Australian Aid

AMEP
Australia Mongolia Extractives Program

Advanced Training for CBM Geologists

Gas Measurement

Ulaanbaatar, Mongolia

16 June 2022

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Cipher Doc#: 22-426

Schedule

Advanced Training for CBM Geologists			
from	To	total time (hr:min)	Topic
9:00	9:15	0:15	Opening Remarks & Introduction
9:15	10:45	1:30	Origin of Reservoir Properties: from Peat to Pores
10:45	11:00	0:15	Questions/Discussion
11:00	11:15	0:15	Coffee Break
11:15	12:45	1:30	Unconventional Hydrocarbons and Geological Models
12:45	13:00	0:15	Questions/Discussion
13:00	14:00	1:00	LUNCH
14:00	14:45	0:45	CBM Drilling Equipment & Methods
14:45	15:00	0:15	Questions/Discussion
15:00	16:00	1:00	Coal & Rock Review - What and How to Characterise
16:00	16:15	0:15	Questions/Discussion
16:15	16:30	0:15	Coffee Break
16:30	17:30	1:00	Measuring Gas
17:30	18:00	0:30	Critical CBM Reservoir Properties: Know where to Place Your Efforts
18:00	18:15	0:15	Questions/Discussion
18:15	18:30	0:15	*Closing Remarks*

NOTE: Times are in UB, Mongolian Times

Outline of Talk

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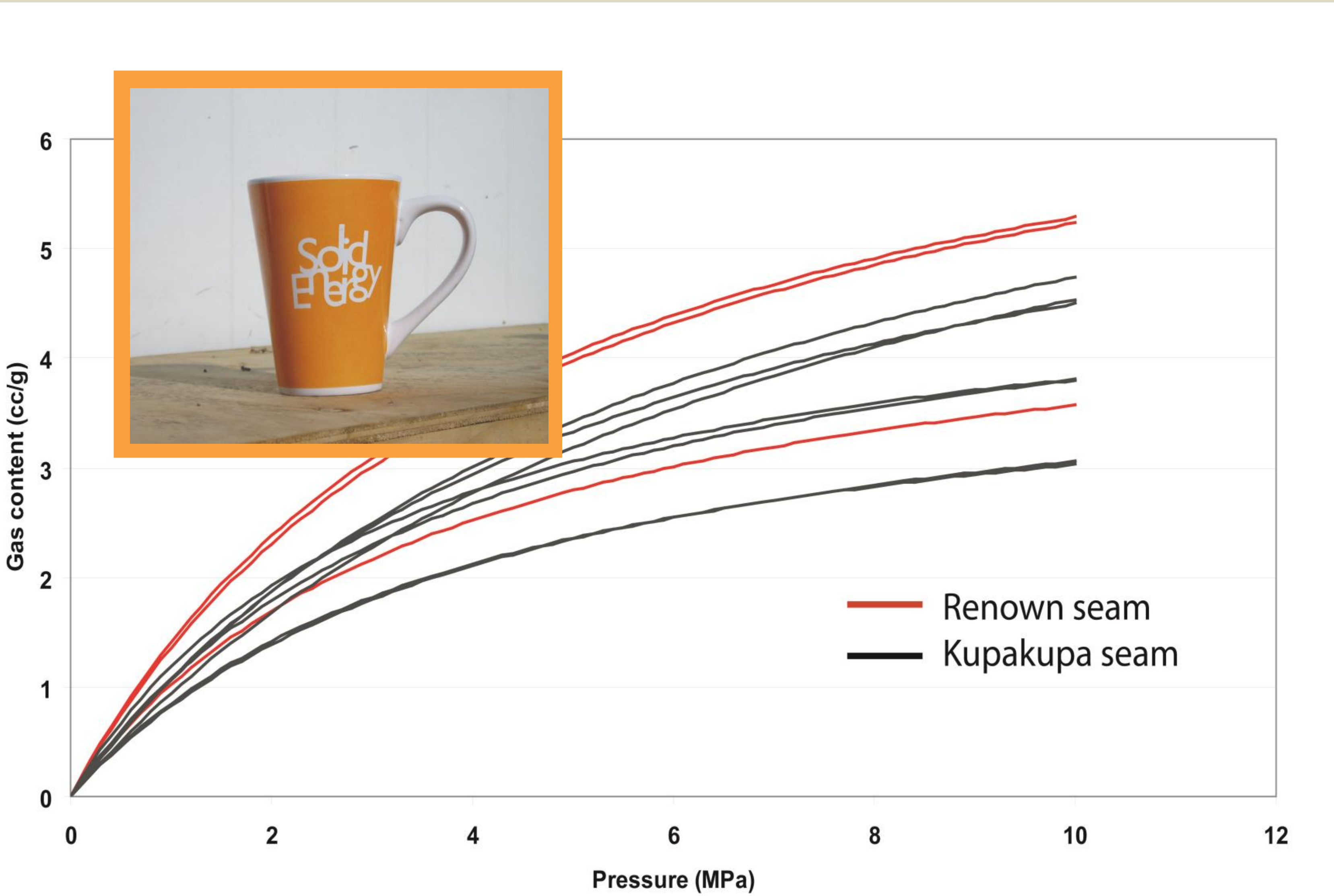
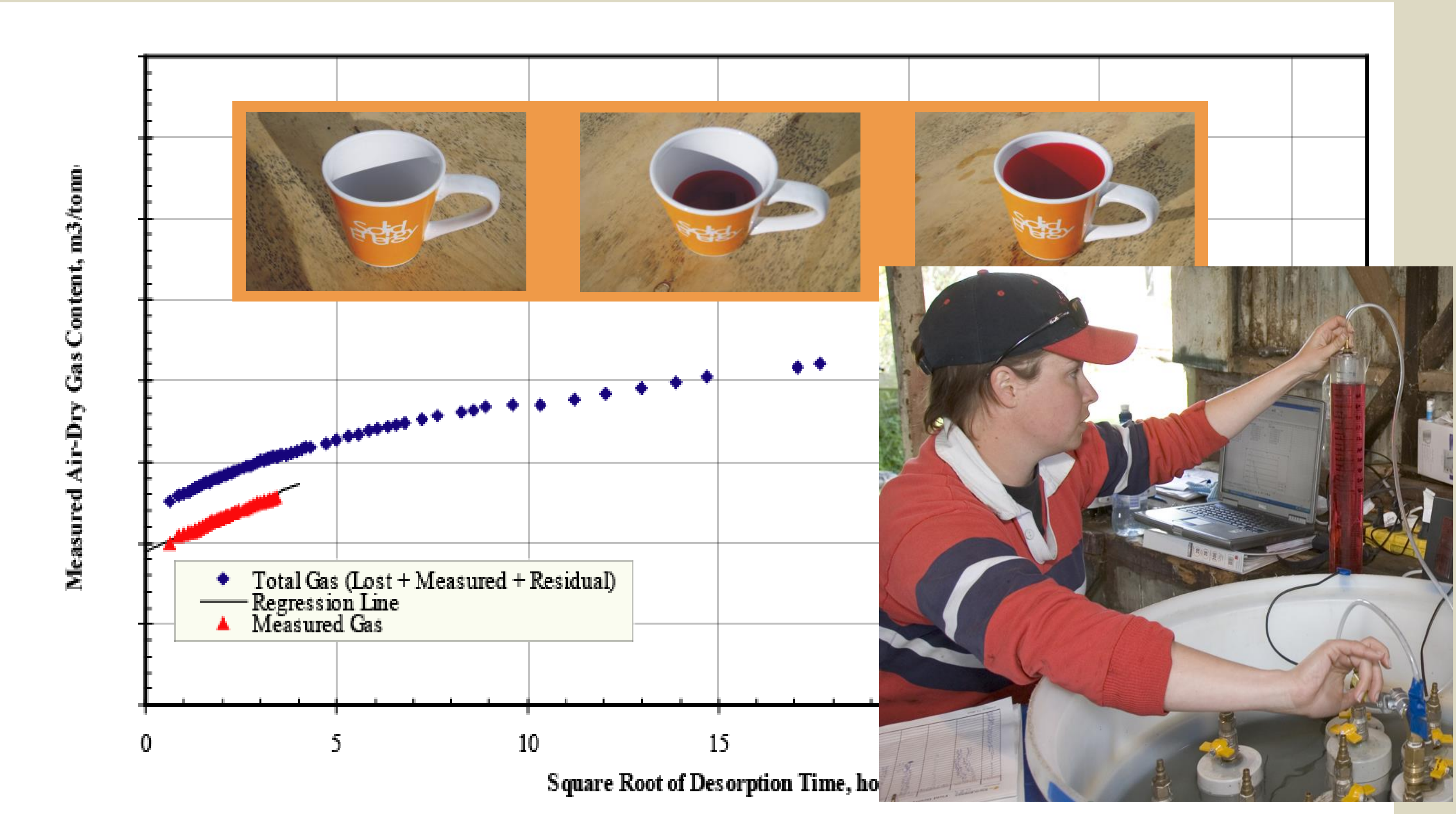
1. Absorption Isotherm (holding capacity)
2. Desorption Isotherm (actual gas present)
3. Gas Saturation (calculated)

Holding Capacity (Adsorption Isotherm) – Lab Measurement



Measured Gas Content (Desorption)



Gas Content

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- The volume of gas in a given mass of coal
- The gas resides only in the carbonaceous material.
- Units m^3/t
- Equally important to characterise the material as well as to know the gas volume.

Eg 6 m^3/t gas content in coal of density 1.35 g/cc compared to 6 m^3/t in material of density 1.60 g/cc

Gas Content Testing

- AS 3980-199
- ASTM (D7569-10)
- Methods
  - Direct
    - Fast
    - Slow
  - Indirect
- Q1, Q2, Q3

Gas Content Basics

- Measured gas content (Qm = Q1+Q2+Q3)
- Gas composition
- Desorption rate
- Magnitude mainly affected by -
  - Sampling and test method
  - Geology/geological history
  - Depth
  - Mineral matter

Terminology

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- Lost Gas (Q1)
- Desorbable Gas (Q2)
- Residual Gas (Q3)
- {Desorbable Gas Content (Q1+Q2)}
- Measured Gas Content Qm (Q1+Q2+Q3)

T *calc to 20^{o}C and 101.3 kPa*

GeoGAS Method

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- Approved by the Mines Inspectorate for mine safety application in 1993
- Robust equipment, maintenance, validation and error checking.
- Method research
- Fast Q3 crushing – 7 minutes

Q3 ring mill

Desorption Sampling Collection – Field Based

Collection of Desorption Coal Samples are field based, and thus:

1. Must be prepared (tools, equipment, procedures)
2. Be prepared for varied weather and hazards
3. Conduct a Risk Assessment prior to each field excursion
4. Have backup plans and equipment ready

