Standard Techniques for Sampling and Data Analysis to Estimate CMM/CBM Reserves

Workshop on Best Practices in Coal Mine Methane Capture and Utilization

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Jonathan R. Kelafant, Sr. Vice President
Advanced Resources International

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“You can’t manage what you don’t measure.”

- Peter Drucker

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Presentation Overview

- Several key reservoir parameters governing the calculation of CMM/CBM resources and ability to produce these resources have either not been measured or have been measured improperly in Colombia.
- Therefore difficult to assess the country's true CMM/CBM potential.
- Presentation seeks to provide an overview of how Colombia can cost-effectively obtain critical reservoir parameters governing storage and flow of methane in coal seams.

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Reservoir Parameters Needed to Accurately Predict CMM/CBM Production

Parameter	Potential Source
Gas content*	Core, canister test
Permeability*	Well test, production data
Desorption isotherm*	Lab measurements on core
Coal rank	Lab measurements
Seam thickness	Logs, core
Pressure	Well test
Temperature	Logs
Cleat spacing	Core samples, outcrop measurements
Diffusion co-efficient	Canister test
Compressibility	Production analysis
Gas saturations*	Gas content/isotherm
Desorption pressure	Canister test, lab measurements

*Denotes critical reservoir parameter

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Key Reservoir Parameters for Storage & Flow of Methane in Coal Seams

Parameter	Importance	Status in Colombia
Permeability	~40% of Production	No published permeability measurements
Gas Content/ Saturation ▪ Gas Content ▪ Isotherms	~ 40% of Production	Mixed results and reliability Measurements often too shallow, not representative of in-situ conditions Non-standard curves yield unreliable results
Other Parameters (Cleat Spacing, Sorption Time, Porosity, etc.)	~20% of production	Mixed availability

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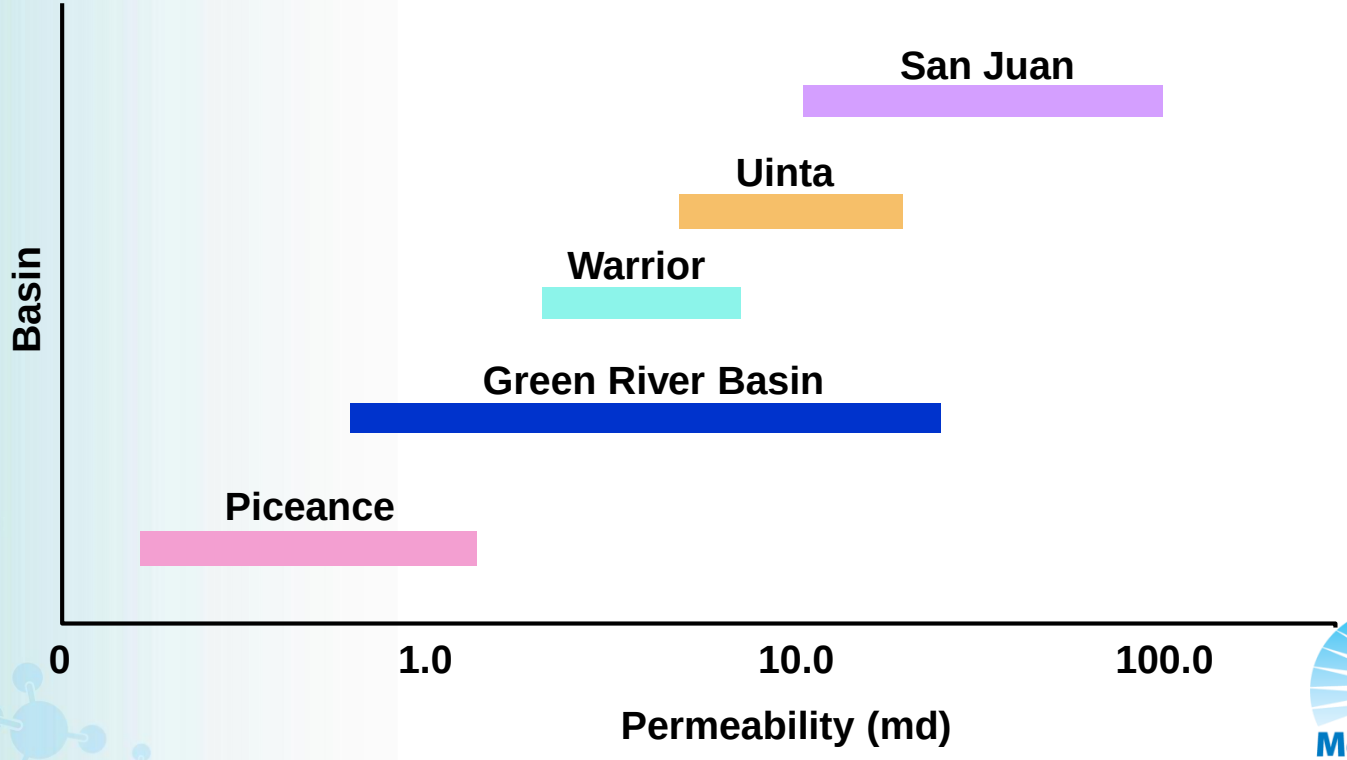
Permeability

- Single most important and variable CBM reservoir parameter.
- Hard to measure: Core useless. Well test better. Production simulation best.
- Generally about 1.0 mD is minimum necessary for economic CBM production (depends on thickness, gas content, saturation, costs, and gas prices).
- Permeability tends to improve over time as reservoir drys out and shrinks, opening cleats.



