# CBM Reservoir

Gas Deliverability

Ferian Anggara





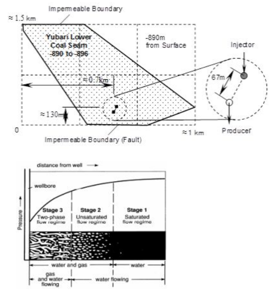
## Outline

- Overview
- Adsorption (Gas content)
- Porosity
- Permeability (Cleat system)
- **Gas Flow**
- Reserve Analysis
- Dynamic reservoir
- ~~Enhanced recovery~~

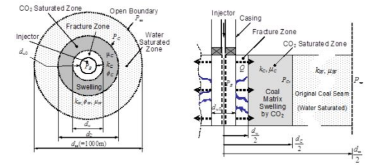




## Relative permeability




Radial flow model of CO2 injection into coal seam

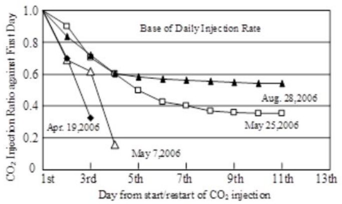


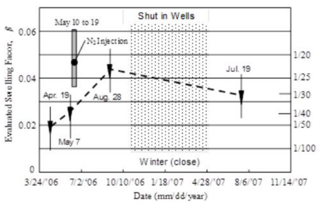

Sasaki et al., 2011





## Swelling ratio



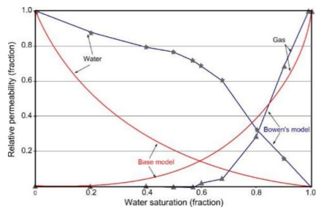



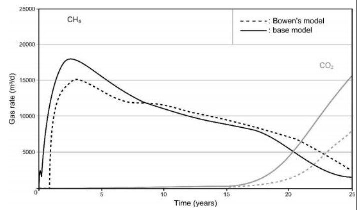

Sasaki et al., 2011





## Effect of relative permeability

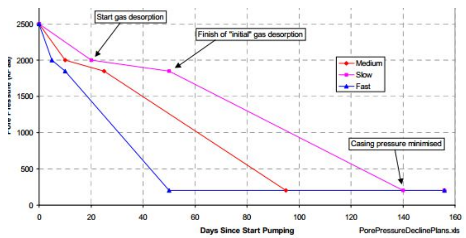



Anggara, 2014



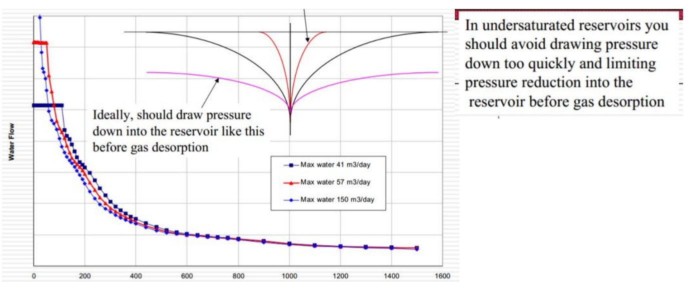





William, 2007








William, 2007



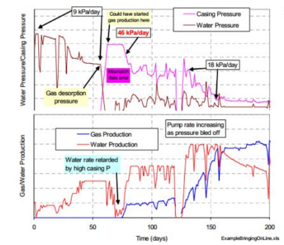


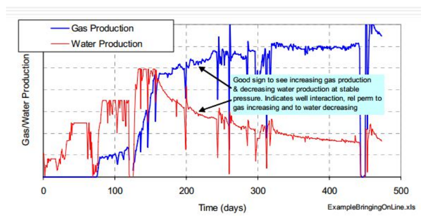
- *Too rapid reduction in pore pressure can (theoretically) result in BOTH reduced absolute permeability too near the well bore and reduced gas relative permeability away from the well bore because the pores are still too water saturated.*
- *Add the clogging of coal paths from fines during running through gas desorption too quickly and you have a sick well…*

William, 2007








William, 2007

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- **Pore volume:** can not use in coal to predict gas charge
- **Kim's Formula:** flawed, or at least outdated

Moore, 2010



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# Kim's Formula – est. of gas in coal

$$g = \frac{(1-w-a)*V_w}{V_d*(K_o P^{no} - bT)}$$

Rank – √
Ash – √
Depth – √

where,
g=adsorbed gas volume, cc/g
a=ash
b=constant [0.14]
$k_o=0.8*(V_{FC}/V_M)+5.6$
$n_o=0.39-0.1*(V_{FC}/V_M)$
P=pressure, atmospheres
T=temperature, C
$V_d$=gas volume, dry coal
$V_w$=gas volume, moist coal
W=moisture content
$V_w/V_d=0.75$
$V_{FC}=-0.515V_{ash}+51.2$
$V_m=-0.10V_{ash}+4.61$
$V_{Vm}=100-V_A-V_{FC}-V_M$
$V_A=64.94*P_B-(-66.27)$

