Investigation of Coal Wettability for the CO_2 Sequestration and ECBM Applications: A Review

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Outline

- Introduction
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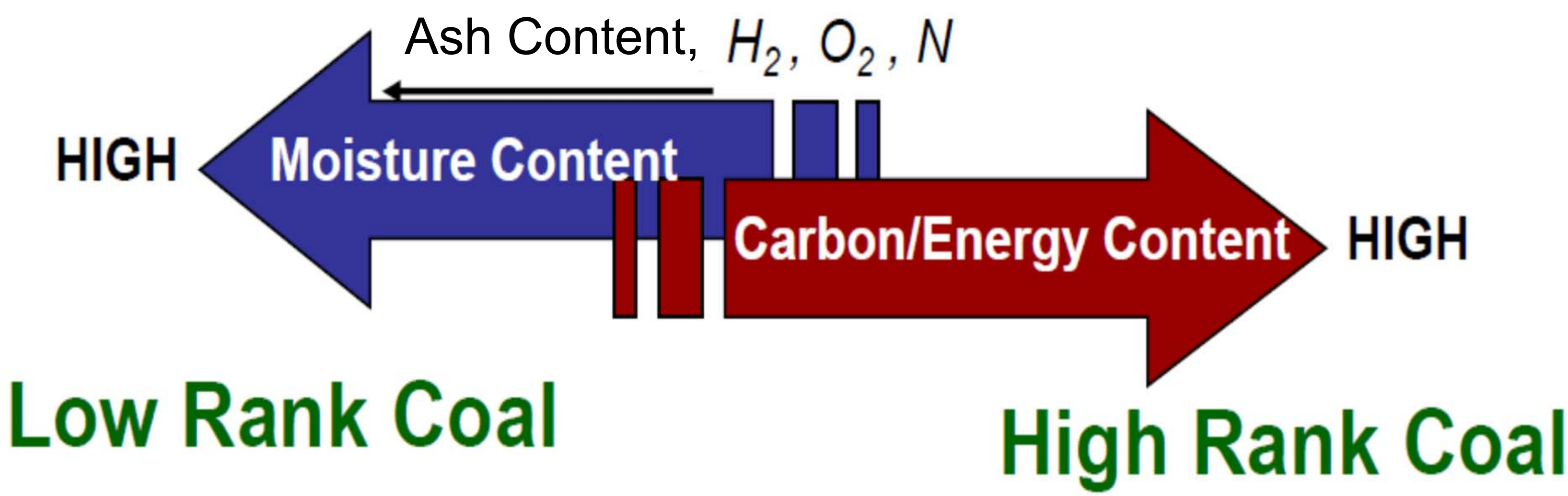
- Results
  - Effect of pressure
  - Effect of coal rank
  - Effect of water salinity
  - Effect of temperature
  - Effect of gas impurities
- Summary

Introduction

Coal is a complex organic rock and is often classified by rank.



lignite, subbituminous coal, bituminous coal, and anthracite

Example for Coal Characterization

Component	Moisture	Volatile Mater	Fixed Carbon	Ash
Concentration, wt%	0.2	47	50.8	2

Proximate analysis for the coal sample.

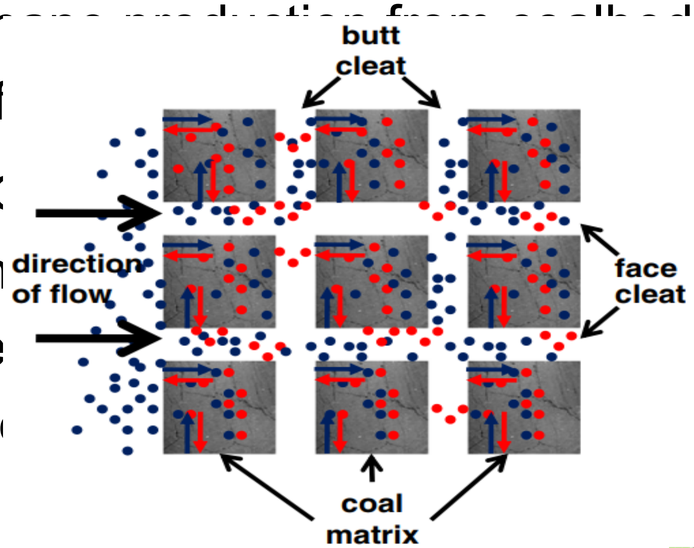
Element	C	O	Al	Si	S	Ca	Fe
Concentration, wt%	82	10	0.8	0.44	2.53	0.25	2.23