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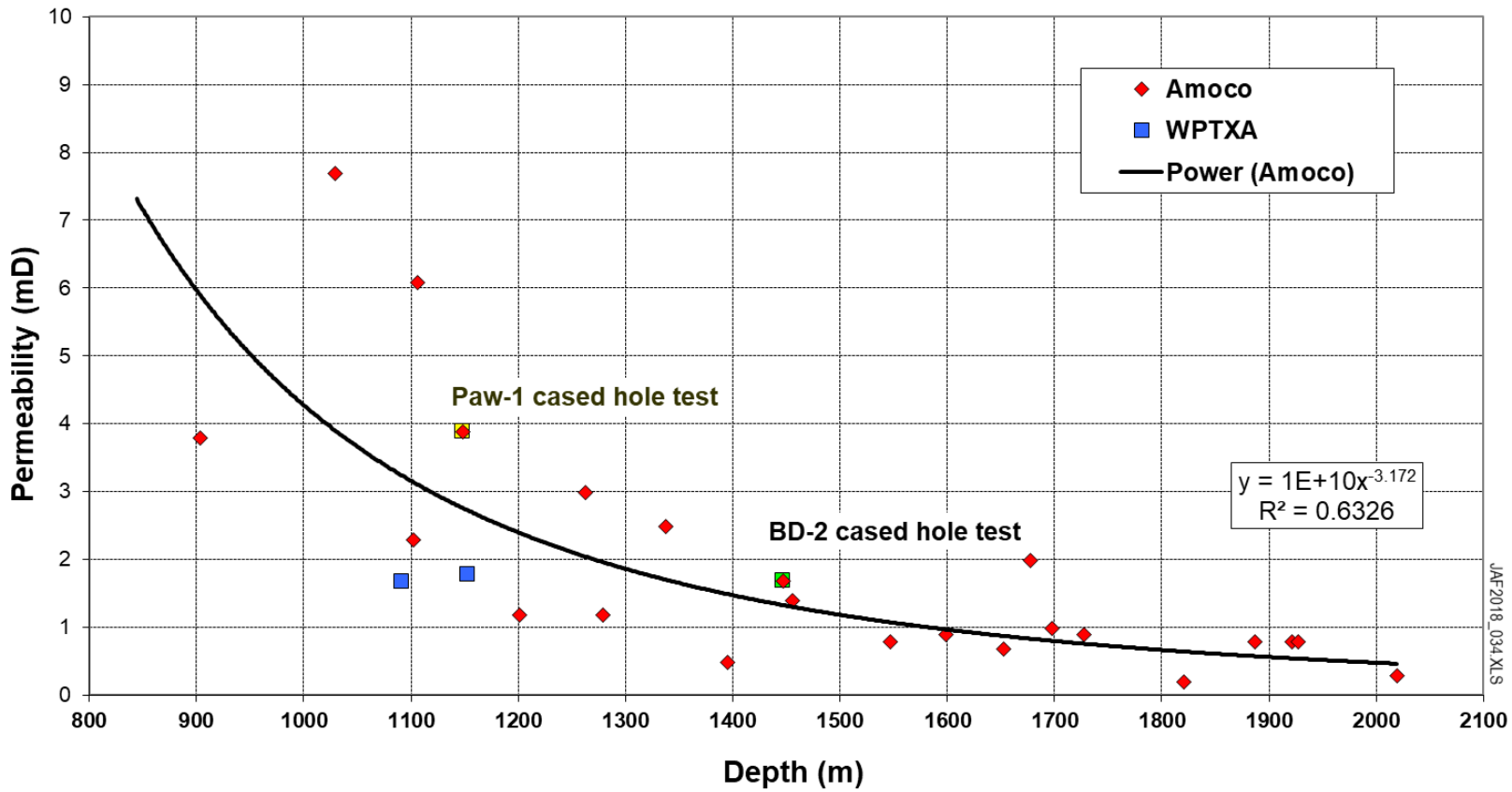
- Permeability must be measured in situ (core unreliable)
- Permeability generally declines with depth



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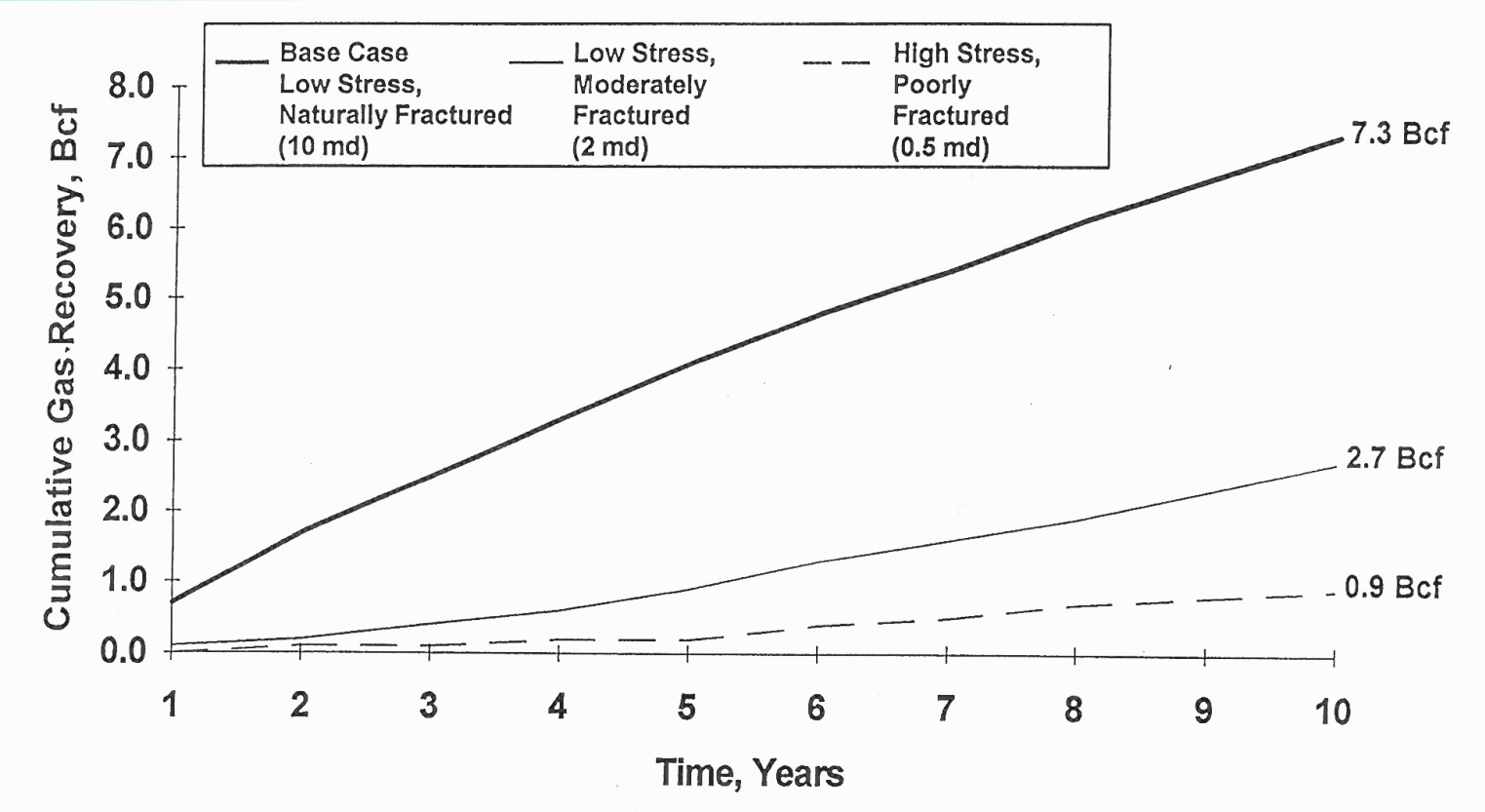
Variability in Gas Productivity Due to Permeability