Desorption Isotherm

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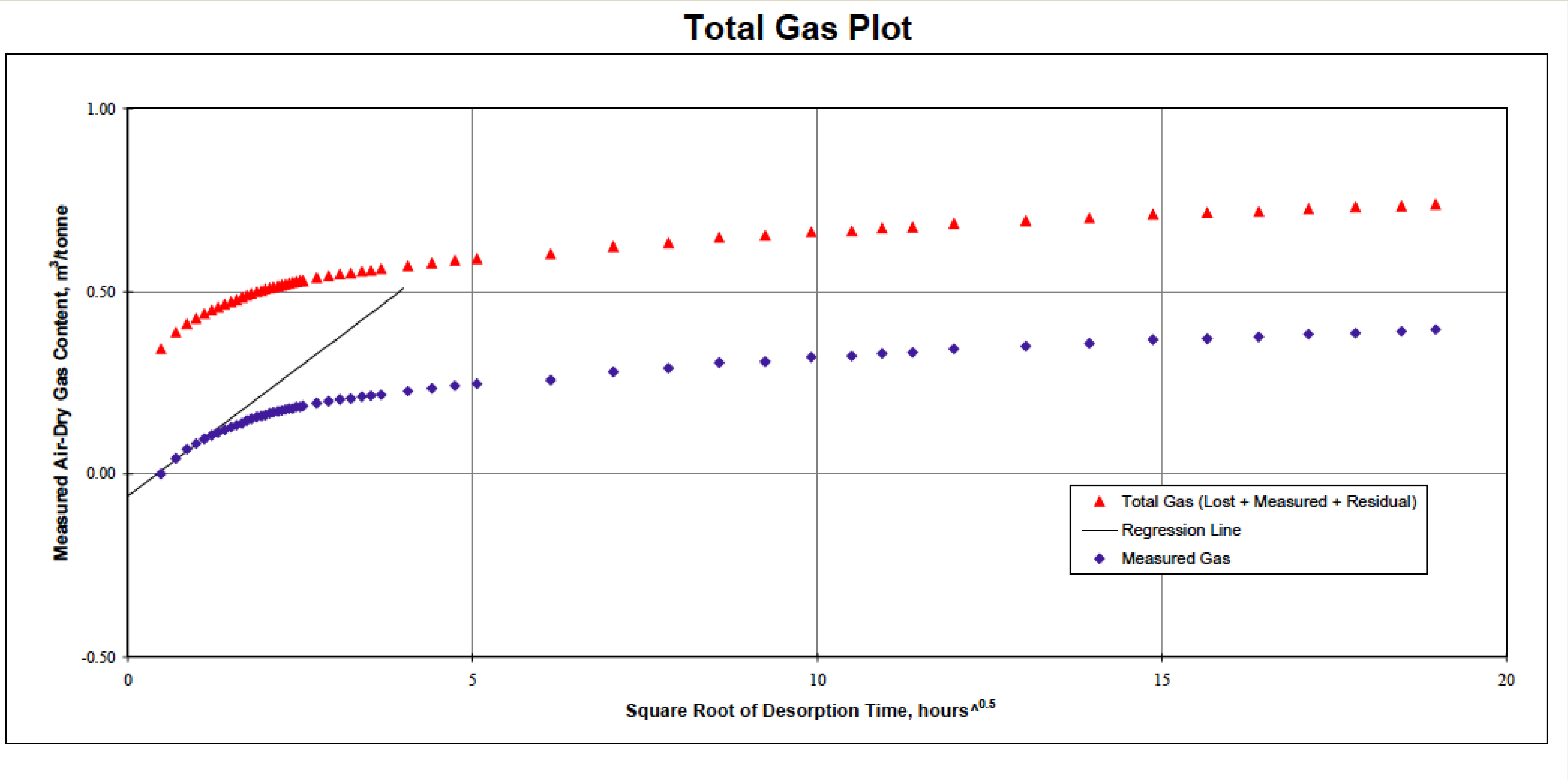
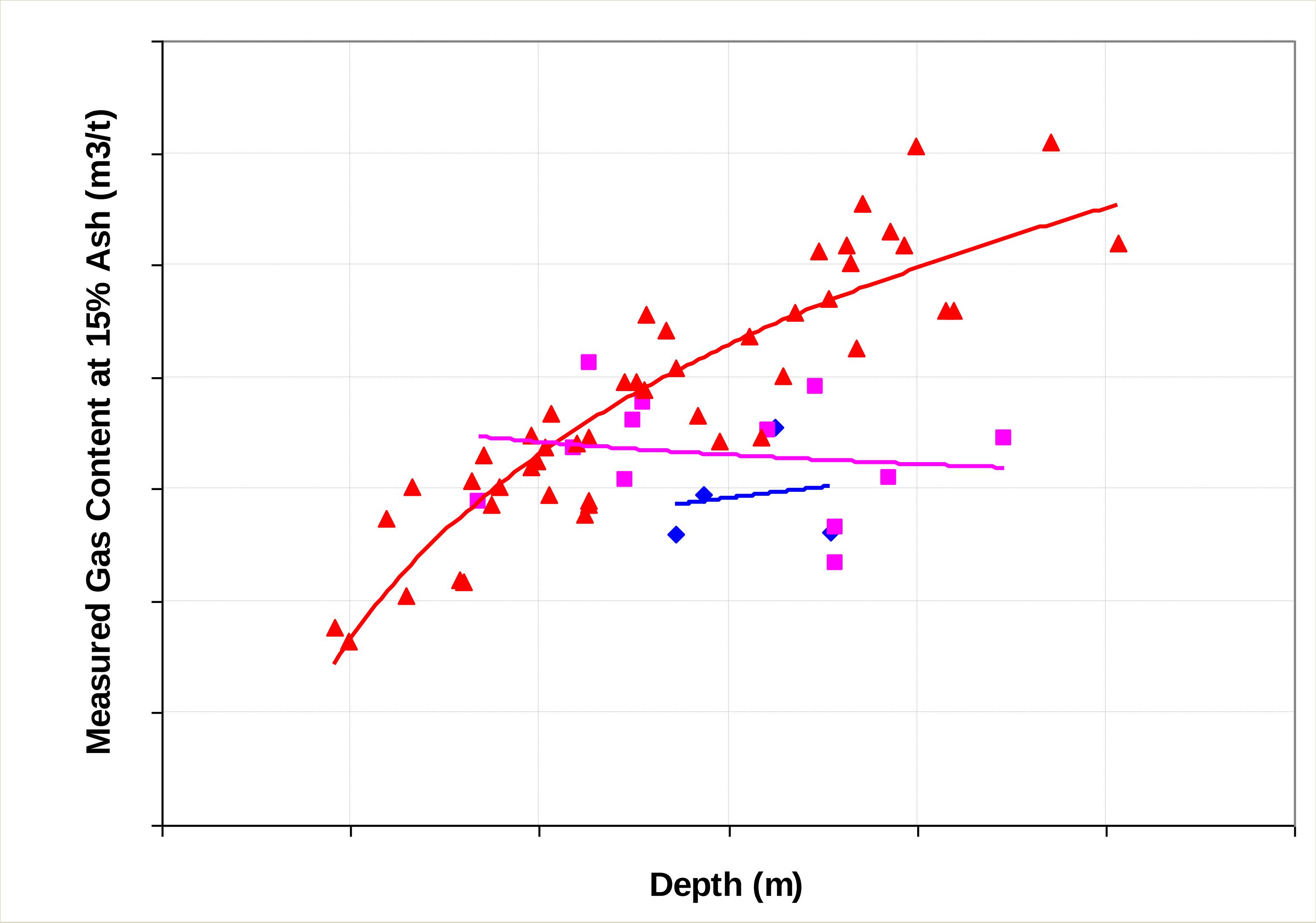


Determining Gas Content for the Full Seam

					Measured Gas		Desorption Rate @		Ash/Density			Gas Composition			
GeoGAS Sample Number		Seam	Depth from	Depth to	at Sample Ash	at 15% Ash	GeoGAS DRI	IDR30 (m^3/t)	Sample ARD (g/cc)	RD or Calc RD (g/cc)	Sample Ash (% adb)	$CH_4/(CH_4+CO_2)$	CH_4% Air Free	CO_2% Air Free	N_2% Air Free
		GM	*417.24*	*417.69*	*9.48*		*1256*				*30.4*				
GRO0138		GM	417.69	418.42	12.83	12.52	1668	1.87	1.31	1.43	13.3	0.99	93.73	1.41	4.86
GRO0139		GM	418.42	419.19	13.26	12.36	1740	1.84	1.32	1.37	9.9	0.99	95.29	1.16	3.55
GRO0140		GM	419.19	419.94	11.89	11.56	1626	1.36	1.35	1.42	13.0	0.98	94.05	1.58	4.37
		GM	*419.94*	*420.78*	*12.03*		*1594*				*15.7*				
			420.78	*421.14*	*6.77*		*897*				*46.0*				
		GM	*421.14*	*421.31*	*0.00*						**85.0**				
		GM	*421.31*	*422.55*	*10.66*		*1412*				*23.6*				