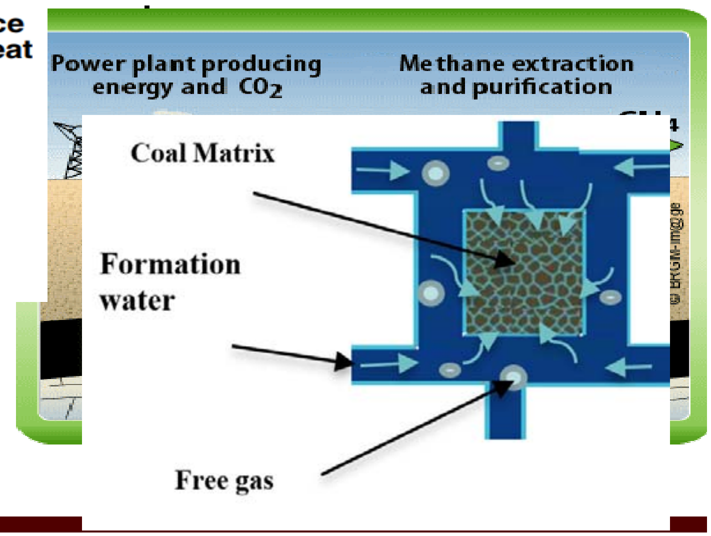
Composition of the coal.

- The coal sample was characterized as a **high-volatile A bitumen coal (hvAb)** (ASTM D388).

Introduction

- Coal is characterized by its dual porosity; matrix pore system and cleats network system.
- CO_2 sequestration in coal :
  1. Enhances meth… s (ECBM).
  2. Reduces the ef… ing CO_2.
- CO_2 can be Sto… chanisms:
  1. Free gas within…
  2. Adsorbed mole…
  3. Dissolved in gr…





Wettability Investigation

- The efficiency of ECBM and CO_2 sequestration is strongly dependent on the wetting behavior of the coal–water–CO_2 system.
- If the coal is CO_2 wet.
  - CO_2 will fill the micro-pores
  - CO_2 diffusion rate from the cleat network, through the micro-cleats, to the matrix surface, will improved. (improve replacement of the methane on the surface)

diffusion coefficient of $CO_2 = 1.7\times10^{-7}$ m^2/s at 100 bar and 300 K

diffusion coefficient of $CO_2 = 2\times10^{-9}$ m^2/s at 100 bar and 300 K (diffusion through water)

Experimental Tools

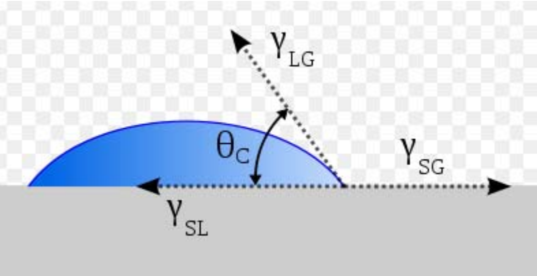
Wettability Investigation

- Contact Angle Measurements
- Adsorption isotherm measurements
- Zeta Potential measurements
- Fourier-transform infrared spectroscopy (FTIR)