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Determination of the Gas Content

- Direct Method
  - Core desorption measurement – U.S. Bureau of Mines
  - Core desorption measurements – other
  - Drill cuttings desorption measurements
- Indirect Method
  - Sorption isotherm/pressure
  - Analogy
    - Gas content/depth relationships
    - Geophysical logs

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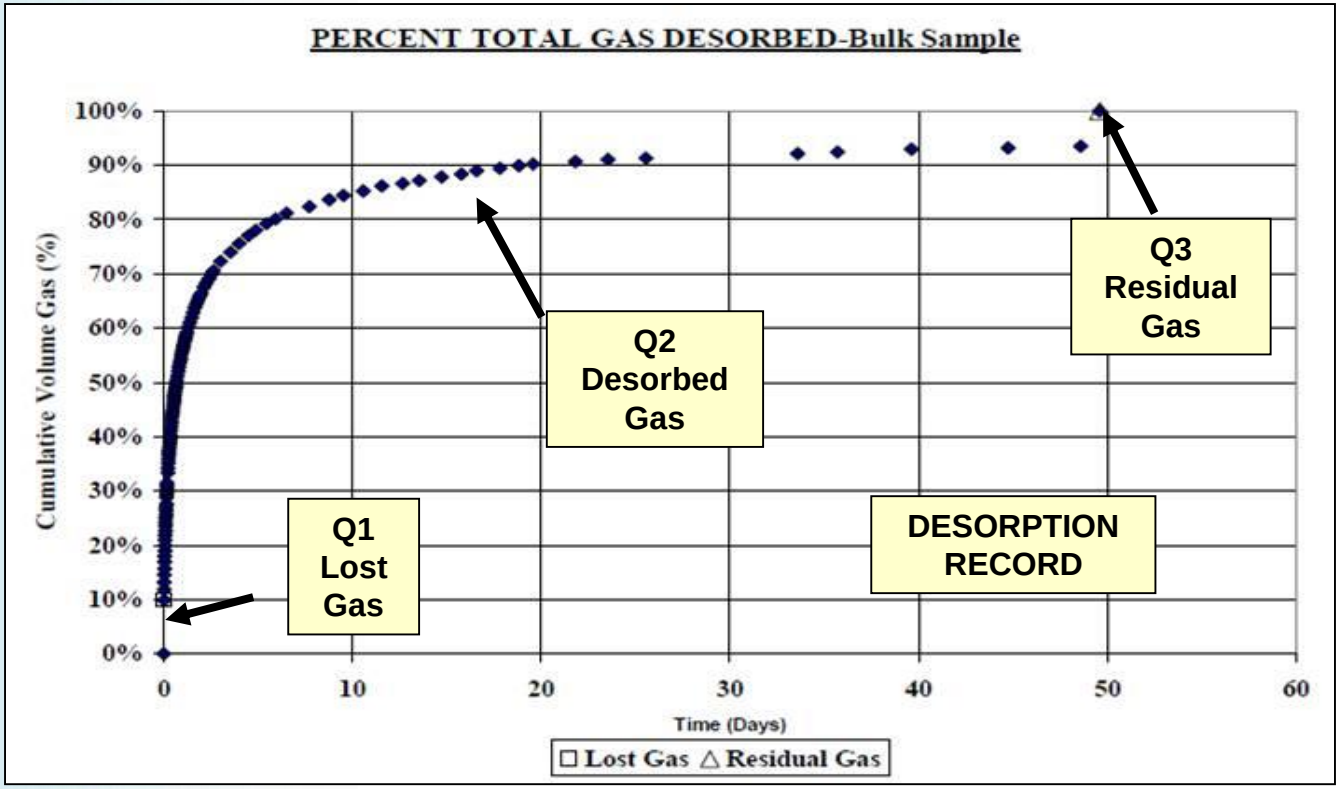
Desorbing Coal Core for Gas Content



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CBM Gas Content – Final Desorption Analysis

Q1 : Desorbed Gas

Q2 Lost Gas

Q3 : Residual Gas

Total Gas Content

sample ID	sample weight (g)			desorbed gas (cm^3)	lost gas (cm^3)	residual sample wt (g)			residual gas volume (cm^3)	gas content(cm^3/g)			methane content(cm^3/g)			sorption time (days)
	air dried basis	dried basis	dry and ash free basis			air dried basis	dried basis	dry and ash free basis		air dried basis	dried basis	dry and ash free basis	air dried basis	dried basis	dry and ash free basis	
002-3-1	1365	1347	1263	18053	186				0	13.39	13.58	14.48	11.8	11.96	12.76	17.29
002-3-2	1010	998	879	11595	117	345	341	300	57	11.65	11.79	13.38	9.3	9.41	10.68	19.11
002-3-3	1410	1391	1123	17484	335	370	365	295	83	12.67	12.85	15.91	11.69	11.85	14.67	10.17
002-3-4	1540	1520	1229	16059	350	295	291	235	138	10.68	10.83	13.39	9.79	9.92	12.27	17.73
002-3-5	1560	1536	963	13533	274	350	345	216	138	8.88	9.01	14.37	8.04	8.17	13.03	16.74
002-3-6	1245	1229	1131	17761	280	350	345	318	87	14.53	14.72	15.99	13.06	13.24	14.38	16.45
002-3-7	1445	1424	1356	21411	281	360	355	338	87	15.05	15.27	16.05	13.66	13.85	14.56	15.21
002-3-8	1565	1542	1476	23366	314	365	360	344	78	15.13	15.35	16.04	13.94	14.14	14.77	14.83
Coal Average										**12.75**	**12.92**	**14.95**	**11.41**	**11.57**	**13.39**	**15.94**
002-15-1	620	614	607	8995	143				0	14.74	14.87	15.06	13.04	13.16	13.32	5.54
002-15-2	850	843	776	9879	205				0	11.86	11.96	13	10.41	10.49	11.41	9.75
002-15-3	1015	1007	759	9581	175				0	9.61	9.69	12.86	8.39	8.46	11.23	4.57
Coal Average										**12.07**	**12.17**	**13.64**	**10.61**	**10.7**	**11.99**	**6.62**