Example Gas Content Gradients



Gas Content Gradients Sydney/Bowen Basins

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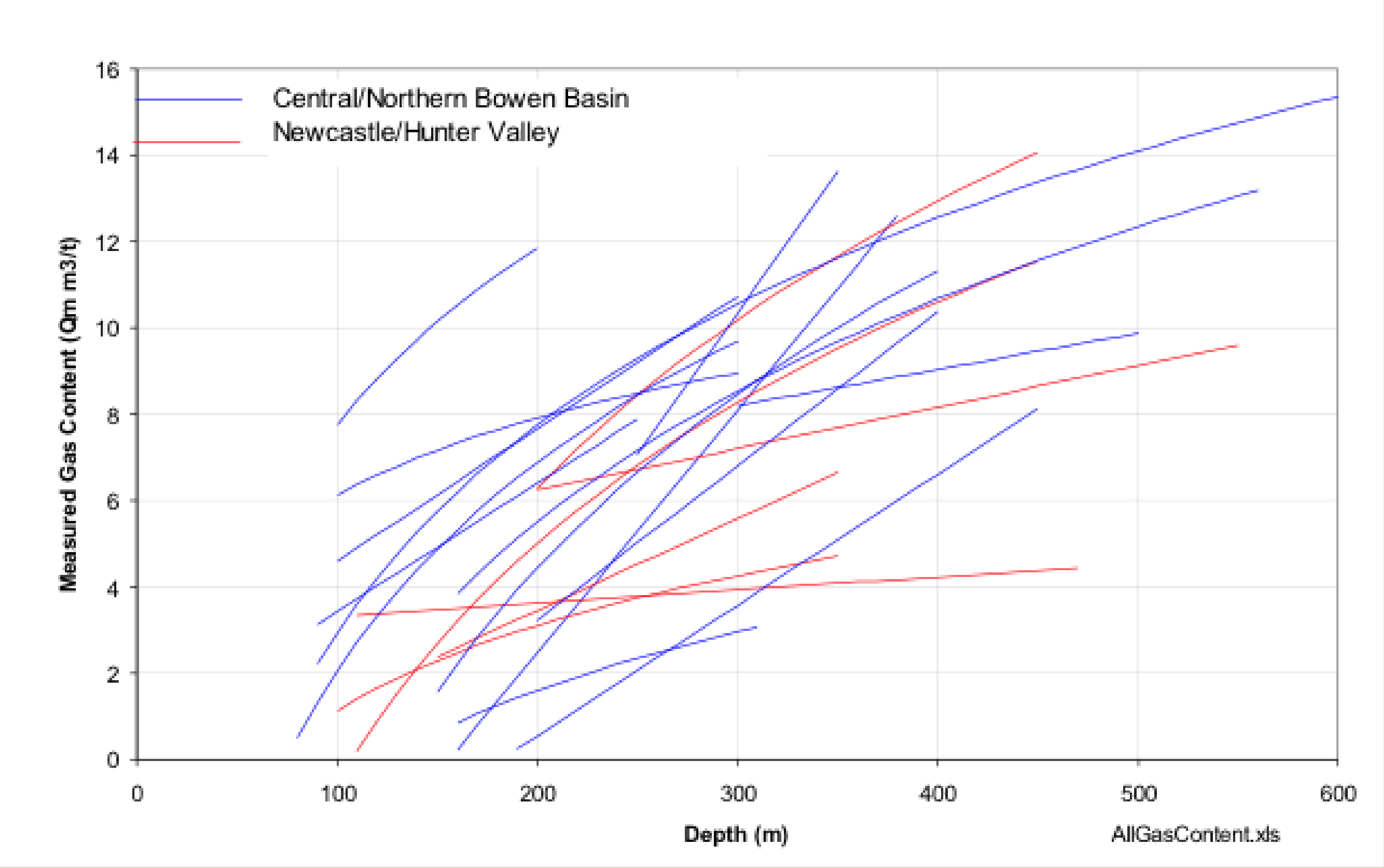
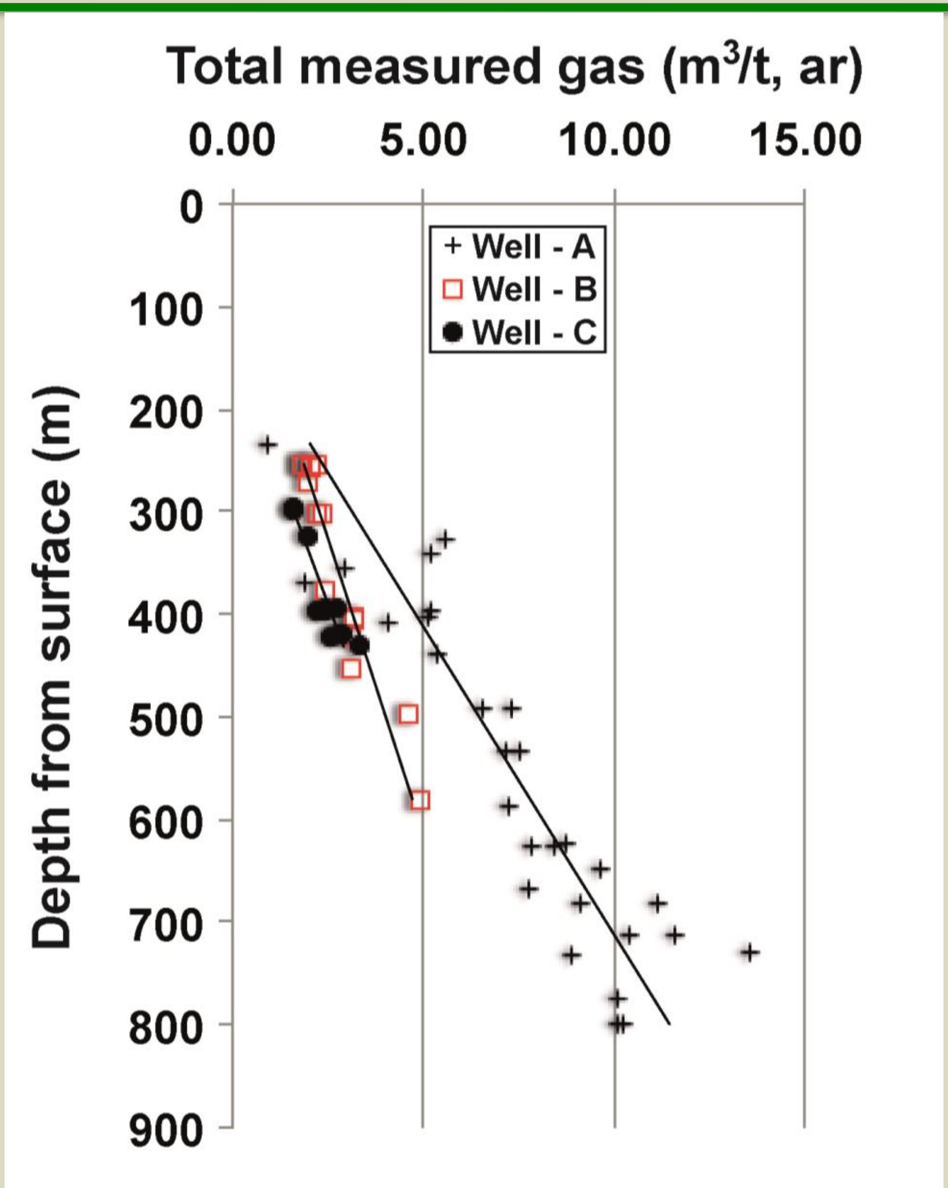


Gas Content Trends: Kalimantan, Indonesia



(from Moore et al., 2014)

Terminology

- Lost Gas (Q1)
- Desorbable Gas (Q2)
- Residual Gas (Q3)
- {Desorbable Gas Content (Q1+Q2)}
- Measured Gas Content Qm
  (Q1+Q2+Q3)

T calc to 20°C and 101.3 kPa

Desorption Well-Site Procedures

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1. **Reservoir Temperature**: Temperature at depth of the coal is measured (or estimated through other means)
2. **Times**: While coring of coal these times are required:
3. Time top of sample was cored
4. Time when core barrel started out of well
5. Time when core barrel reached surface
6. Time when each canister was sealed
7. N.B. All possible speed must be used, consistent with good safety practices, to pull the core and place in the sealed containers for desorption testing.
8. **Description**: Coal core is described at well site then quickly placed within 600 mm PVC desorption canisters. NOTE: if adsorption isotherm samples are required they must be taken before coal is placed in the canister – see below.
9. **Sealing**: While sealing of canisters (at the well site), they may be purged with helium or argon. This is optional, and is considered to increase the risk of a leak occurring in the canister due to getting dirt on the O-ring seal at the base. Once canister is sealed, the ball valve at the top of the canister is quickly opened and shut and the stopwatch started. This is the start of the measured gas (Q2) process.
10. **Leak Test**: A leak test is conducted prior to placing coal in canister. It is useful to observe canister in the water bath to see if there are any leaks.
11. **Labelling**: Each canister is labelled with *canister #*, *hole #, from* and *to* depths
12. **Transport**: Once all the coal from the core barrel is in canisters, canisters are immediately transported to a central field location for gas desorption measurement.

Canister Labels

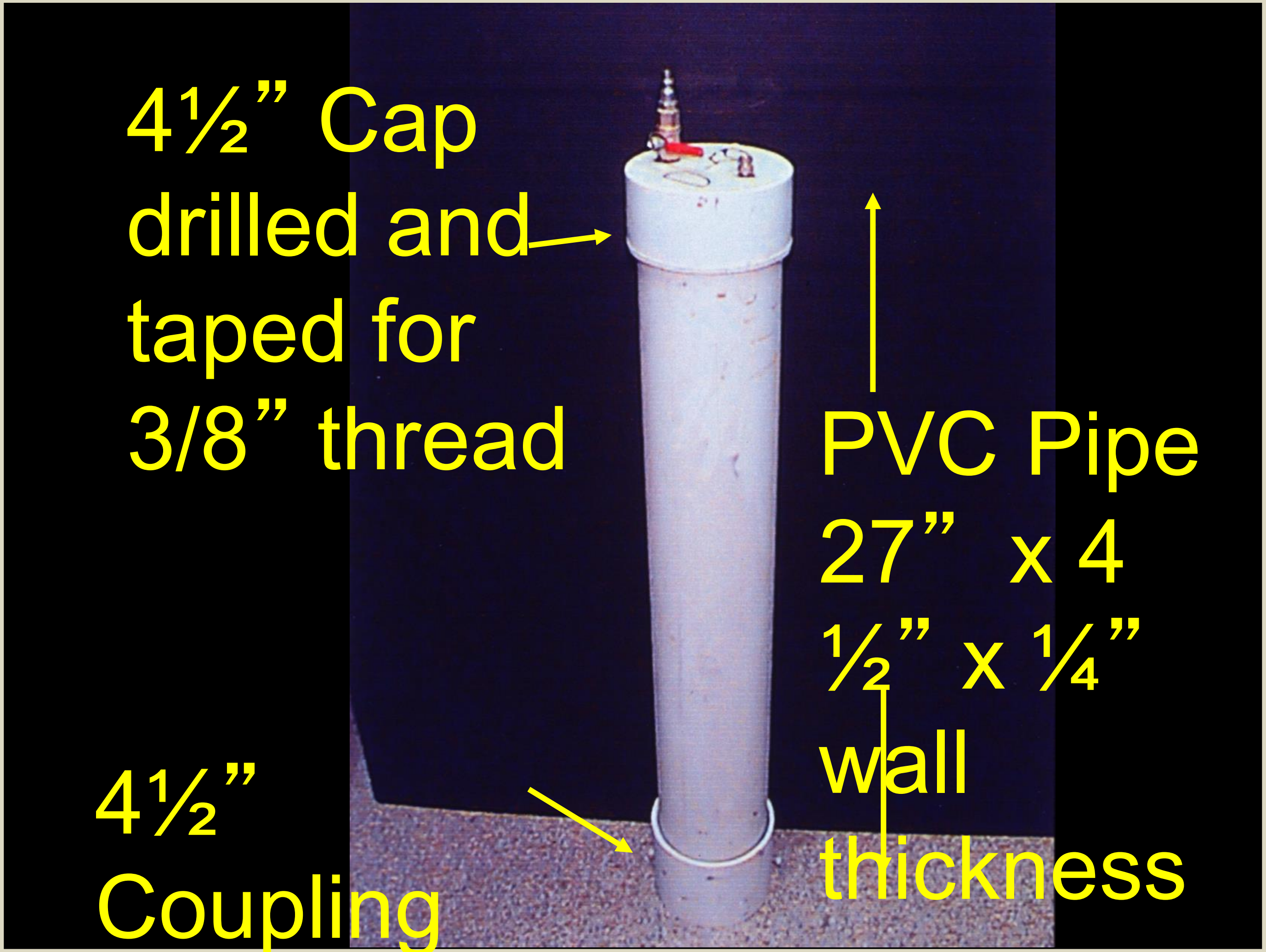
- **Think through what the canister labeling system will be prior to each field excursion**
- **More information is always better**
- **But simple, unique labels**
- **Waterproof labeling**

Quick Description of Core after Reaching Surface

Core before inserting in canister and methanometer for safety

USGS Method – slow to moderate desorption

USGS Method – slow to moderate desorption



USGS Method – slow to moderate desorption

Canisters are placed in Water Bath

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USGS Method – slow to moderate desorption