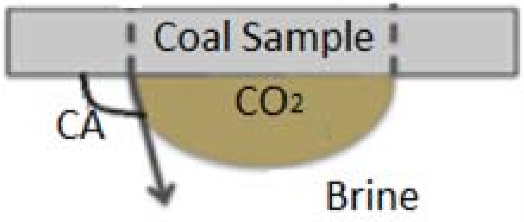
Wettability Investigation

Contact Angle Measurements

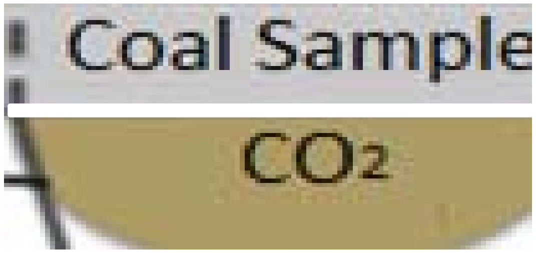
Sessile Drop



Captive Bubble



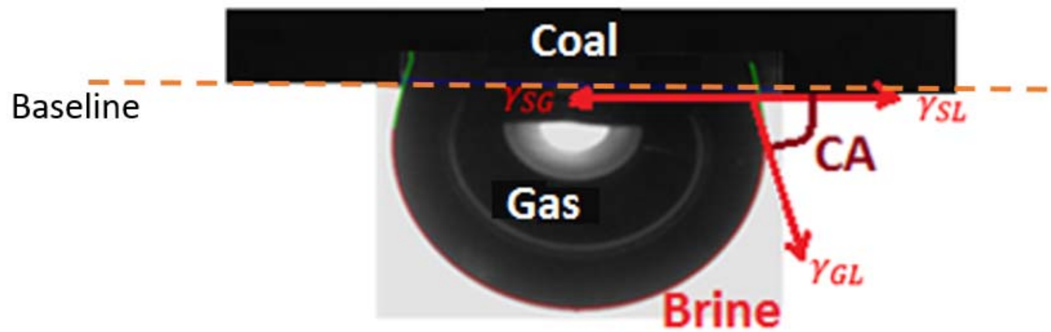
Captive-bubble method is more represent the CO_2 sequestration process, where the CO_2 displaces the water from the coal surface.



Contact Angle Measurements

- The Contact angle characterize the wetting behavior of the solid surface.
  - < 90° Water wet
  - > 90° CO_2 wet

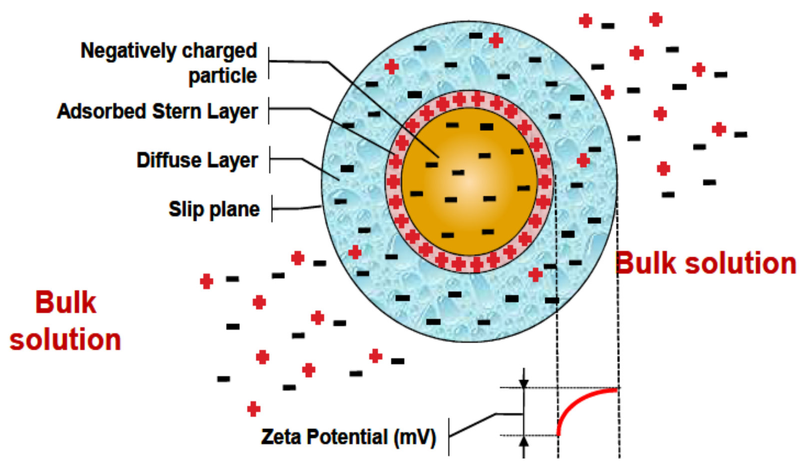
$$\cos(\theta) = \left(\frac{\gamma_{SG} - \gamma_{SL}}{\gamma_{GL}}\right),$$



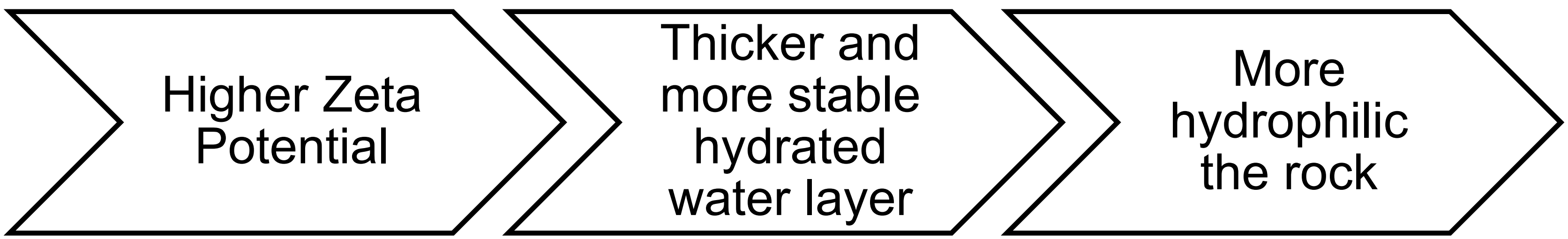
where θ is the contact angle measured in the liquid, γ_{SG} is the gas/solid interfacial tension, γ_{SL} is the liquid/solid interfacial tension, and γ_{GL} is the gas/liquid interfacial tension.