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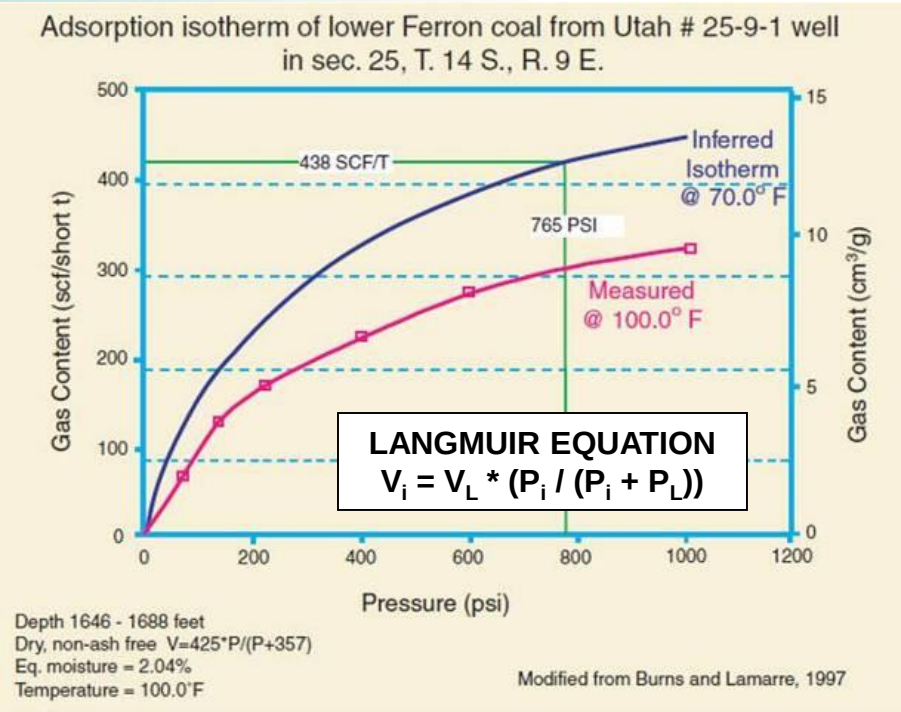
Sorption Isotherm - Measurement

- Fresh coal samples, preferably from canisters after gas content desorption (>100 g).
- Low-ash (<20%) samples much preferred since less adjustment to d.a.f. basis.
- Run at constant reservoir temperature ("isotherm"). HT = lower sorptive capacity (entropy).
- Langmuir EQN : VL = Langmuir Volume (asymptote) PL = Langmuir Pressure (curviness)



- Lab pulverizes coal, allows it to reach equilibrium moisture.
- Inject methane, allow coal to sorb. Measure methane volume.
- Typically run at 6 to 8 different pressures to fit Langmuir curve.
- Try to run various coal ranks and maceral content combinations to bracket reservoir variability.
- Couple weeks. Cost $1000-2000.
- Few labs in the world are reliable.

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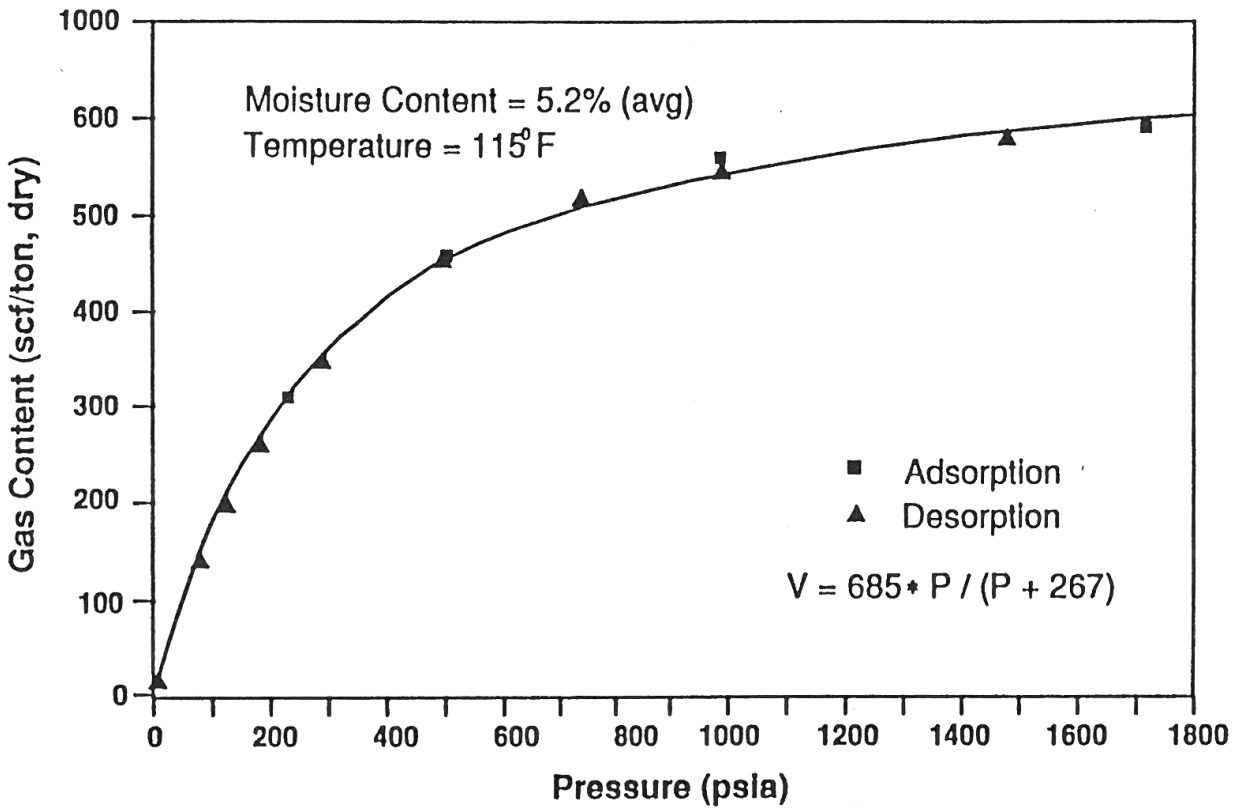
Adsorption/ Desorption Isotherm