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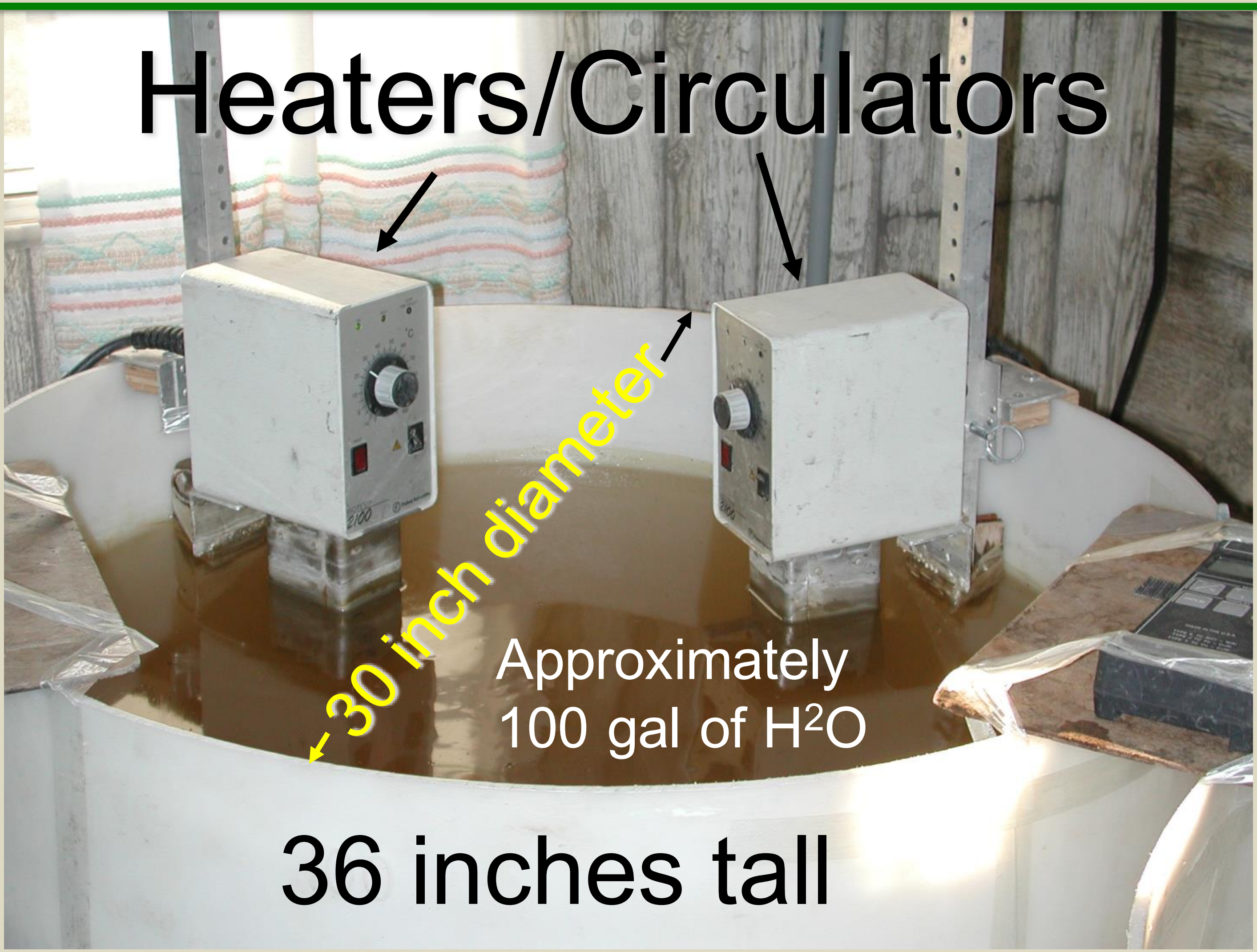
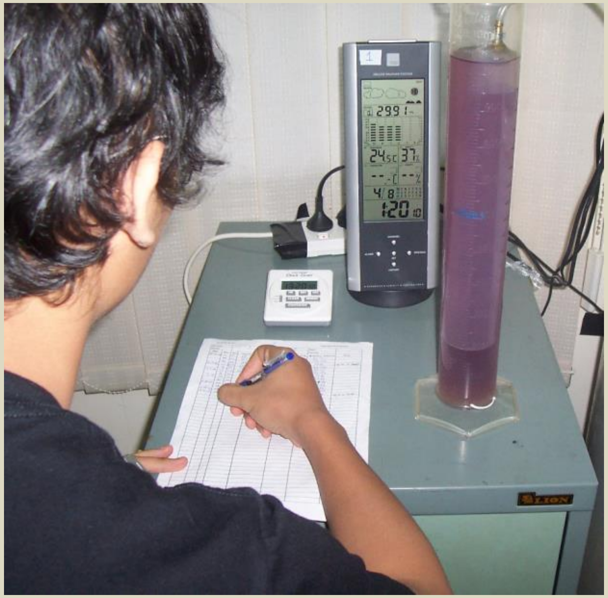


Desorption Measurements and Recording



Geologist		Date Cored			
Project Owner		Time start coring			
		Time core pulled up			
		Time core at surface			
		Time canister sealed			

Date	Hour	Min.	Volume (mL)	Water Bath Temp. (°C)	Ambient Temp. (°C)	Ambient Pressure (Hg)	Notes

At each desorption reading the following measurements are made and entered on the Desorption Data Form ():

- **Gas desorbed (cm^3)**
- **Date and time**
- **Canister temperature (° C)**
- **Ambient temperature (° C)**
- **Ambient pressure (in Hg)**

Example Desorption Sheet

Well Name		Canister No.		Region	
Operator		Page		Coal Field	
Formation		Sample Top (m)		Easting (m)	
Coal Interval		Sample Base (m)		Northing (m)	
Core Run #				Collar RL	
Geologist		Date Cored			
Project Owner		Time start coring			
€ipher		Time core pulled up			
		Time core at surface			
		Time canister sealed			

Date	Hour	Min.	Volume (mL)	Water Bath Temp. (°C)	Ambient Temp. (°C)	Ambient Pressure (Hg)	Notes

- **Each canister gets an individual sheet or as many as needed.**
- **All fields need to be filled in for proper analytical tracking**
- **Never underestimate the usefulness of more information**
- **Field notes should be made in PEN; changes if needed need to be initialed by a Supervisor**

Quick Description of Core after Reaching Surface

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Water bath: Canisters at the field desorption station are logged in and immediately placed in a water bath that is kept at reservoir temperature.

Desorbing Times: The schedule for desorption times are as follows*:

Interval	*Length of Time*	*No. Measurements*
Every 15 minutes[1]	9 hours	36
Every 1 hour	7 hours	7
Every 3 hours[2]	12 hours	4
Every 12 hours	5 days	10
Every 24 hours	5 days	5
Every 72 hours	15 days	5
Every 7 days	To full desorption[3]	

Quick Description of Core after Reaching Surface

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Interval	*Length of Time*	*No. Measurements*
Every 15 minutes[1]	9 hours	36
Every 1 hour	7 hours	7
Every 3 hours[2]	12 hours	4
Every 12 hours	5 days	10
Every 24 hours	5 days	5
Every 72 hours	15 days	5
Every 7 days	To full desorption[3]	

[1]The 15 minutes sampling must be followed precisely unless there is no gas. The other time increment steps are to follow accordingly. However, if the gas volume of a canister falls at or below 10 ml per reading (where measurement error becomes too great) at any particular step then that canister should be elevated to the next time measurement period.

[2]After the last canisters are finished with the three hourly recording, they can be transported from the field desorption station back to the laboratory for remaining desorption. Laboratory desorption is also conducted at reservoir temperature.

[3]Full desorption is achieved (unless otherwise instructed) through doubling the measurement period (e.g. 1 week to 2 weeks; 2 weeks to 4 weeks) as each canister falls below the 10 ml level. However, often client requirements and time constraints limit the amount of time available for full desorption. In consultation with the client, the desorption period can be shortened. This will result in a higher residual gas (Q3) measurement.

Terminology

- Lost Gas (Q1)
- Desorbable Gas (Q2)
- Residual Gas (Q3)
- {Desorbable Gas Content (Q1+Q2)}
- Measured Gas Content Qm (Q1+Q2+Q3)

T calc to 20^{o}C and 101.3 kPa

What is Lost Gas (Q1)?

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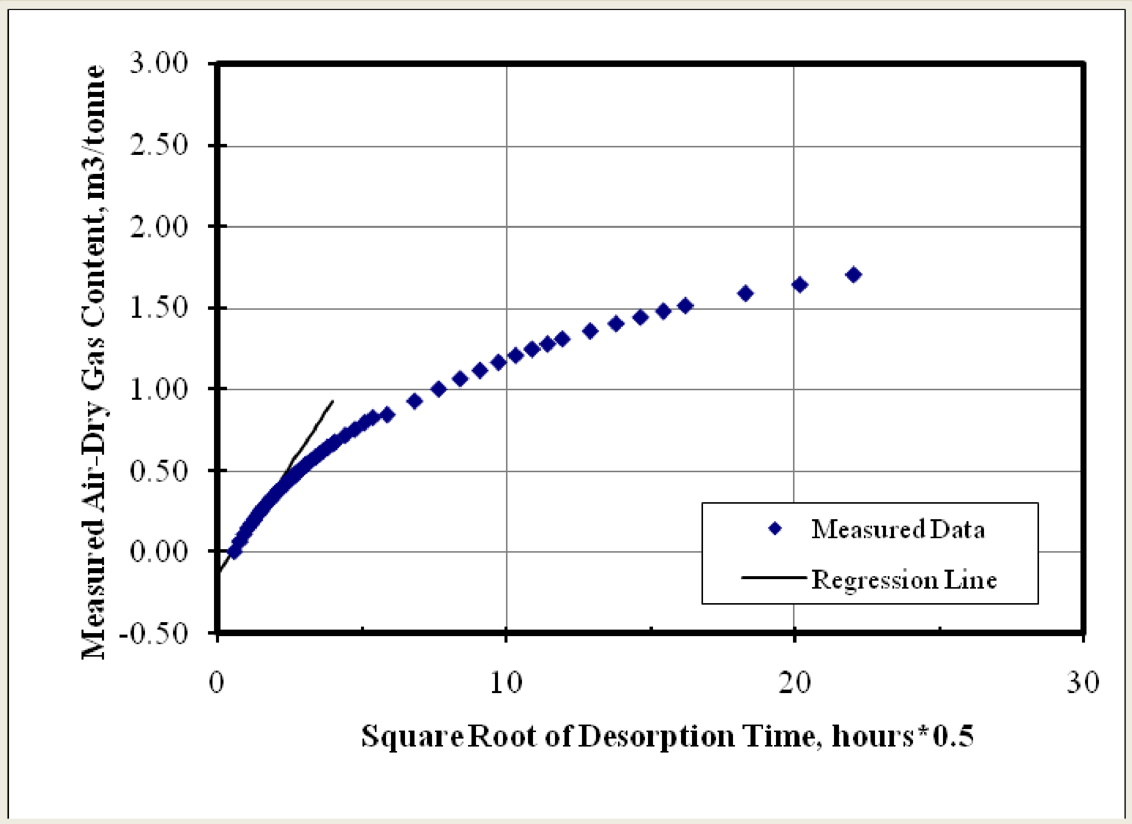
- Theoretical amount of gas emitted from a core sample during the time from leaving the bottom of the well until sealed within a canister
- Calculated from a series of initial gas desorption measurements
- The frequency and the style of these initial measurements varies
- A regression analysis is then performed on these initial measurements
  - Linear regression
  - Polynomial regression

Lost Gas Determination



- Initial desorption measurements made in short intervals (e.g. every 15 mins) for the first 9 hrs, or as long as accurately can be accomplished (see '10 cc rule')
- Other methods (Australian) collect a continuous amount of gas for 20-60 minutes keeping track of gas by either a time or volume basis
- In either case, a linear regression is usually conducted to determine lost gas

