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### S-D Model

$$(\sigma - \sigma_0)_{enhanced} = (\sigma - \sigma_0)_p + (\sigma - \sigma_0)_y \quad \text{Eq. 5-3}$$

$$(\sigma - \sigma_0)_p = -\frac{v}{1-v} (p - p_0) + \frac{E c_f}{3(1-v)} \left( \frac{p}{p_0} - \frac{p_0}{p} \right) \quad \text{Eq. 5-4}$$

$$(\sigma - \sigma_0)_y = -\frac{v}{1-v} (p - p_0) + \frac{E}{3(1-v)} \left( \frac{p(\alpha_1 v_1^2 c_{f1} + \alpha_2 v_2^2 c_{f2})}{1 + \beta(c_{d1} v_{d1} + c_{d2} v_{d2})} - \frac{p_0(\alpha_1 v_1^2 c_{f1})}{1 + \beta c_{d1}} \right) \quad \text{Eq. 5-5}$$

$$\frac{k}{k_0} = e^{-3\alpha_f (\sigma - \sigma_0)_{enhanced}} \quad \text{Eq. 5-6}$$

where  $\alpha_1 = \alpha_1 V_1$ ;  $V_1 = 1/\beta$ ;  $c_f$ : cleat-volume compressibility (MPa<sup>-1</sup>);  $\sigma$ : effective horizontal stress (MPa);  $\sigma_0$ : initial;  $\sigma_0^p$ : primary;  $\sigma_0^y$ : CO<sub>2</sub> injection.

Shi and Durucan, 2005

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### Illustration showing coal matrix blocks and cleat system of a coal

Busch and Gensterblum, 2011

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# Reservoir Management

## Enhanced CBM Recovery-2

Ferian Anggara

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### A bundled-matchstick geometry represent of coal seam

Seidle et al., 1992

Busch and Gensterblum, 2011

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### Coal

Major Rank Class	Sub Class	Gas (dry) % ash-free	Bituminous Content % ash-free	Carbon % ash-free	Hydrogen % ash-free	Proximate Moisture % at air-dry	Proximate Moisture % at air-dry	Proximate Moisture % at air-dry	Proximate Moisture % at air-dry
Peat	Hypo	75							
	Meso	50-60	15						
Lignite	Meso	35-30	20						
	Meso	22-22	24	0.6					
Subbituminous	Hypo		1.0						
	Meso		1.6						
Anthracite	Meso		2.0	2.1					
	Meso		2.5	3.0					
Semi-graphite & Graphite	Meso		4.0	4.5	2.3				
	Meso		7.0		1.0				

Ward, 1984

Levine, 1993

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### Schedule

- Introduction (20/2)
- Group presentation (27/2)
- Unconventional (CBM) Reservoir Management (6/3)
- Unconventional (CBM) Reservoir Management (13/3)
- Unconventional (Shale gas) Reservoir Management (20/3)
- Unconventional (Oil shale) Reservoir Management (31/3)
- Unconventional (Methane hydrate) Reservoir Management (2/4)

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### Langmuir parameters

$$V_{ads} = V_L \frac{P}{P_L + P}$$

$$\frac{1}{V_{ads}} = \frac{P_L}{V_L} \left( \frac{1}{P} \right) + \frac{1}{V_L}$$

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### Gas injection rate

Shi and Durucan, 2005

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### Next meeting: Permeability reduction

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**Table A-1: Dry, ash-free Langmuir isotherm parameters**

Langmuir Pressure, $P_L$	Methane		Carbon Dioxide		Nitrogen	
	kPa	psia	kPa	psia	kPa	psia
4,088.0	4,088.0	4,088.0	1,993.0	1,993.0	27,241.0	3,951.0
Dry, Ash-Free Langmuir Volume, $G_L$	m <sup>3</sup> /kg	scf/lbm	m <sup>3</sup> /kg	scf/lbm	m <sup>3</sup> /kg	scf/lbm
	0.0102	486.0	0.0310	993.0	0.0102	482.0

