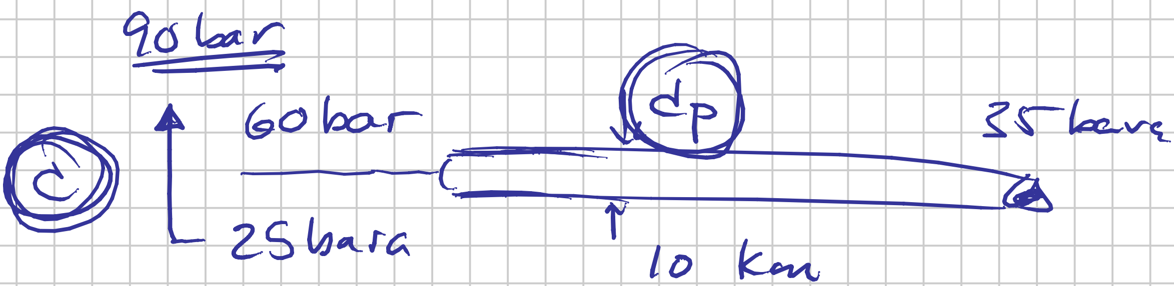
DPC

linear or whatever

d_T

T_{DPC}



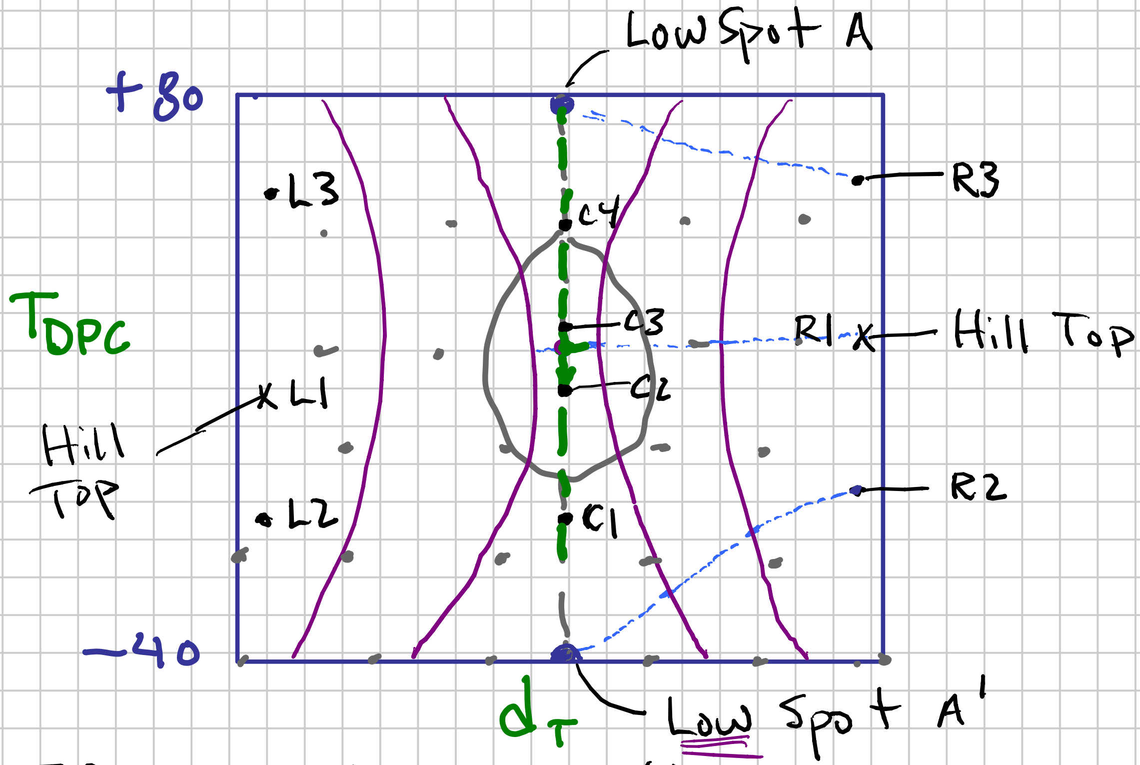


$d_T = 117$
$T_{DPC} = +80\,°C$
} $NPV = 1.587 \cdot 10^{11}$ USD

$d_T = 117$
$T_{DPC} = -40\,°C$
} $NPV = 1.598\ 10^{11}$ USD

CONTOURS = NPV

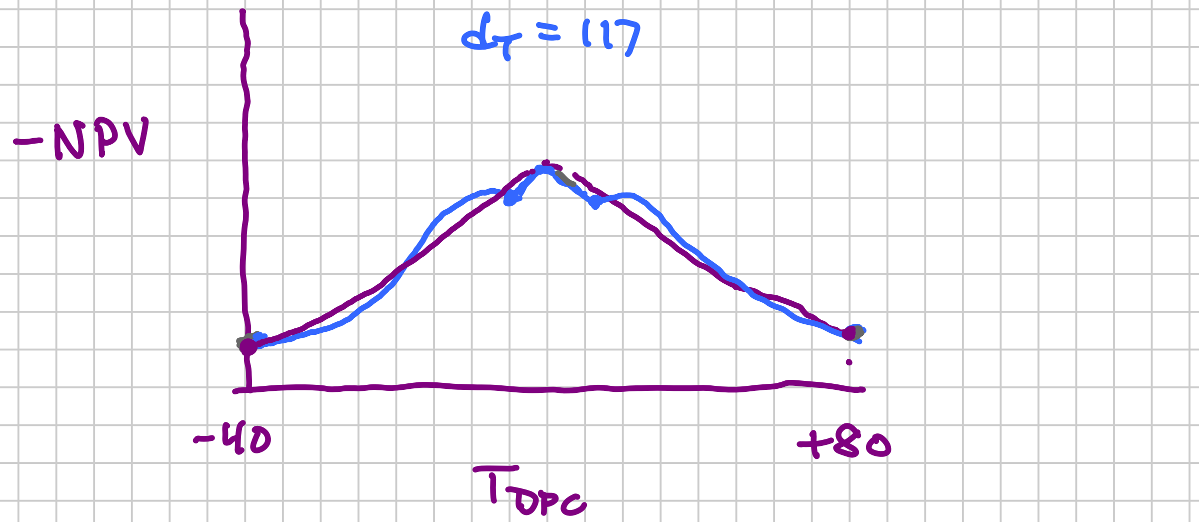
QUIZ



(1) If you put a marble anywhere on the surface, where would it end up? (starting values → final values)

Starting Point	Ending Point
R1	
R2	
R3	
⋮	

(2) Sketch NPV (T_{DPC}) along "optimal" $d_T \sim 117$ mm.



CLASS PROJECT:

3 groups (L, C, R) will evaluate 3 development scenarios for our Integrated Field Project.

- Make sure the Integrated Model is "right" and has all key 1st order effects handled.

- Germans have said they will buy gas from our field, up to 50% of IGIP (G) for a period of 8–12 plateau (negotiable).