Lost Gas Determination – Wyoming, USA

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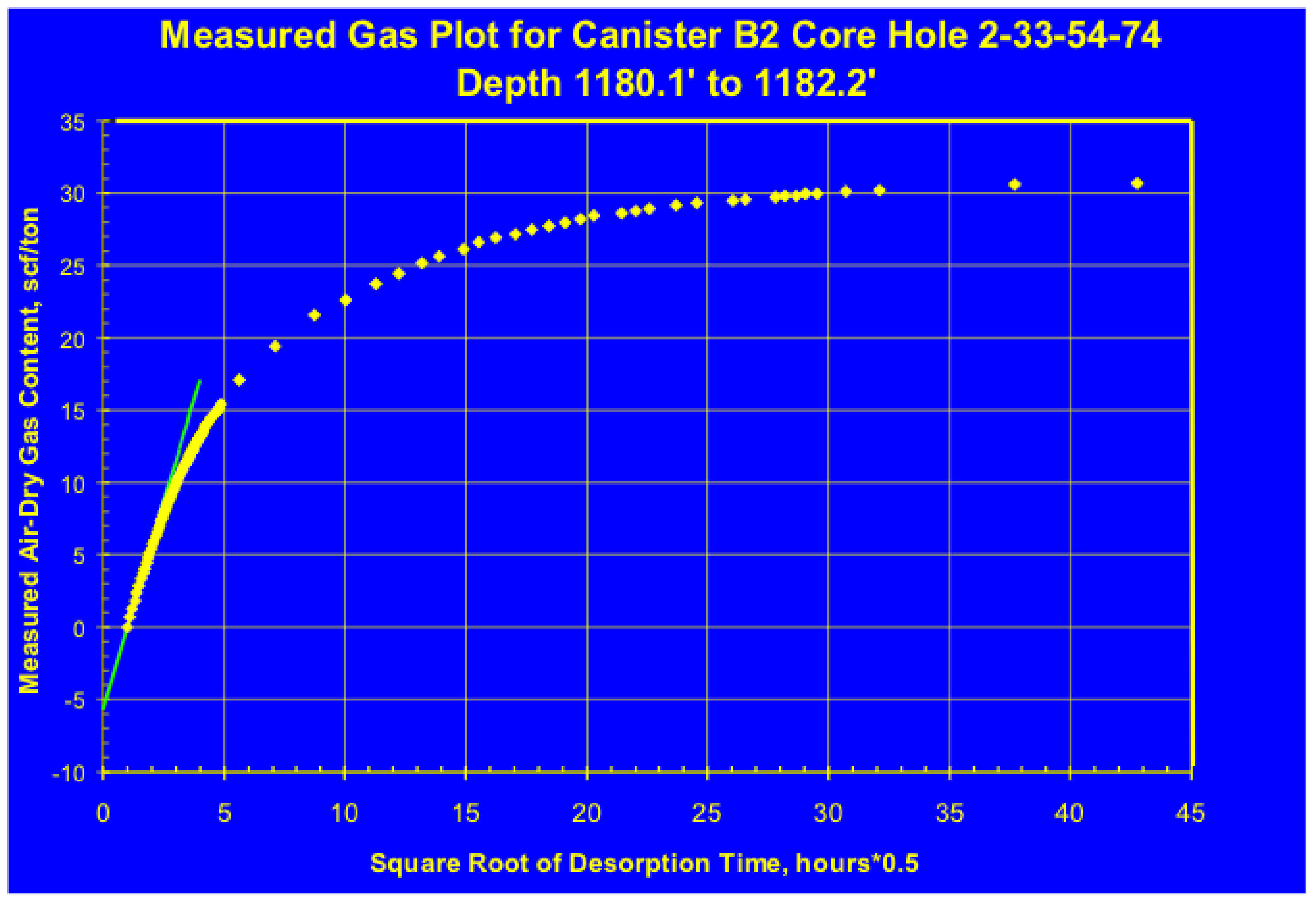
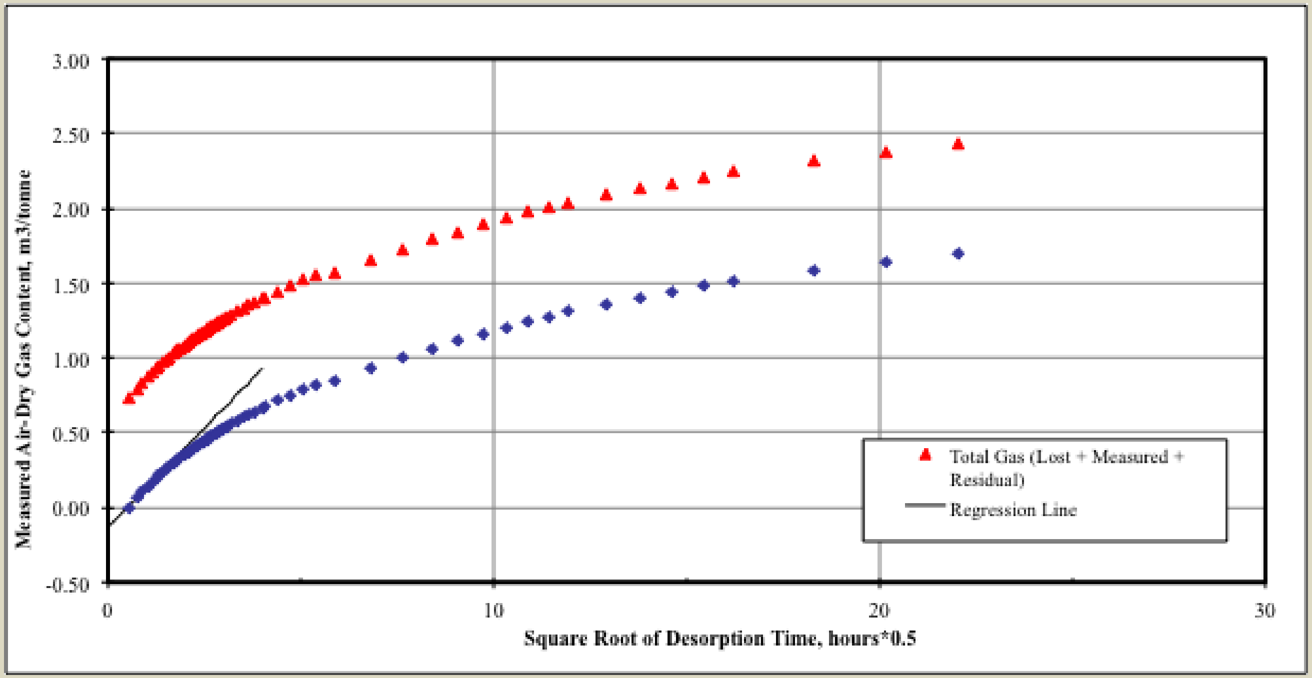
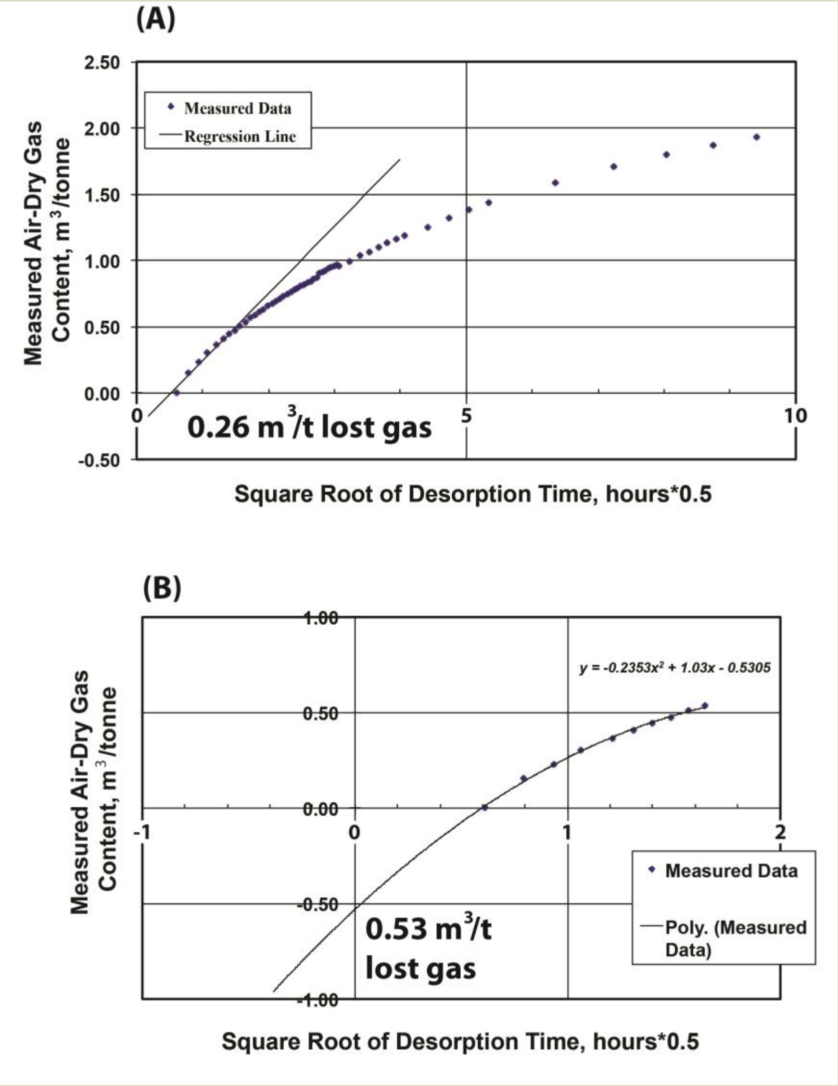


Lost Gas Graphs



- Graphs are usually shown depicting
  - ✧ 'measured' or 'desorbed' gas (blue curve above) and
  - ✧ Total Gas (Measured+Residual+Lost) (red curve above)

Linear vs Polynomial Regression for Lost Gas



- Classically, lost gas have been calculated with a linear regression
- In moderate to low permeable coals, this is probably correct
- Some procedures now use a polynomial regression, which has been argued is more representative to how more permeable coal might lose gas
- The difference between the two lost gas regressions can result in significant increases in total gas
- There is a possibility to incorrectly use the polynomial regression, thus caution should be used

Cautions in Lost Gas

- The most important attribute for Lost Gas is a swift recovery of core from when the core barrel begins tripping out of hole to when core is sealed in canister.
  - ✧ Although the coal core should measured and described, this needs to be done swiftly and without delay
  - ✧ Core should be in shade
  - ✧ Each canister, once sealed, leak tested <u>every time</u>.
- Long 'trip' times (i.e. 45 mins and longer) will result in significant errors in Lost Gas calculations
- Trip times longer than an hour will result in very dubious lost gas estimates and are best discarded.
- If Lost Gas estimates are even greater than the measured gas estimate, this indicates data which needs to be heavily scrutinized if not out-rightly rejected.

Terminology

- Lost Gas (Q1)
- Desorbable Gas (Q2)
- Residual Gas (Q3)
- {Desorbable Gas Content (Q1+Q2)}
- Measured Gas Content Qm (Q1+Q2+Q3)