Zeta Potential Measurements

- Zeta potential can be measured for dispersions, and double layer thickness can be calculated from it.
- Rock wettability, on the other hand, depends on the stability of the water layer surrounding the rock surface, which is a function of the zeta potential.
- Zeta potential technique will be used to explain the causes of wettability alteration.



Zeta Potential Measurements



Adsorption Isotherm Measurements

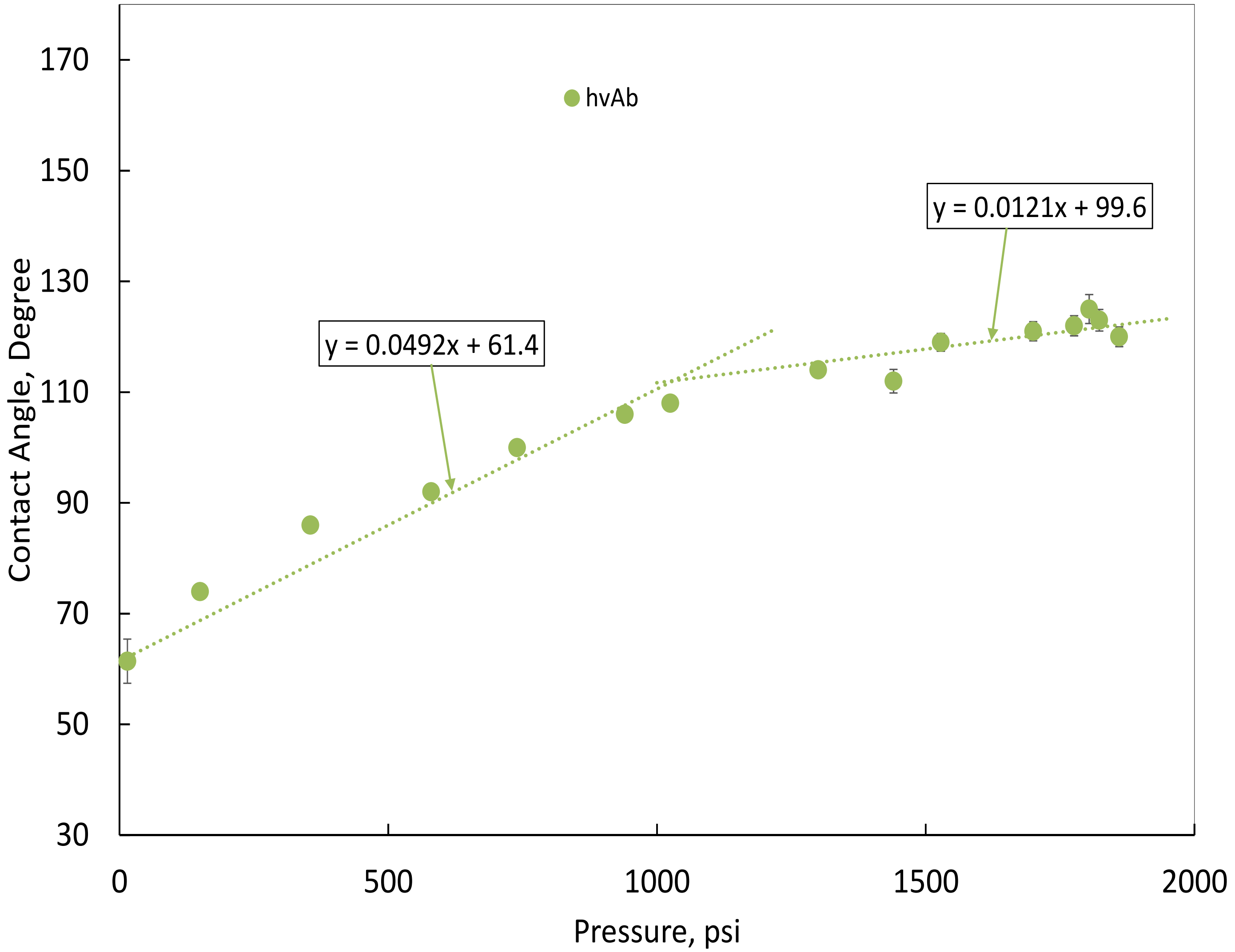
- Adsorption isotherm aims to measure the adsorbed gas volume as function of pressure at constant temperature