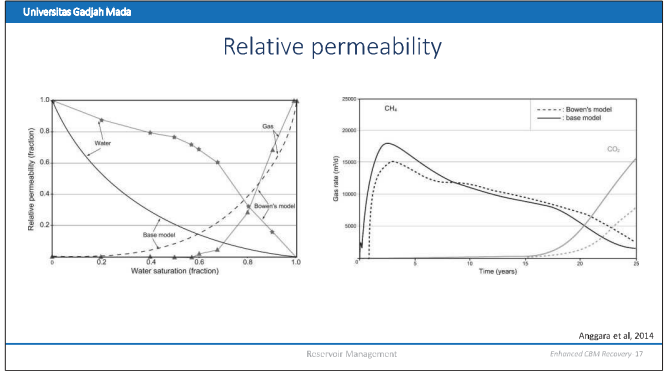
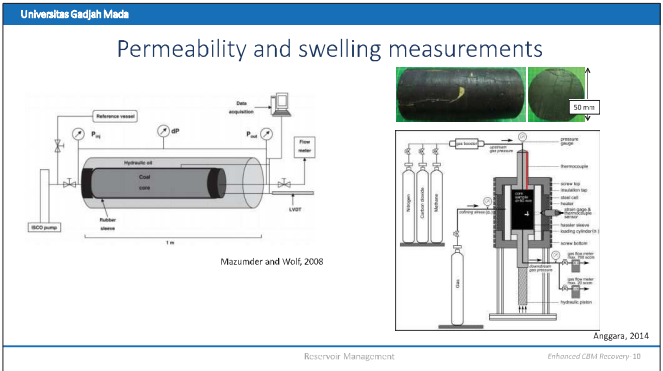
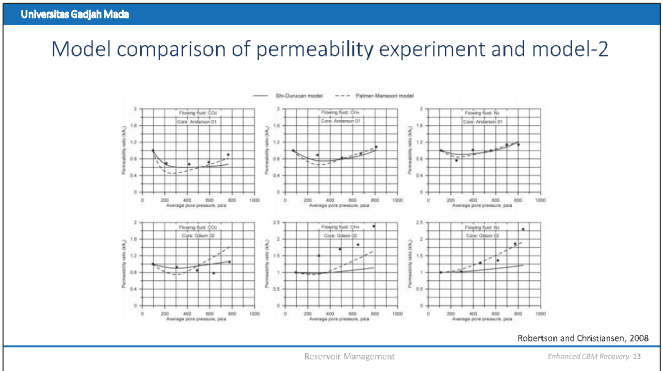
  

**Table A-2: Relative permeability relationship**

Water Saturation $S_w$	Rel. Perm. to Water $K_{rw}$	Rel. Perm. to Gas $K_{rg}$	Water Saturation $S_w$	Rel. Perm. to Water $K_{rw}$	Rel. Perm. to Gas $K_{rg}$
1.00	1.000	0.000	0.30	0.088	0.912
0.975	0.814	0.0035	0.45	0.067	0.933
0.950	0.731	0.007	0.40	0.049	0.951
0.90	0.601	0.018	0.35	0.035	0.965
0.85	0.490	0.033	0.30	0.024	0.976
0.80	0.392	0.051	0.25	0.016	0.984
0.75	0.312	0.070	0.20	0.007	0.993
0.70	0.251	0.090	0.15	0.002	0.998
0.65	0.200	0.118	0.10	0.0013	0.999
0.60	0.158	0.147	0.05	0.0006	0.999
0.55	0.115	0.180	0.00	0.0000	1.000

Law et al., 2002

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Numerical Simulation

**Coalbed Properties**  
 Coal seam thickness = 9 m [29,527 ft]  
 Top of coal seam = 1253.6 m [4112.8 ft]  
 Absolute permeability of natural fracture = 3.65 md  
 Porosity of natural fracture system = 0.001  
 Effective coalbed compressibility =  $1.45 \times 10^{-6}$  /kPa [ $1 \times 10^{-6}$  /psi]