T calc to 20^{o}C and 101.3 kPa

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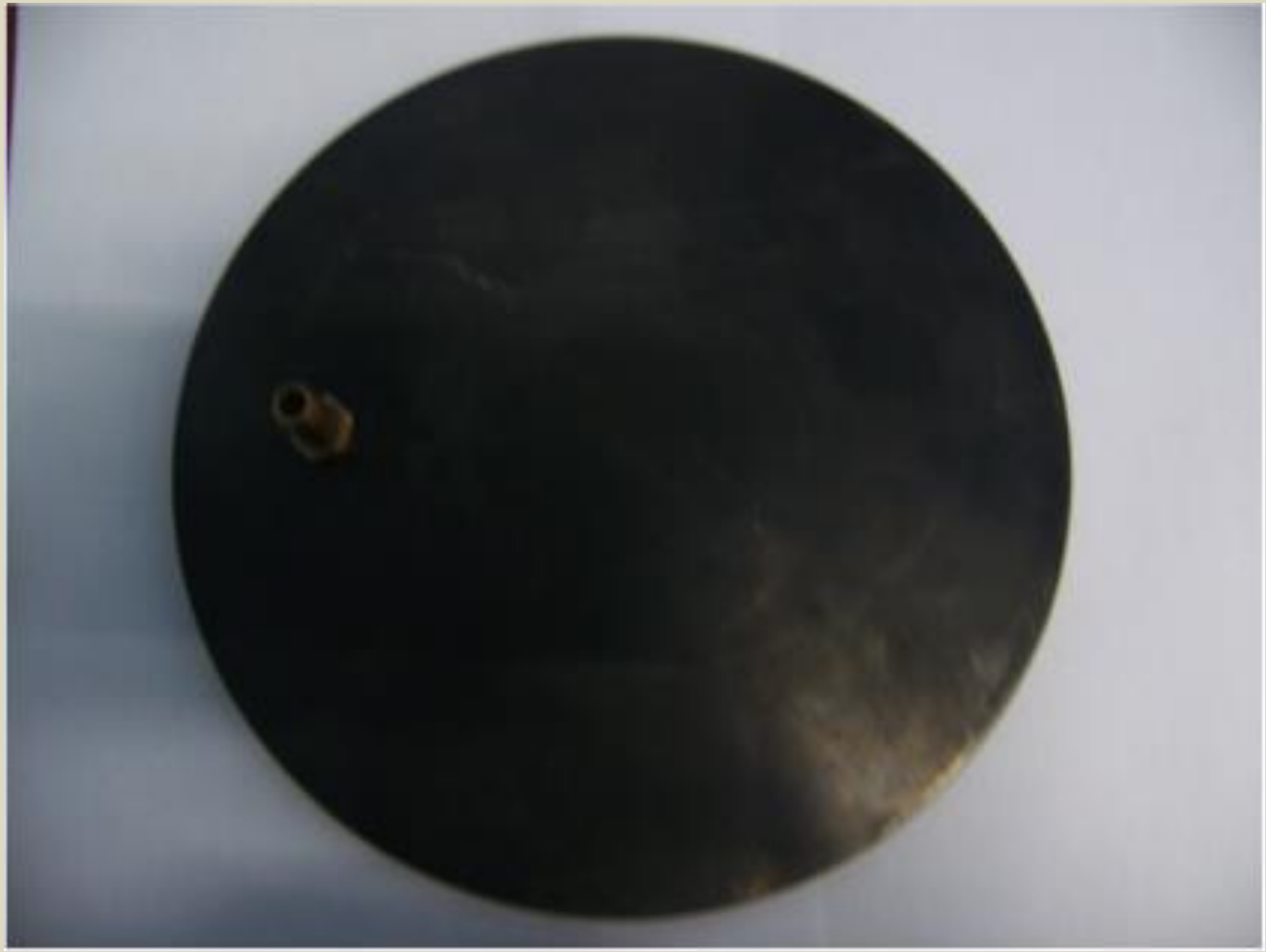
What is Residual Gas?

- Residual gas is that gas which can not be desorbed or is very hard to desorb.
- The amount of residual gas varies from basin to basin, coal to coal, sample to sample.
- Residual gas can be as little as 1-2% of the total (Lost+Measured) gas or as great as 10-15%

Ring mill with pneumatic clamp

The Eponymous Rings in a Ring Mill

Top of Ring Mill with Gas Outlet



Under-side of Ring Mill showing O-ring

Variations of Ring Mills

Equipment List for Residual Gas Analysis & Decommissioning

- Canisters
- Ring Mill
- Ring Mill Head (bowl)
- Gas tight lid for Ring Mill Head with O-Ring seal and valve to attach tube from manometer
- Tube from Ring Mill Head to manometer
- Zero head manometer
- Barometer
- Temperature probe
- Balance capable of accurately weighing canister and sample. Range from 0 – 10,000 g, resolution +/- 1g.
- Reference weights (3)- 5kg, 1kg, 200g. **ALWAYS** be careful with the reference weights, store them safely when not in use. They are only useful if they are undamaged. If they are damaged, or dropped, they need to be **RECALIBRATED**.
- Timer
- Digital camera
- Spare batteries for barometer, timer and digital camera
- Waterproof labels
- Marker pens
- Ziplock bags
- Thick plastic sample bags (approximately 300mm x 400mm)
- Duct tape, or other suitably strong tape
- Data sheets
- Tables and chairs or stools in order to work comfortably

Residual (Q3) Gas Measurement

1. Measure the final desorbed volume from the canister while it is in the water bath. Record the readings (date, time, volume, ambient air pressure from barometer, water bath temperature). Enter readings on desorption form with comment “Final Reading”.
2. Check that the balance is weighing accurately. Place the reference weights (5kg, 1kg and 200g) on the balance and record the weights. If the balance has up to a 1% variance from the weights can be corrected by calculation in the spreadsheet. If the balance has more than 1% variance from the weights, stop and fix the balance - do **not** continue until the balance problem is fixed. Return the canister (from Step 1) to the water bath, until ready to continue.
3. Take canister from the water bath, dry off the excess water from outside canister and weigh the canister- record the weight on the Desorption Form and Residual Gas Analysis Form, (Canister + Coal).
4. Unscrew the base of the canister and fill the canister with water. Screw the base back on. Make sure that you COMPLETELY fill the canister, so that there is no air in the canister when the base is screwed back on. Weigh and record the weight on the data sheet (Canister + Coal + Water).
5. Drain the water from the canister and remove the coal from the canister- place the coal on a clean plastic bag or clean PVC split.
6. Select the sample that will be used for the residual gas analysis (a subset of the total coal in the core). Select the most intact sample as this is likely to have the most remaining gas. The sample should weigh around 400g (check on balance, no need to record the figure). Briefly describe the sample, making note of the brightness, cleat and fracture spacing, and record in field notebook (if there is a second person get them to record the description while the 1st person goes on to Step 7).
7. Put the sample in the mortar bowl and break it up into pieces that will fit into the ring mill bowl, sub 10mm diameter approx. Record the time on the data sheet (Time of First Crush)
8. Weigh 150-200g of coal pieces on the balance. Record the weight on the Residual Gas Analysis Form (Weight - Sample A).
9. Put the sample in the ring mill bowl. Make sure that you put ALL of Sample A into the ring mill bowl.
10. Check to make sure that the O-ring seal on the top is clean. Put the top of the mill head onto the mill head bowl.
11. Put the mill head into the ring mill and clamp.
12. Attach the tube from the mill head to the manometer.

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Residual (Q3) Gas Measurement [cont'd]

13. Pre test LEAK CHECK the system by opening the valve on the manometer and filling the manometer with air. Close the valve and push the manometer down into the water. Carefully look at the water level to see if it is rising inside the manometer. Keep the pressure on for 10 seconds while carefully watching. If the water level is rising you must fix the leak before you start the test!
14. If system does not leak, the test can start.
15. Zero the manometer, then record the ambient pressure, temperature and start time on the Residual Gas Analysis Form
16. TEST. Run the ring mill for 20 to 30 seconds then switch off.
17. Record the measured volume of gas on the Residual Gas Analysis Form every 15 seconds for the first 2 minutes then 30 seconds intervals until there is no measurable gas coming off the sample. Don't forget to get all the measurements, (the first one, at 15 seconds, is easy to miss).
18. If there is still gas coming off the sample (positive values- **increasing**) keep measuring at 30 second intervals until it stops increasing.
19. When finished measuring, remove the sample from the ring mill bowl and place it a ziplock bag. Label the bag with the project name, canister number and sample number (A or B). Get as much air out of the bag as possible before closing it.
20. Repeat steps 8 to 19 for Sample B. REMEMBER TO ALWAYS CONDUCT A LEAK TEST BEFORE STARTING THE RING MILL.
21. Once you have finished the second sample (B) briefly describe the remainder of the core, making note of the brightness, cleat and fracture spacing and record in field notebook. Write the project name and canister number on a waterproof label, place it beside the remainder of the coal core. Write "Residual Gas Sample" on a second waterproof label and put in the core at the location of the sample taken for ring milling. Take a digital photo of the core.
22. Place all of the coal sample into a plastic bag that has the project name and canister number written on it in waterproof marker pen. Put the two ziplock plastic bags with the ring mill samples in with the rest of the coal sample still in their bags. The big sample bag should be put inside another big sample bag with the waterproof label facing out, between the bags, so that it is easy to read. Get as much air as possible out of the sample bag by twisting the top shut. Tape the top of the bag securely shut with strong tape.
23. The coal sample is now in a well labelled and sealed bag and is ready to be sent to the laboratory for further analyses as required by the client. Store the sample safely until then.
24. Rinse the canister out with water to get rid of all of the coal chips which might still be in it.
25. Fill the canister with water. Again, make sure that you COMPLETELY fill the canister, so that there is no air in the canister when the base is screwed back on. Weigh and record the weight on the Residual Gas Analysis Form (Canister + Water).
26. Drain the water from the canister. Weigh and record the weight on the Residual Gas Analysis Form (Empty Canister).

Before Taking Residual Sampling: Weighing

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Filling Canister with water (with coal inside)

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Weighing the coal for Residual Gas Determination

Grinding the Coal for Residual Gas Determination

Placing Coal into the Ring Mill

Residual Gas (Q3) Gas Measurement

Recording Residual Gas Measurements

RESIDUAL GAS ANALYSIS FORM

Project:			Canister #:		
Date:					
Time of last desorption reading:			Time of first crush:		
Decomissioning Weights					
Canister+coal					g
Canister+ coal + water					g
Canister + water					g
Empty Canister					g
Sample 1			Sample 2		
Weight		g	Weight		g
Temperature		°C	Temperature		°C
Pressure		in Hg	Pressure		in Hg
Start time			Start time		
Elapsed Time	Gas Volume (ml)	Comments	Elapsed Time	Gas Volume (ml)	Comments
0:00	0		0:00	0	
0:15			0:15		
0:30			0:30		
0:45			0:45		
1:00			1:00		
1:15			1:15		
1:30			1:30		
1:45			1:45		
2:00			2:00		
2:30			2:30		
3:00			3:00		
3:30			3:30		
4:00			4:00		
4:30			4:30		
5:00			5:00		

RESIDUAL GAS ANALYSIS FORM

Project:			Canister #:		
Date:					
Time of last desorption reading:			Time of first crush:		
Decomissioning Weights					
Canister+coal					g
Canister+ coal + water					g
Canister + water					g
Empty Canister					g
Sample 1			Sample 2		
Weight		g	Weight		g
Temperature		ºC	Temperature		ºC
Pressure		in Hg	Pressure		in Hg
Start time			Start time		
Elapsed Time	Gas Volume (ml)	Comments	Elapsed Time	Gas Volume (ml)	Comments
0:00	0		0:00	0	
0:15			0:15		
0:30			0:30		