- Most coal follows Langmuir adsorption behavior

$$\mathbf{V_{adsorbed}} = \frac{\mathbf{V_L P}}{\mathbf{P + P_L}}.$$

Wettability Results

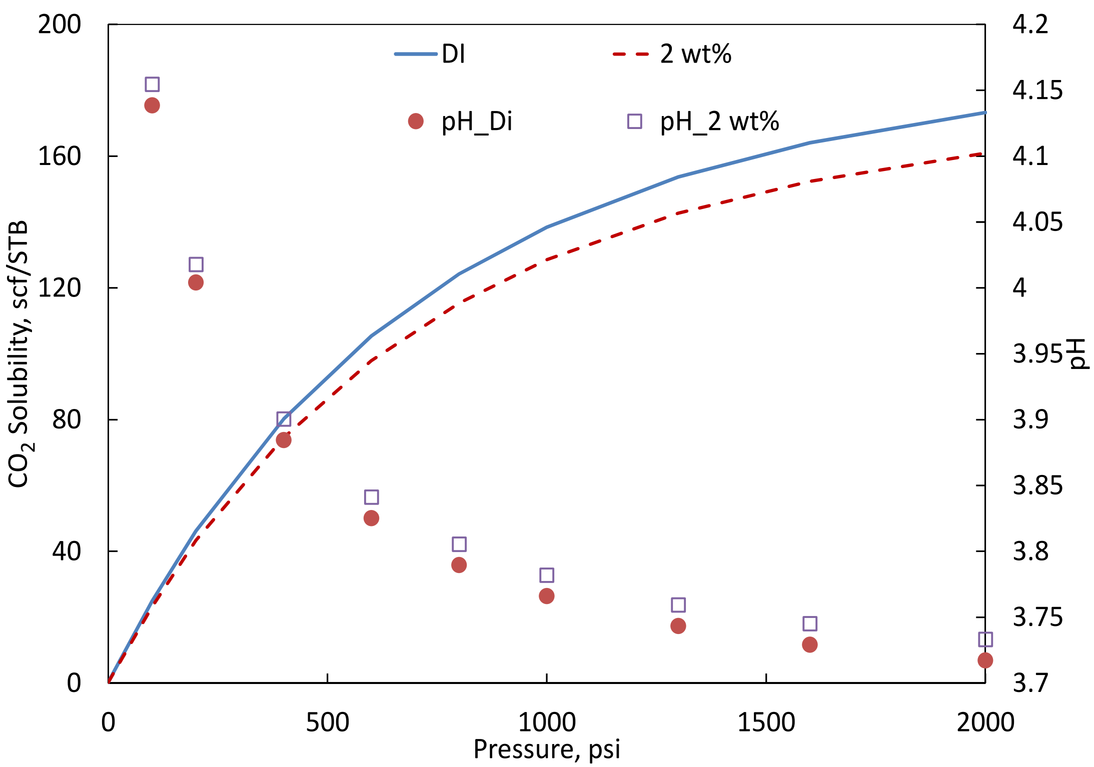
Effect of Pressure on Contact angle Measurements