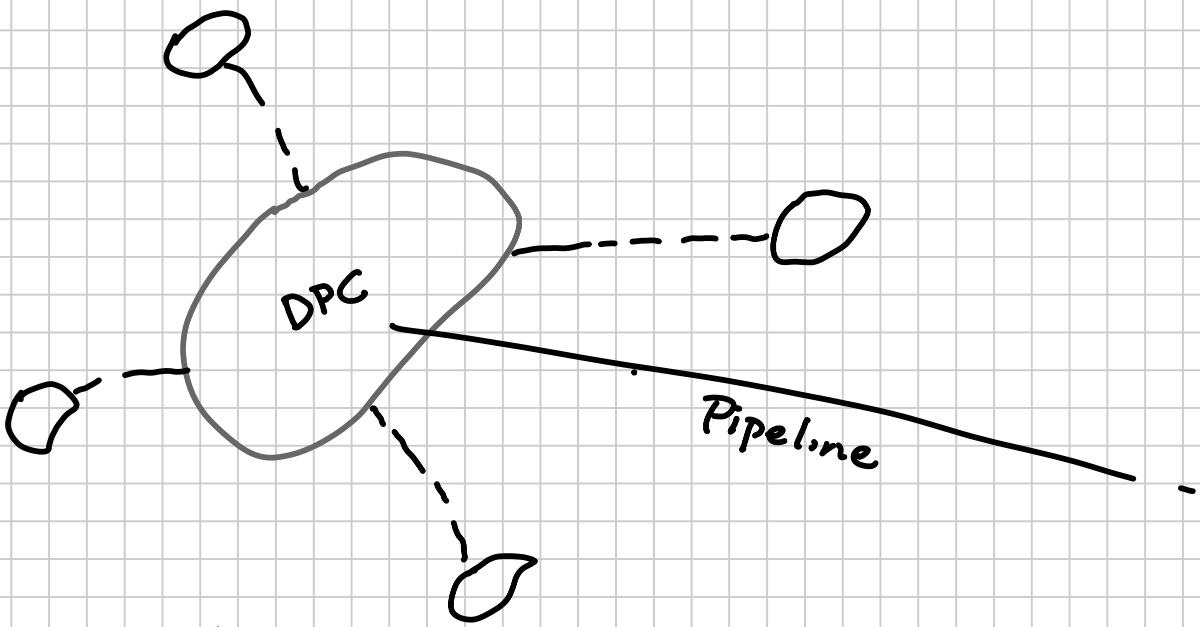
GROUP	CASE	G	A	VR
R (wall)	"AGAK"	Current G^*	Current A^* (kh)	1
C	"LGHK"	$\frac{2}{3} G^*$	$\frac{1}{2} A$	3
L (Window)	"HGLK"	$\frac{3}{2} G^*$	2 A	1/3

$G^* = 3 \cdot 10^{11}$ sm³

$A^* = 10^{-2}$

$$VR = \text{Voidage Ratio} = (G \cdot A)^{-1} \sim \left[\frac{(q_{gF})_{max}}{G}\right]$$

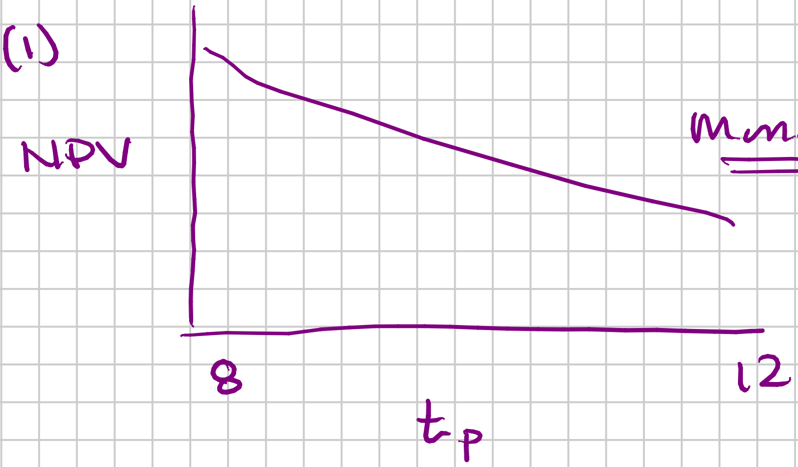
Arp's constant %/yr "D"



O $\left\{ \begin{array}{l} q_{fgx} \ (\pm) \\ t_x \ (\pm) \end{array} \right\}$ → NGLs $\Rightarrow$ ΔNPV

OBSERVATIONS

(1)