**Initial Reservoir Conditions**  
 Temperature = 45°C [113°F]  
 Pressure (assumed uniform from top to bottom) = 7650 kPa [1109.5 psia]  
 Gas saturation = 0.408 (1.00% CH<sub>4</sub>)  
 Water saturation = 0.592

**Water Properties at 45°C (113°F)**  
 Density = 990 kg/m<sup>3</sup> [61.8 lb/ft<sup>3</sup>]  
 Average in-situ coal density = 1434 kg/m<sup>3</sup> [89.5 lb/ft<sup>3</sup>]  
 Average in-situ moisture content (by wt),  $w_w = 0.0672$   
 Average in-situ ash content (by wt),  $w_a = 0.156$

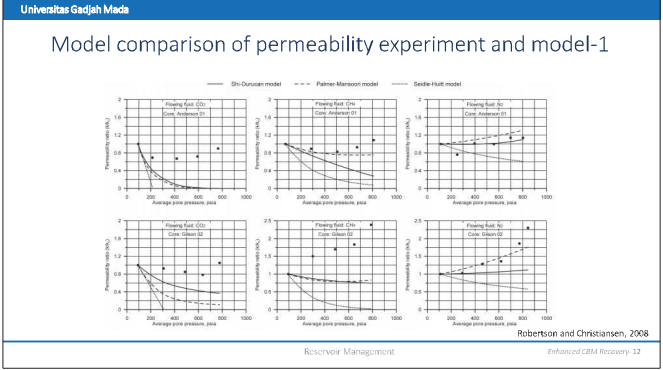
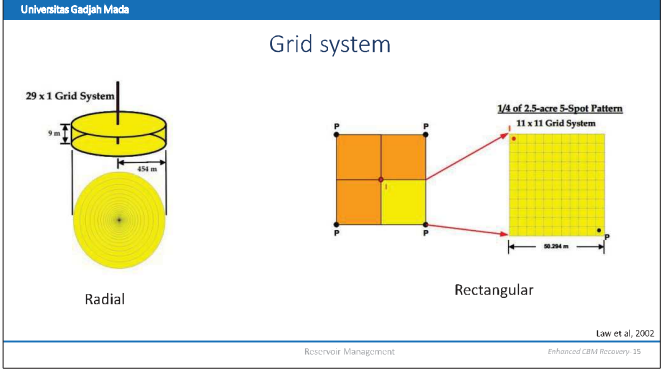
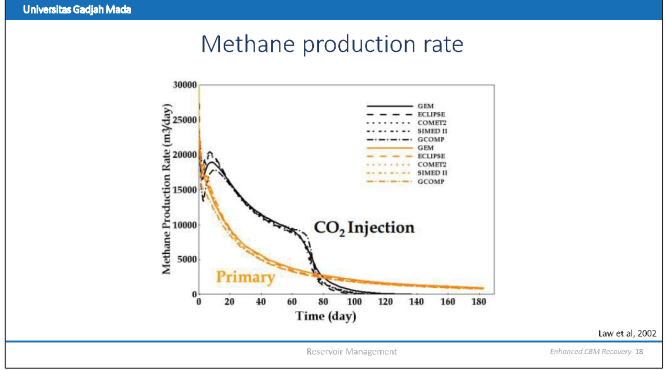
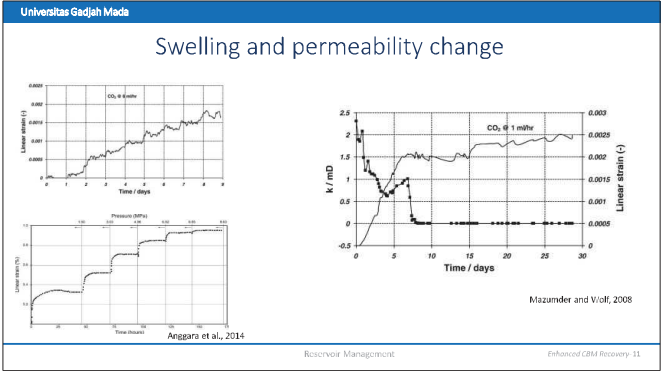
**Grid System**  
 Rectangular (5-yx) grid system:  $11 \times 11 \times 1$  (see Figure 2)  
 Area = 1/4 of 2.5-acre pattern [165 ft]  
 Pattern half width = 50.294 m [165 ft]  
 x and y-directions: see Table C-1  
 well radius,  $r_w = 9$  m [29.5 ft]