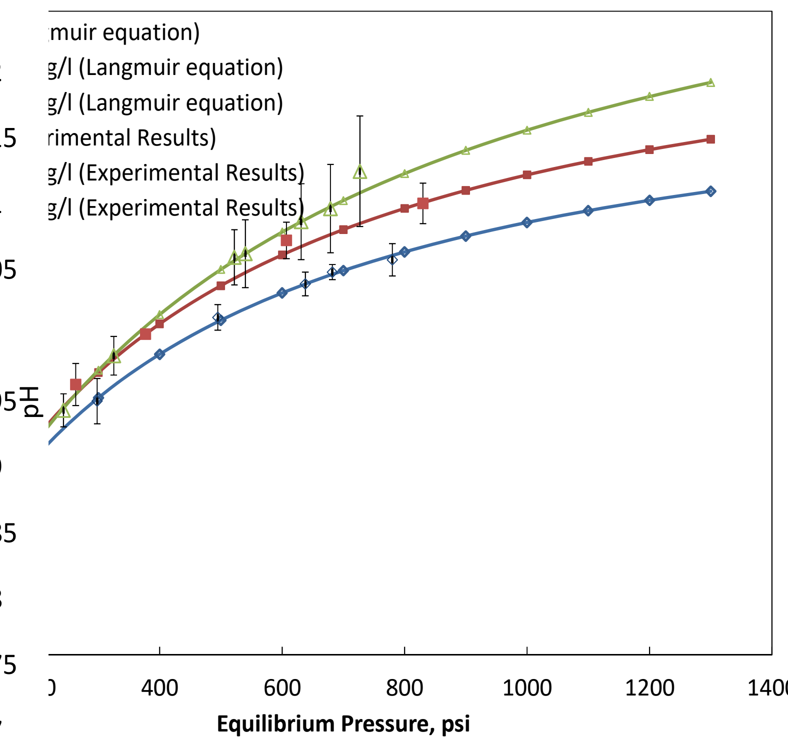


DI water
40°C

Discussion

Effect of Pressure



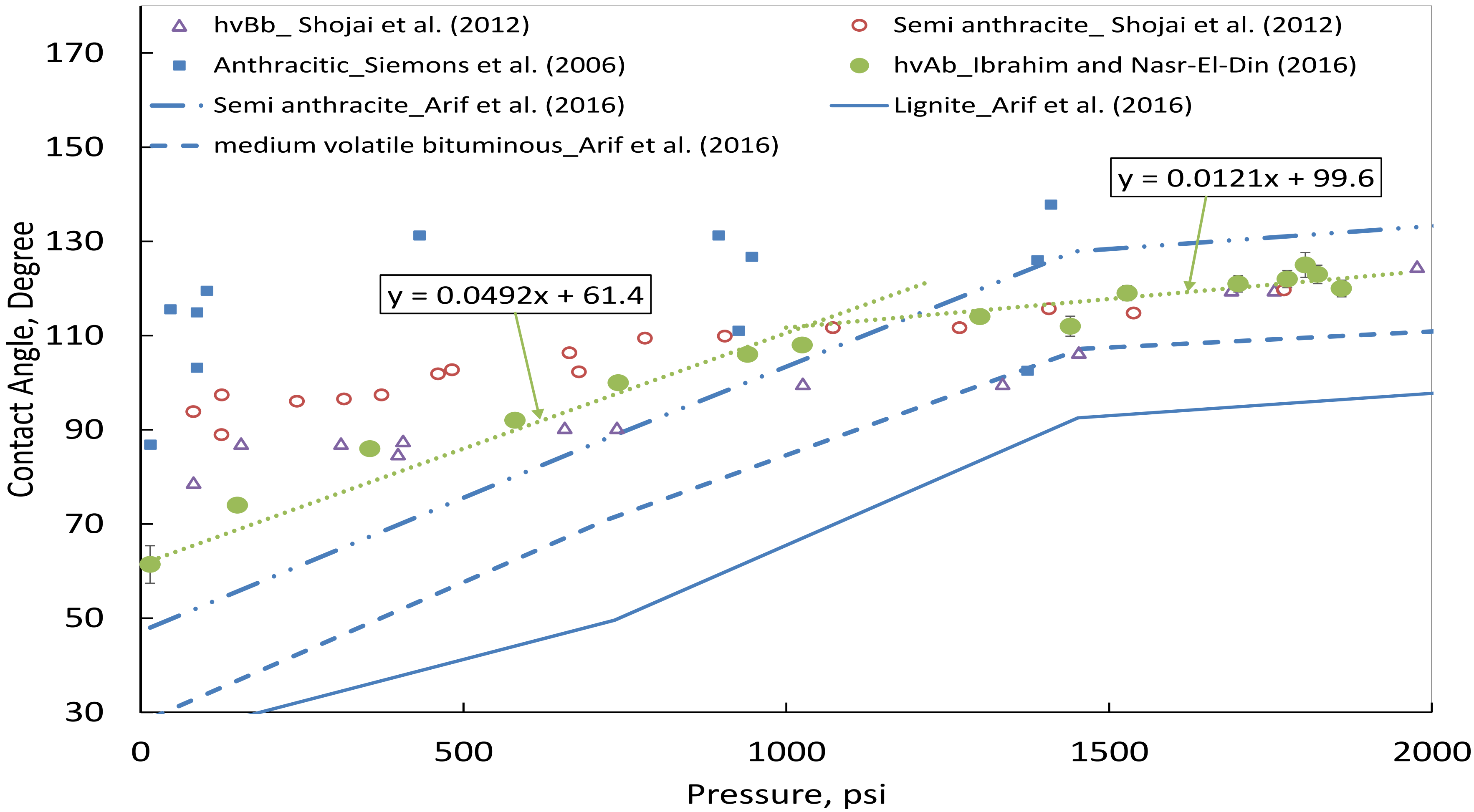


γ_{GL}

γ_{SG}, γ_{SL}, and γ_{GL} are the gas/solid, the liquid/solid, and