**BUT!**

Critically:
No Saturation Estimate

Worryingly:
Developed on Bituminous Coals of Pennsylvania

Moore, 2010



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# Gas in-place (GIP)

GIP= A x CT x d x GC

- A : area or distribution of coal being estimated
- CT: coal thickness
- d : density
- GC: gas content

Moore, 2010



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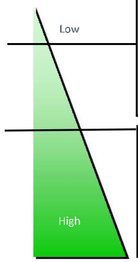
–Category

–Risk

–1P (P90)

–2P (P50)

–3P (P10)




•Proved reserves should be "reasonably certain", or stated otherwise, you should have a 90% probability of producing at least the booked amount
- SPE/WPC Definitions
- SEC Definitions

•Business decisions often made (and appropriately so) on the basis of "most likely" or "expected" case – generally close to a 50/50 chance of being high or low

Arrow, 2007



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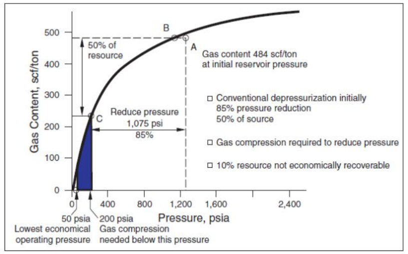
# Estimating Reserve and Recovery factor




$$R_f = \frac{V_i - V_a}{V_i}$$

where

$R_f$ = recovery factor
$V_i$ = initial volumetric gas content, scf/ton
$V_a$ = abandonment gas content, scf/ton



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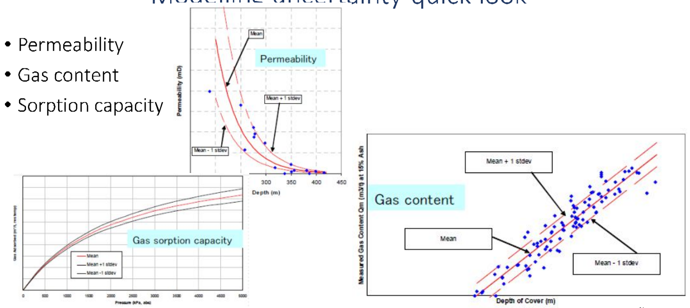
# Modelling uncertainty-quick look-

- Permeability
- Gas content
- Sorption capacity




William, 2007



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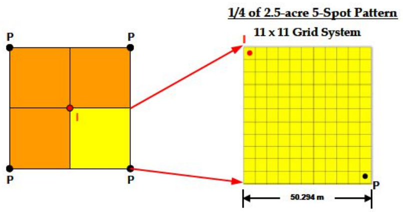
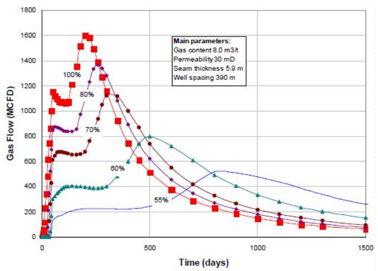
# Schematic diagram of well-spacing




Law, 2002

## Effect of gas saturation

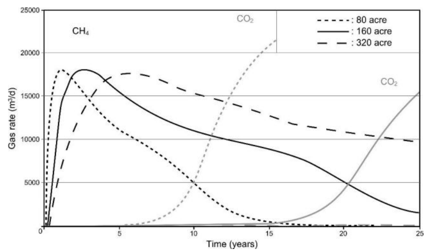



William, 2007





## Effect of well-spacing

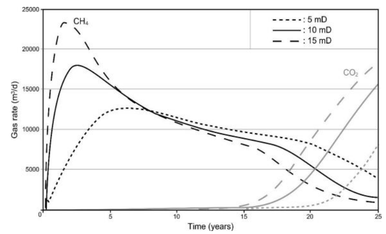



Anggara, 2014





## Effect of permeability



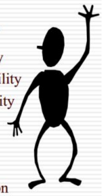

Anggara, 2014





## Main Gas Reservoir Parameters

- **Gas content**
- **Gas quality**
- Desorption rate
- **Gas sorption capacity**
- **Desorption pressure**
- **Gas saturation**
- **Net coal thickness**
- Reservoir temperature
- **Pore pressure**
- **Permeability**
- Relative permeability
- Directional Permeability
- Change in permeability
- **Porosity**
- Compressibility
- Coal mineral matter
- Hydrological isolation



They are ALL important, some more than others depending on the reservoir character

William, 2007





End