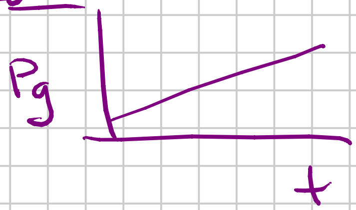
monotonic ⇒ ~~Use 8 yr (fix)~~ ~~eliminate~~

⇓

$t_p = 12$ yr

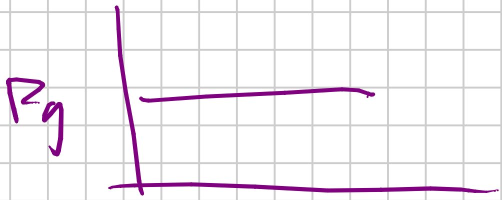
* P_g = const.

> **$P_g(t)$** ⇒ may lead to **non** monotonic



+ DCF = 10%

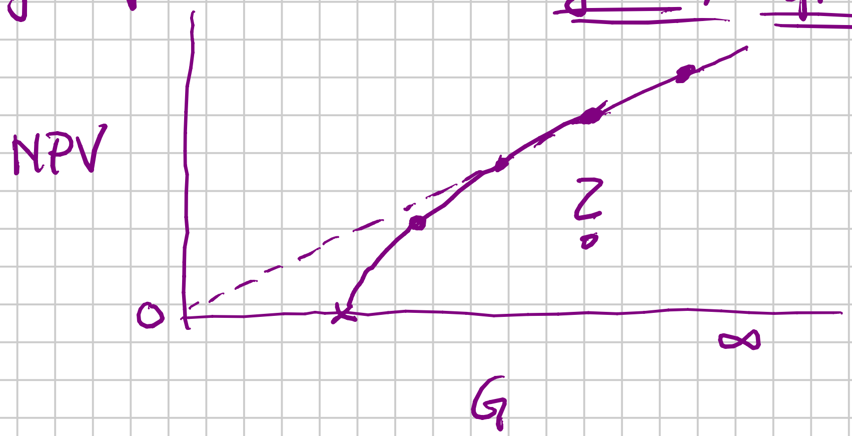
~



DCF = 0%

	AGAK	LGHK	HGLK
G [Sm^3]	$3 \cdot 10^{11}$	$2 \cdot 10^{11}$	$4.5 \cdot 10^{11}$
"K" [md]	500	1000	250
t_p [yr]	8*	8*	8*
d_t [mm]	115	142	93
T_{DPC} °C [NPV $]	80 [$9.8 \cdot 10^9$] ↓ −40 [$9.5 \cdot 10^9$]	80 [$4.0 \cdot 10^9$] ↓ −40 [$3.4 \cdot 10^9$]	80 [$16.0 \cdot 10^9$] −40 [$16.4 \cdot 10^9$]
T^*_{DPC} (saddle)	−2.5	−6.5°C	~ 0°C

* Very dependent on $P_g(t)$, $P_{ngl}(t)$, [DCF]



Assessment: ① 3.5 − 16.0 · 10^9 USD NPV ±

② DPC − Yes or No

• Add ΔNPV (Asset Tie-Ins?)

{ t_x, q_x, f_{ngl} }

CONING CHOKE PROXY

⇓

$$q_g = q_{gmax} \cdot C^{n_g}$$

$$q_o = q_{omax} \cdot C^{n_o}$$

$$q_w = q_{wmax} \cdot C^{n_w}$$

If:

$n_g = n_o = n_w = 1$: Linear

- $n_g = n_o \Rightarrow GOR = c$
- $n_o = n_w \Rightarrow WC = c$

$$GOR = \frac{q_g}{q_o} = \frac{q_{gmax}}{q_{omax}} \cdot C^{(n_g - n_o)}$$

$$WC = \frac{q_w}{q_w + q_o} = \frac{C^{n_w}}{C^{n_w} + WOR_{max} \cdot C^{(n_o - n_w)}}$$