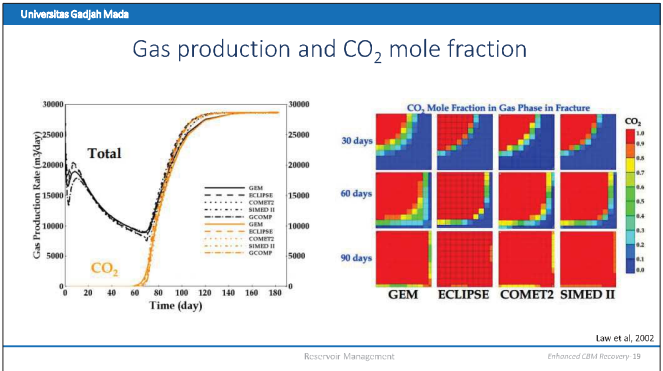
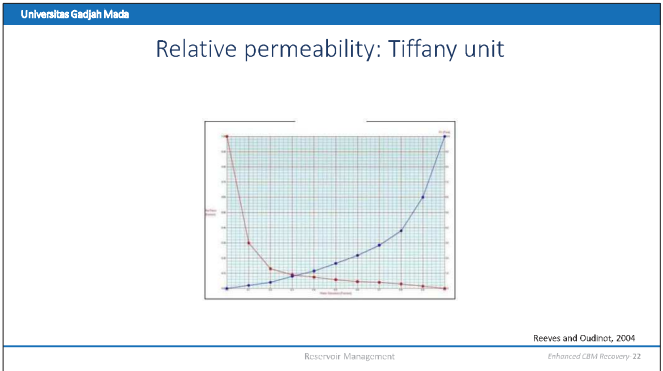
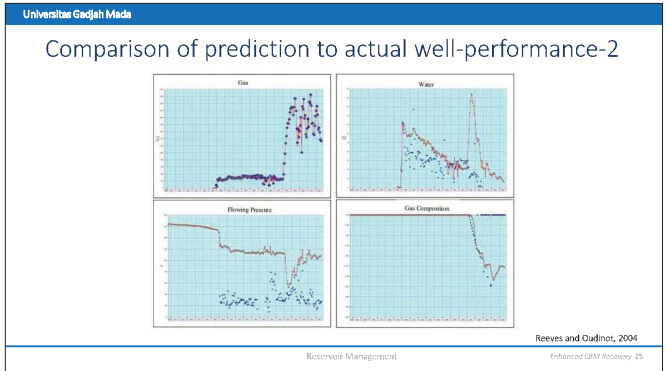
**Operating Conditions**  
 Well location:  
 Injection well: (i = 1, j = 1, k = 1)  
 Production well: (i = 11, j = 11, k = 1)  
 Well radius (2.78" well) = 0.0365 m [0.11975 ft]  
 Well skin factor = 0

182.5-day continuous CO<sub>2</sub> injection/production period (0 – 182.5 days):  
 • CO<sub>2</sub> injection rate (full well) = 28,316.82 m<sup>3</sup>/d [2,175.6 scf/d]  
 • Maximum bottom-hole pressure = 15,000 kPa [2,175.6 psia]  
 • Maximum gas production rate (full well) = 100,000 m<sup>3</sup>/d [3,315.5 scf/d]  
 • Minimum bottom-hole pressure = 275 kPa [39.885 psia]

Law et al., 2002

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End

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