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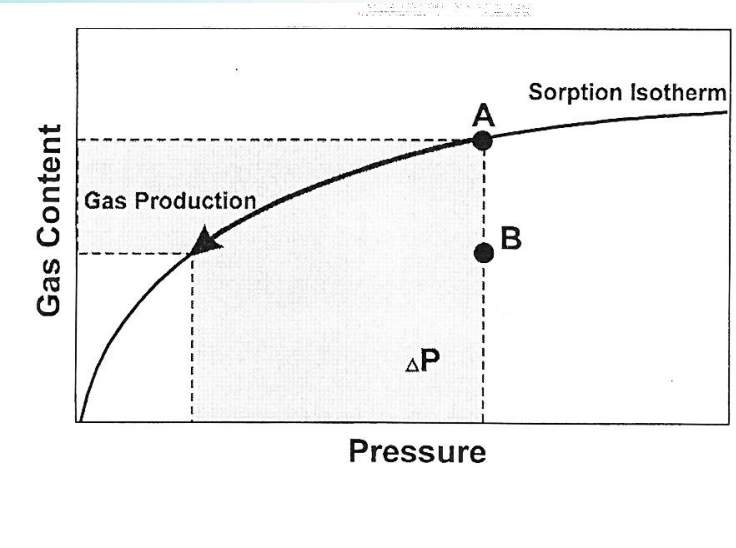
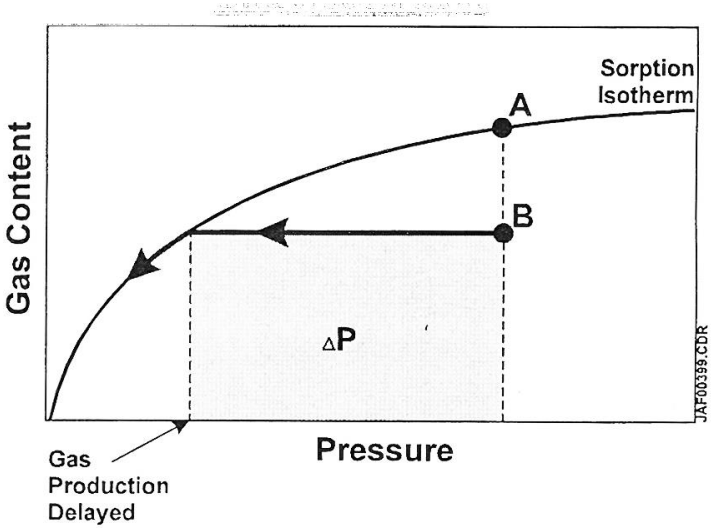
Gas Content and Gas Saturation

- Potential Problem: If actual gas content is less than the theoretical storage capacity of the coal, as defined by the sorption isotherm, then gas production would be delayed and reserves reduced.

Saturated



Undersaturated



Saturated coal seam (A) contains the maximum gas content that is theoretically possible, as defined by the sorption isotherm determined in the laboratory. Gas production begins immediately at start of de-watering and pressure drawdown.

Undersaturated coal seam (B) contains less methane than the coal seam can adsorb, due to a prior de-gassing event. Several years of de-watering and pressure drawdown are required even to elicit gas production; ultimate reserves are reduced.

Gas content is a key parameter to measure during an exploration testing phase.

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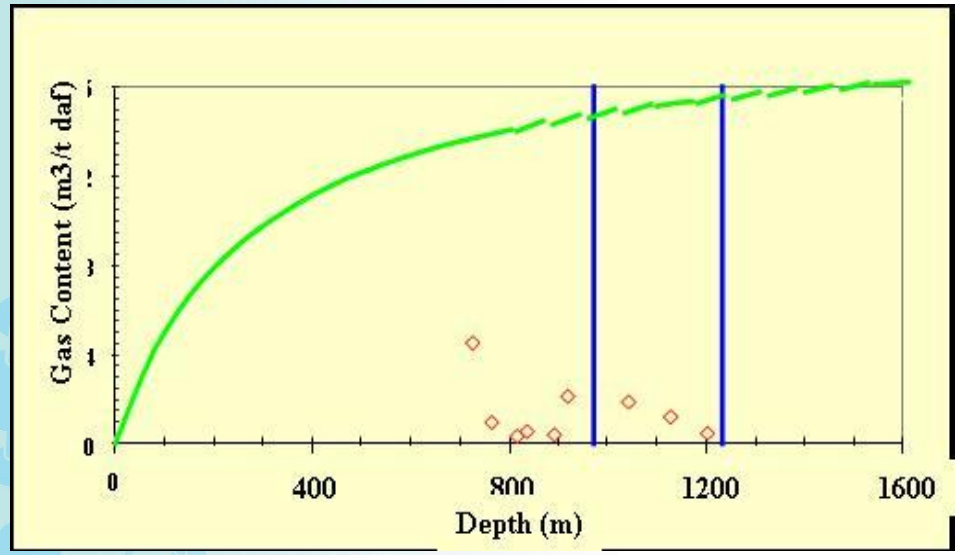
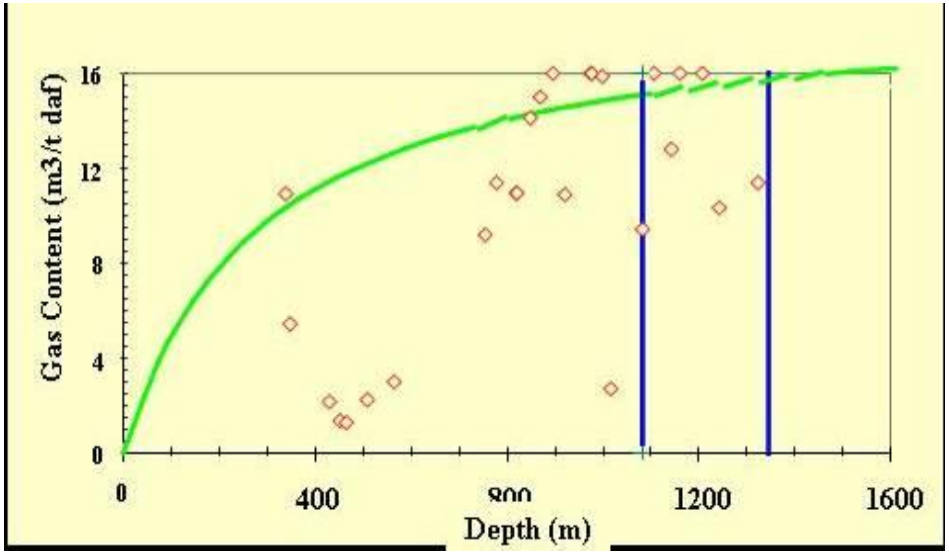
Gas Content and Gas Saturation

- Corehole 1 is highly under-saturated.
- Corehole 2 is saturated below a depth of about 800 m.
- Note data scatter and uncertainty.