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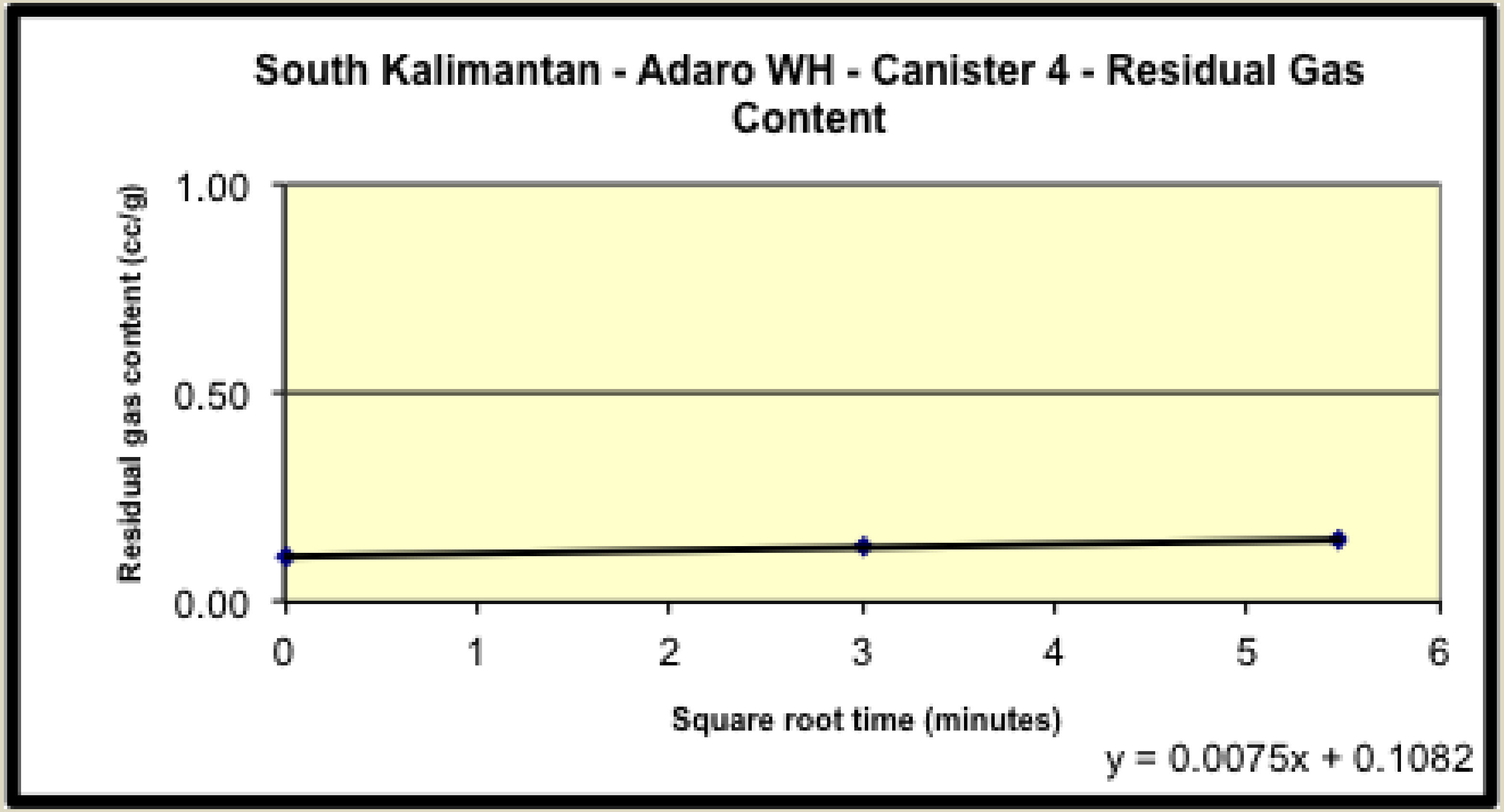
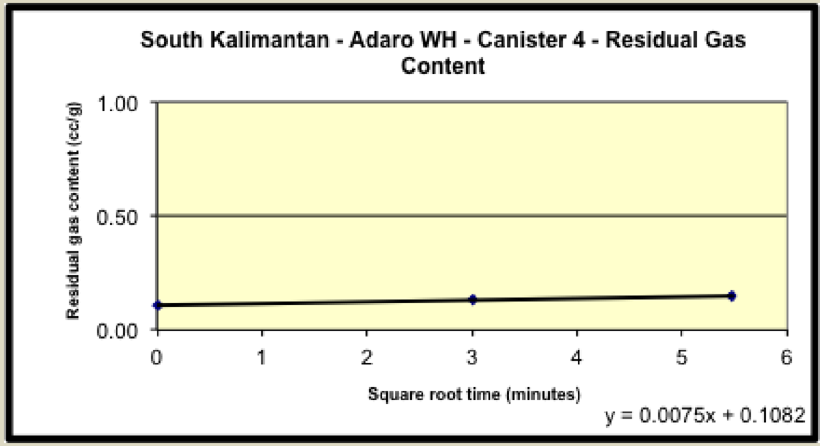
Residual Gas – not a single output!

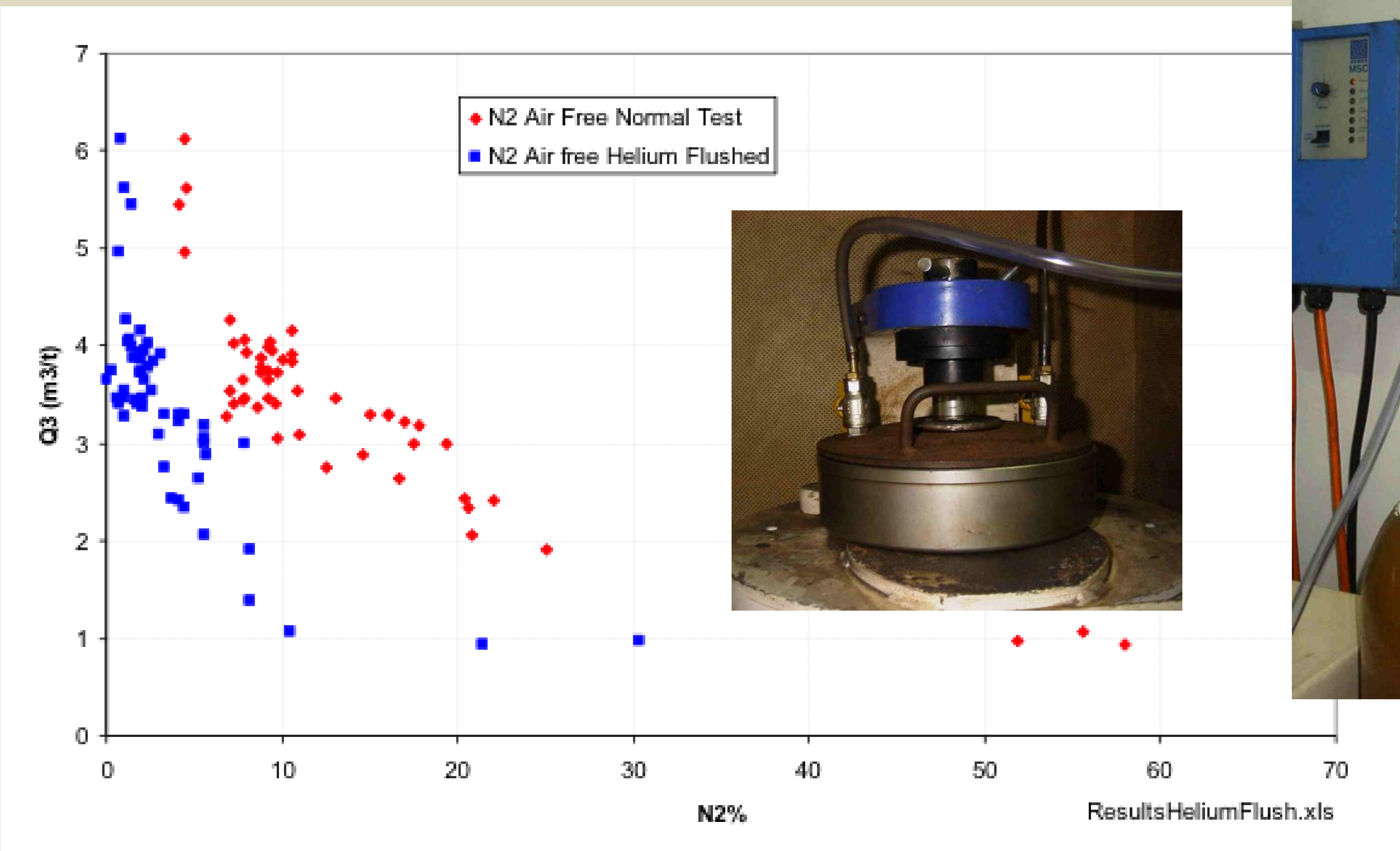


Residual Gas – not a single output – and other problems!

- The 'art' of residual gas measurement is non-trivial
- Grinding the coal for too short a period will not release all of the gas
- Grinding the coal for too long a period may cause heating and creation of gas
- Gas release is not instantaneous
- Gas volume may reverse if left for too long because of oxidation
- Low rank coals are more reactive and thus more prone to oxidation
- Low rank coals are prone to generation of their own gas if overheated.



Alternative Techniques: Helium Flushing



Residual Gas Measurement into Decommissioning

- Remember to sample representatively
- Bag all remaining coal from a canister
- Include the coal from the ring mill after analysis (I usually have the sample from the ring mill, because its so fine grained, put in a separate bag inside the bag of remaining coal from a canister)
- Send to lab for at the very least proximate analyses (maybe Ro too)

Basic Decommissioning

- Weigh canister
- Fill canister with water (with coal sample still in) & weigh [this will give the amount of headspace in the canister, i.e. canister+coal+water minus canister+coal]
- Drain water
- Remove coal material from canister
- Fill empty canister with water & weigh [this will give you weight of the coal, e.g. canister+coal+water minus canister+water]

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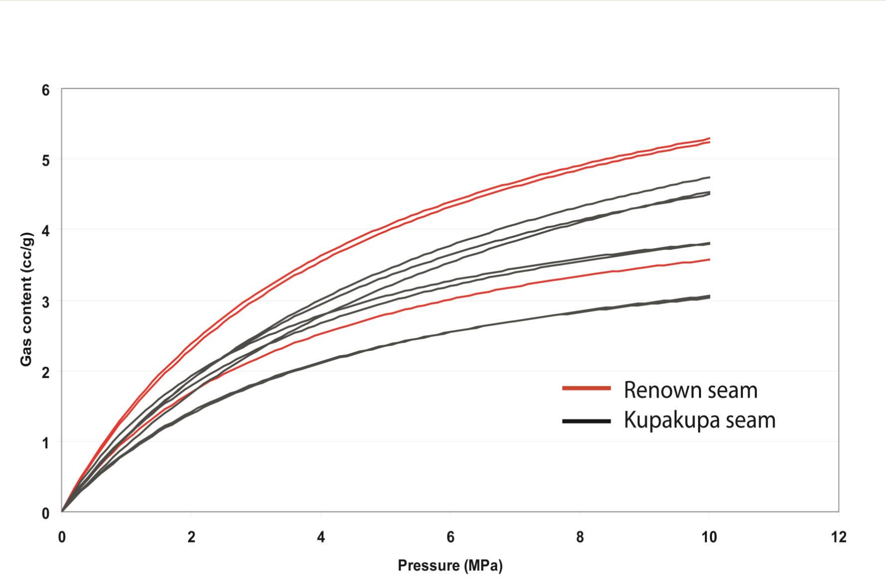
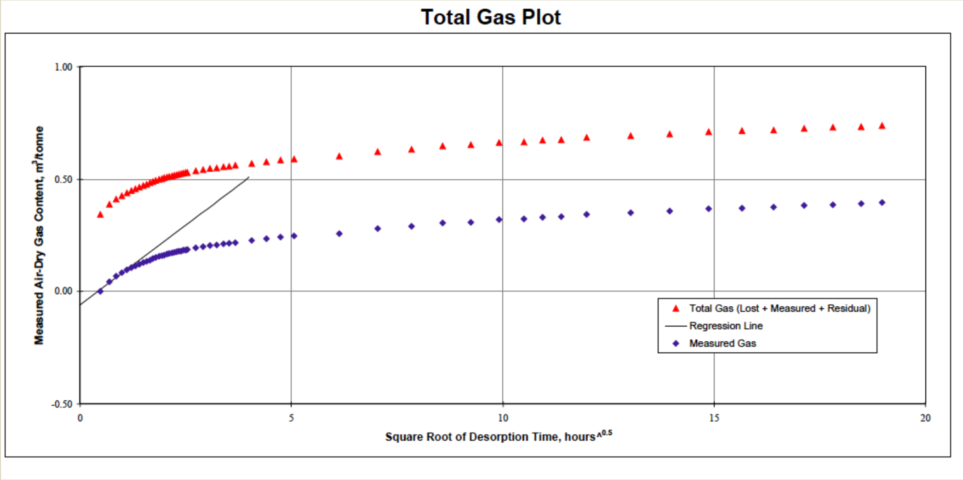
Gas Saturation