Depleted to Undersaturated



Partly to Fully Saturated



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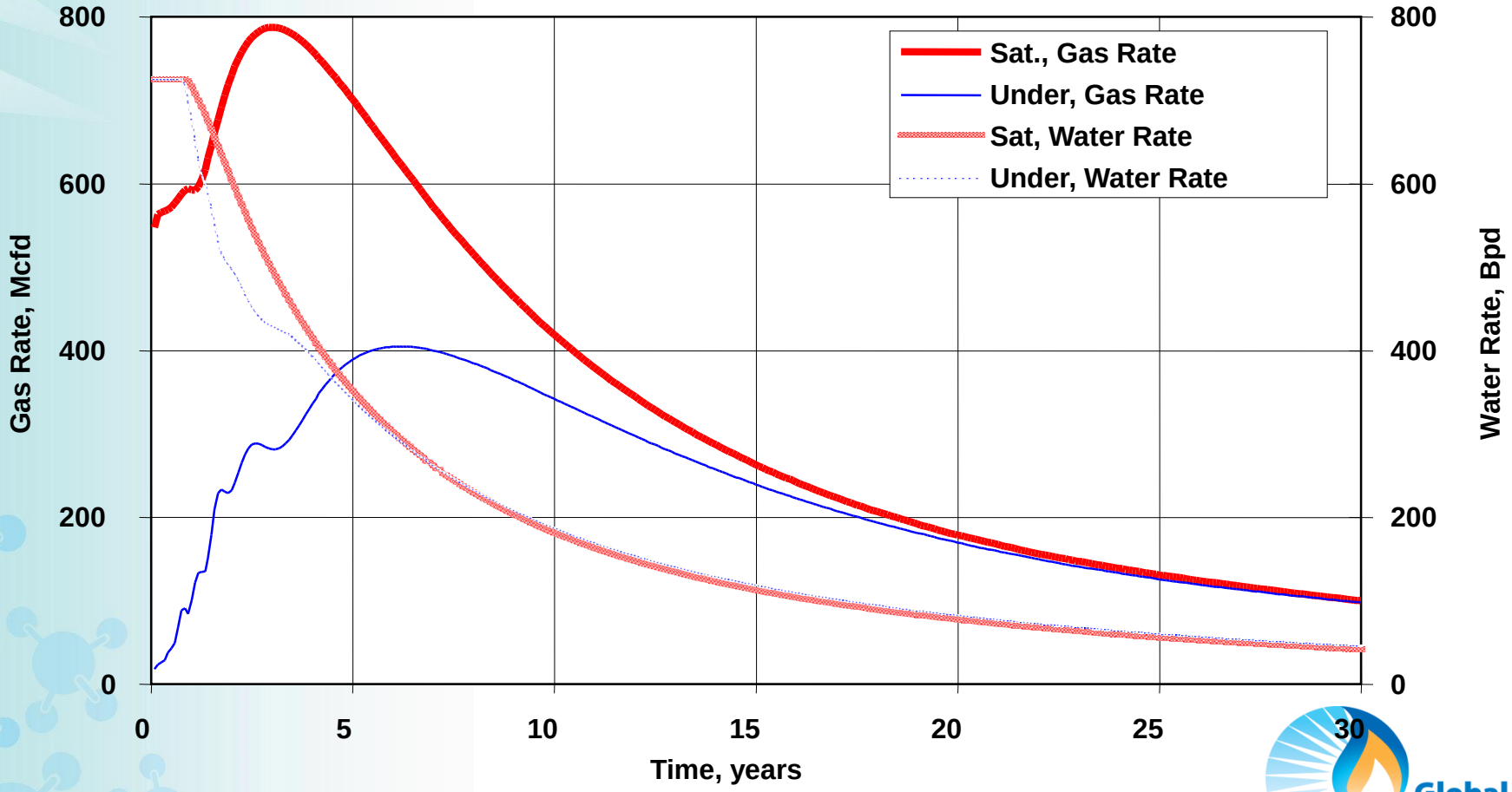
Effects of Undersaturation on Gas Production

- Production Decline: Gas production is delayed and lower for under-saturated compared with saturated coal reservoirs, harming economics.



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How Can the Required Reservoir Parameters be Obtained?

In many countries, diamond-drill coring rigs used in the mining industry can be used to cost effectively obtain critical reservoir parameter samples.

- Capable of continuously coring to depths up to 1,500 m (BQ or 1.5”)
- Most employ a wireline coring system for quick trip times (<10 min); minimizes errors in measuring gas content
- Allows for low-cost delineation of coal geometry, gas content/gas saturation, and other reservoir properties

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Coring the Well

Core bit and barrel

Extracting core from core Barrel

Highly portable mineral coring rig (LF 70), NQ-sized core (1-7/8”), 10 foot core per trip.

- The core is retrieved with a wireline to minimize gas loss
- Advantages
  - Can cut and recover cores without pulling the drillstring
  - Does not require continuous coring
  - Quicker retrieval of the core
  - Usually lower cost than conventional drilling rig

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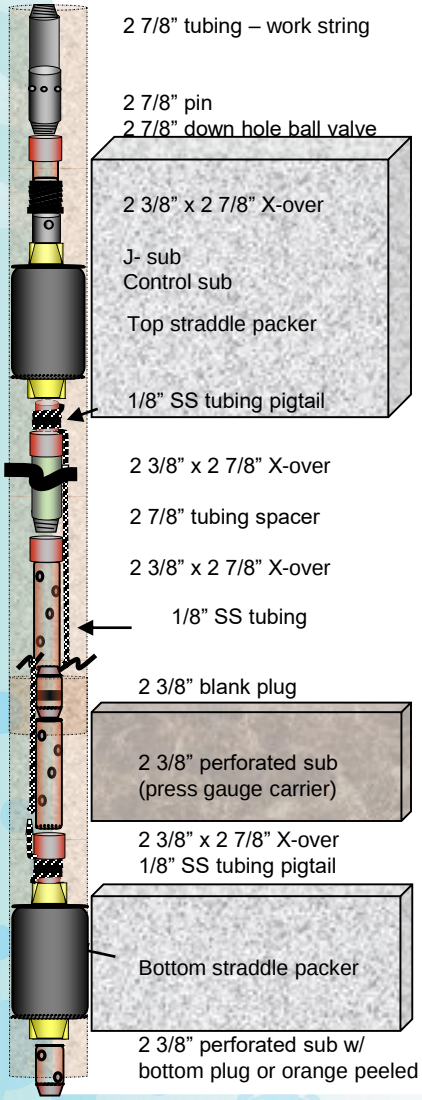
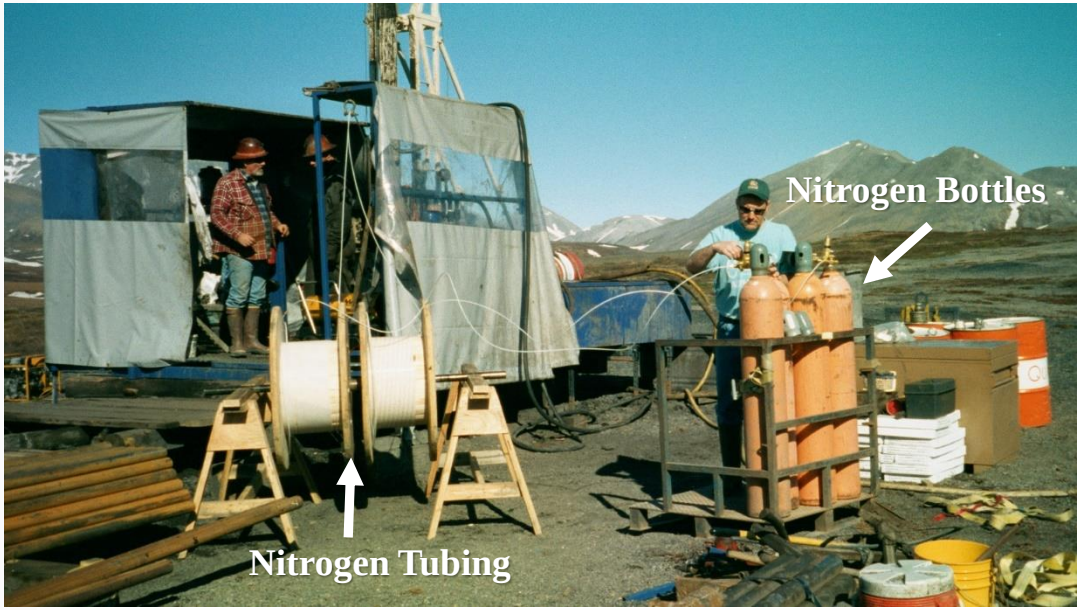
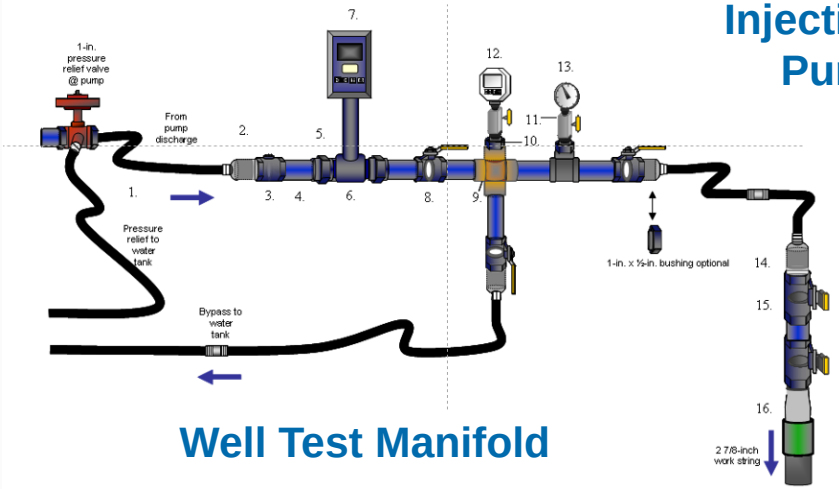
Injection Testing Equipment for Permeability

Straddle Packer System





Surface Set Up



Well Test Manifold

Injection Pump

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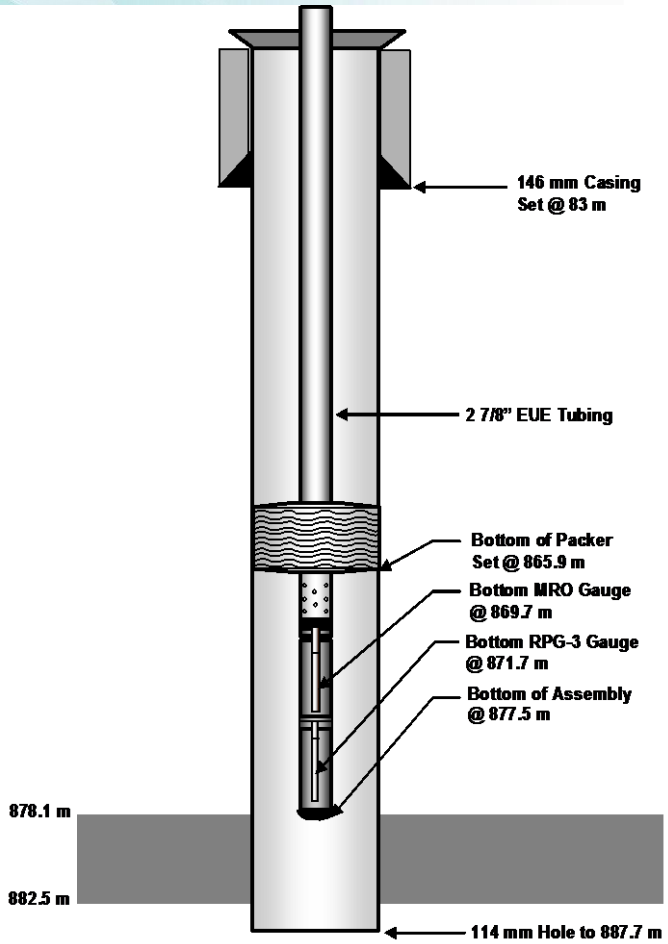
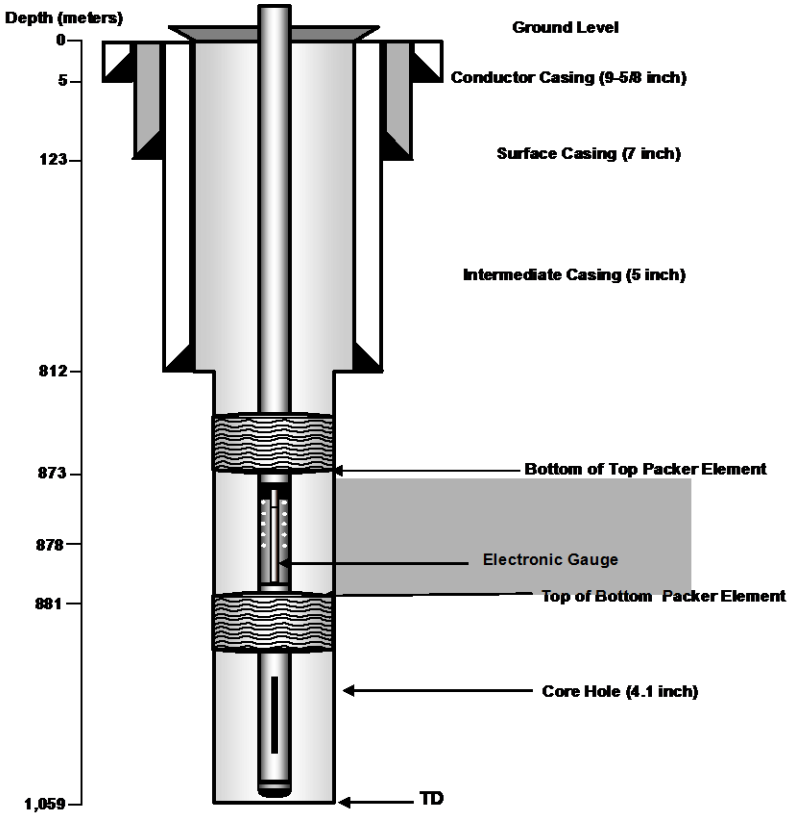
Down-Hole Injection Testing Set-Up