Adsorption isotherm



Desorption isotherm



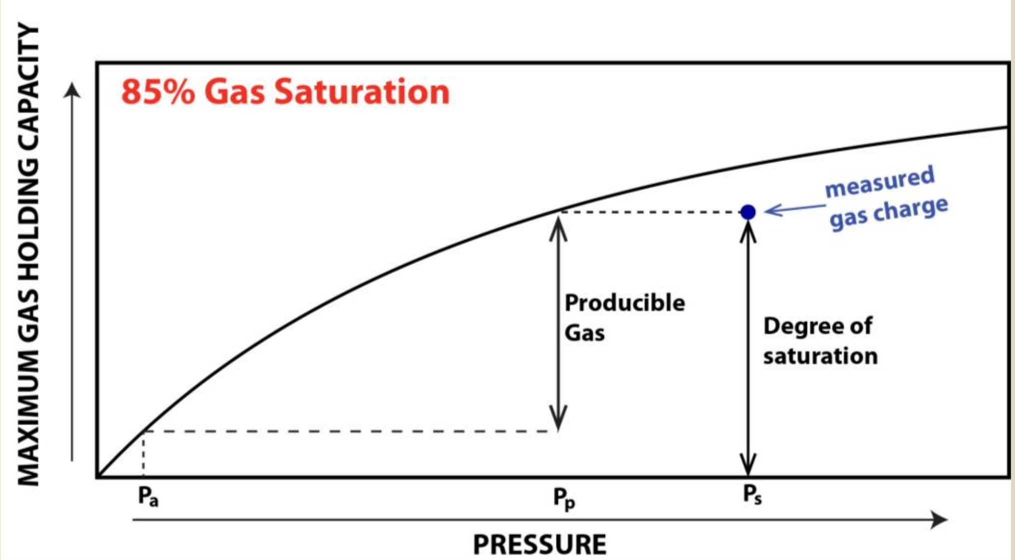
A Definition

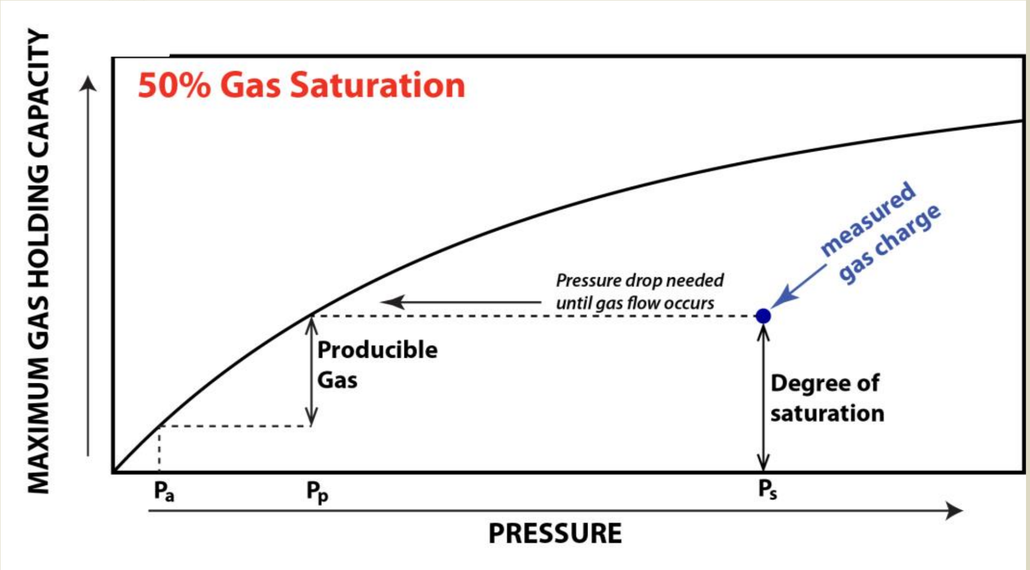
What is Gas Saturation in a Coalbed Methane Reservoir?

- *Gas saturation is a the difference between the actual amount of gas a coal layer can hold versus the maximum potential holding capacity of the coal layer.*

- *Gas saturation is calculated from comparing adsorption (a laboratory measure of maximum gas holding capacity) desorption (an actual measure of gas from coal core) isotherms.*

Adsorption & Desorption Curves





from Moore, 2012

Why is Gas Saturation Important?

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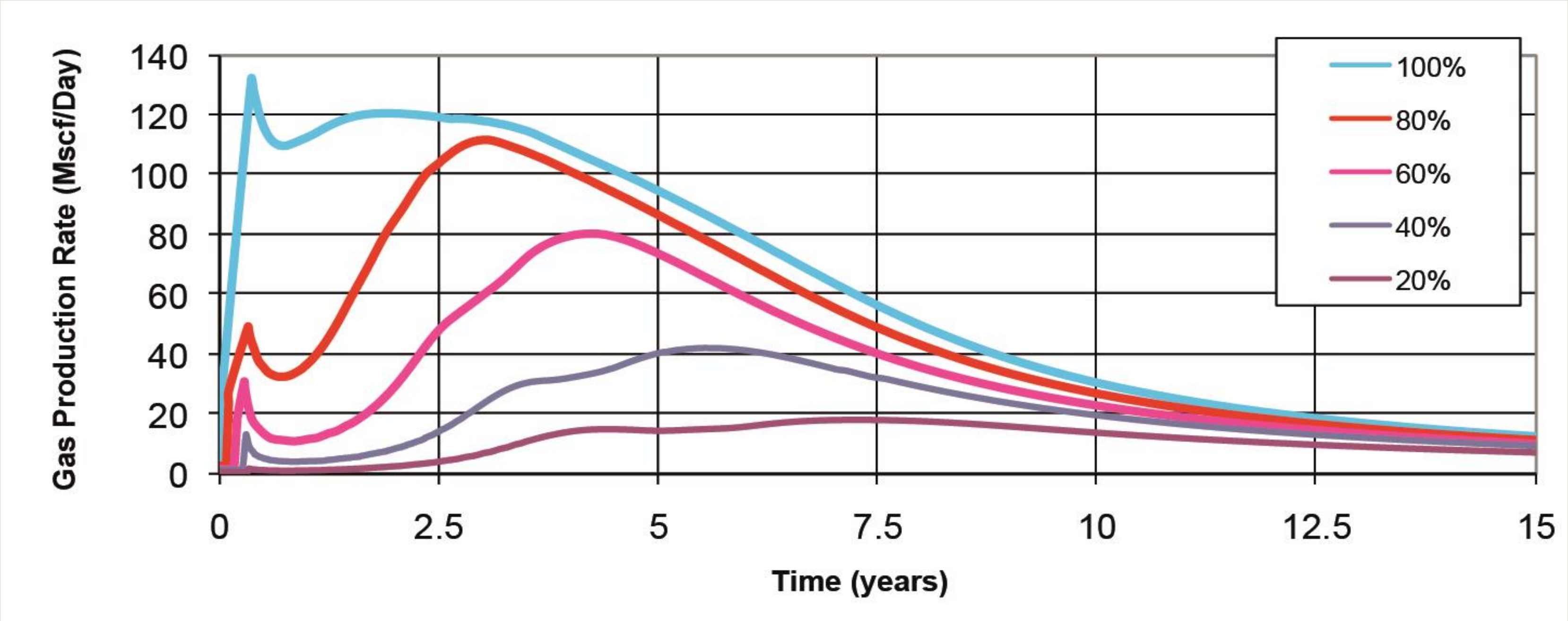
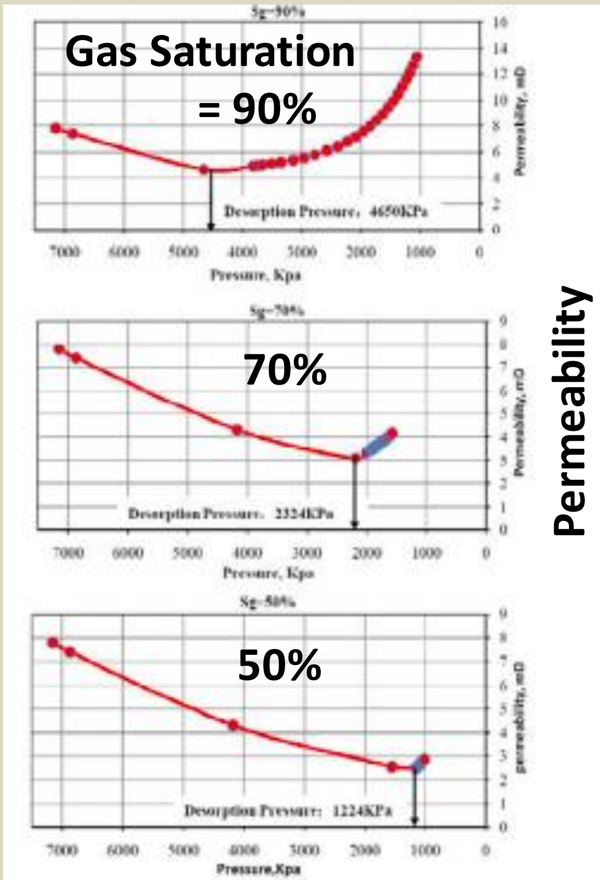
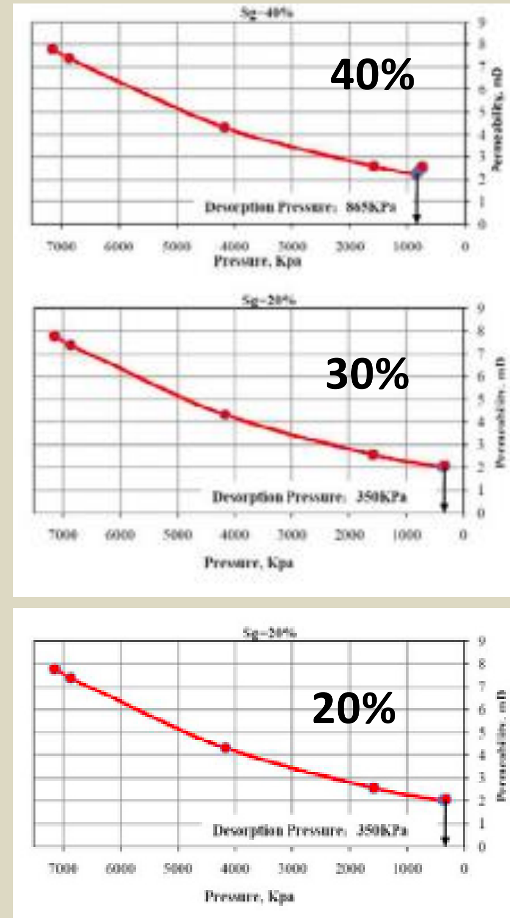


from Moore & Zarrouk, 2011

Why is Gas Saturation Important?





from Zheng et al., 2011

Questions?

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Tim Moore is currently the **Managing Director of Cipher Consulting Pty Ltd** specializing in advising on coal and coalbed methane exploration. He is also **Adjunct Associated Professor at the School of Earth and Atmospheric Sciences, Queensland University of Technology**, Brisbane, Australia and a **Distinguished Visiting Professor at the School of Resources and Geosciences, China University of Mining and Technology**, Xuzhou, China. Tim is also on the Editorial Boards for the International Journal of Coal Geology and the Indonesian Journal on Geoscience. He has over 260 published papers, reports and abstracts. Over the last 40 years, Tim has worked in production companies, academia and government positions in many parts of the world. (tmoore@ciphercoal.com)

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Got Questions?

Please visit our website for more information about activities or contact Oyunbileg Purev, Partnership Manager at oyunbileg@amep.mn.

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