Selection Criteria

- Number of Zones to Test
- Stratigraphic Control
- Hole Stability
- Drilling Efficiency
- Mud Quality
- Equipment Availability
- Costs



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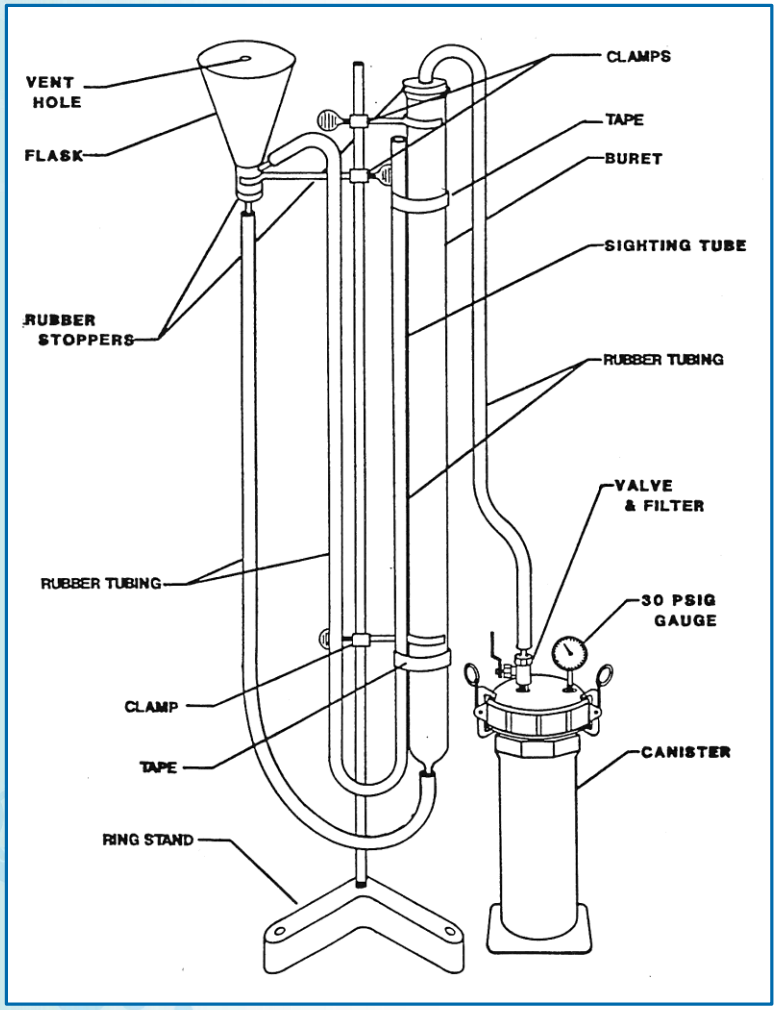
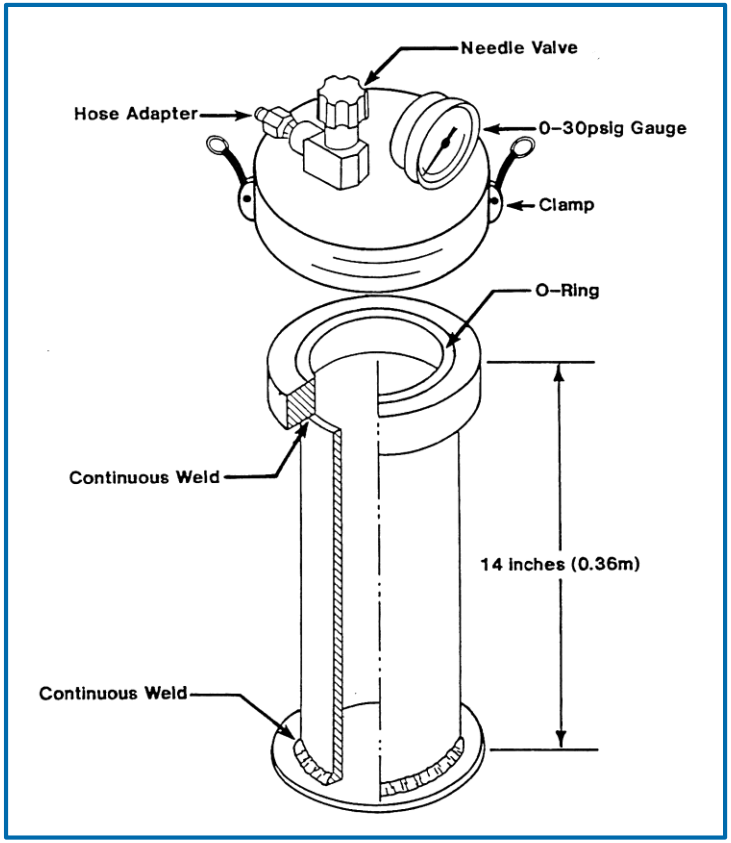
Equipment for Desorption Testing of Coal Samples

Manometric Set-Up



Canister Diagram



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Desorbing the Core

Thermal Bath

Desorption Apparatus

Procedures

- Ensure that you are sampling at in-situ conditions
- Gas content team conducts lost gas desorption.
- 10-min reading intervals for first hour.
  - 15-min intervals from hour 1 to hour 2.
  - 30-min intervals from hour 2 to hour 3.
  - 1-hour intervals from hour 3 to hour 6.
  - 2-hr intervals from hour 6 to hour 12.
  - 4-hr intervals from hour 12 to hour 24.
  - 8-hr interval from hour 24 to hour 48.
  - Once daily thereafter.
- Keep canisters in thermal bath inside trailer for at least two weeks.

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Contact Information

Jonathan Kelafant
Advanced Resources International, Inc.
+1 (703) 528-8420, jkelafant@adv-res.com
www.adv-res.com

Felicia A. Ruiz
Coalbed Methane Outreach Program (CMOP)
+ 1 (202) 343-9129, ruiz.felicia@epa.gov
www.epa.gov/cmop

www.globalmethane.org