the gas/liquid interfacial tensions

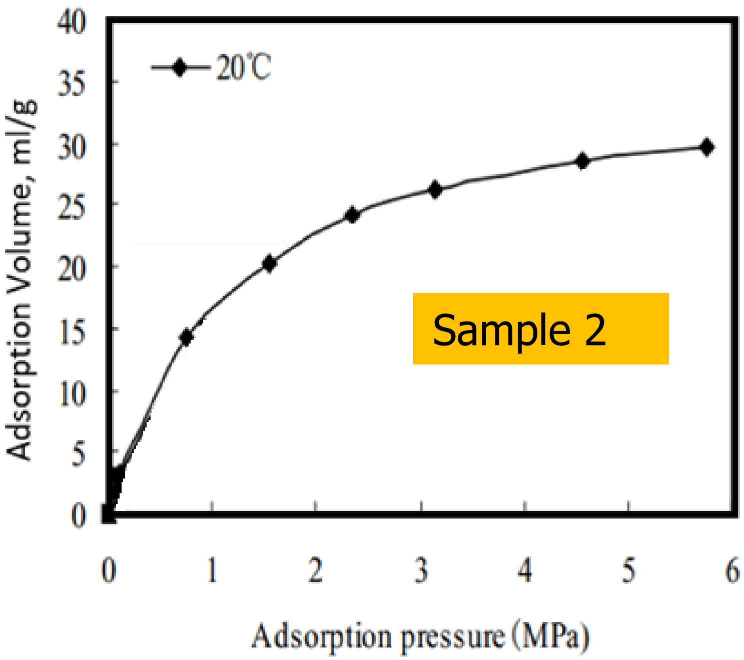
1 Farokhpoor et al. 2013
2 Chiquet et al. 2007

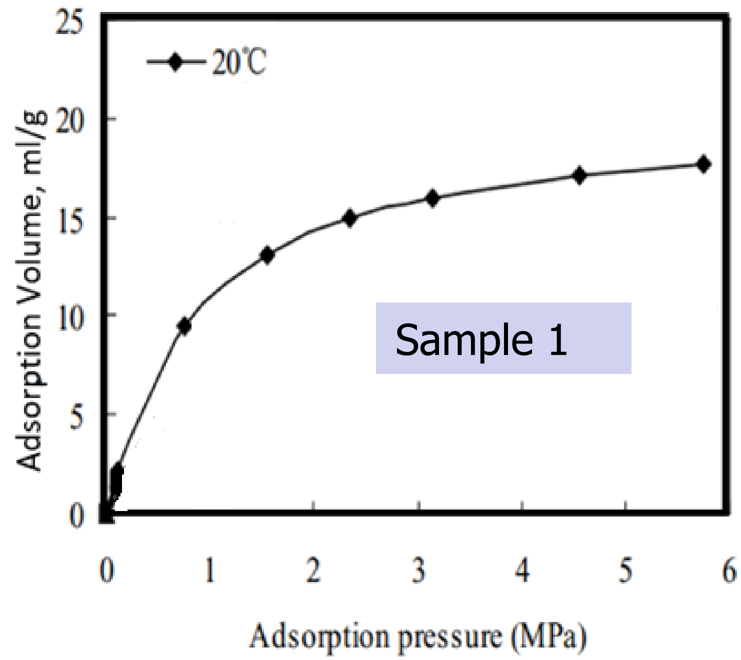
Effect of Coal Rank



Effect of Coal Rank

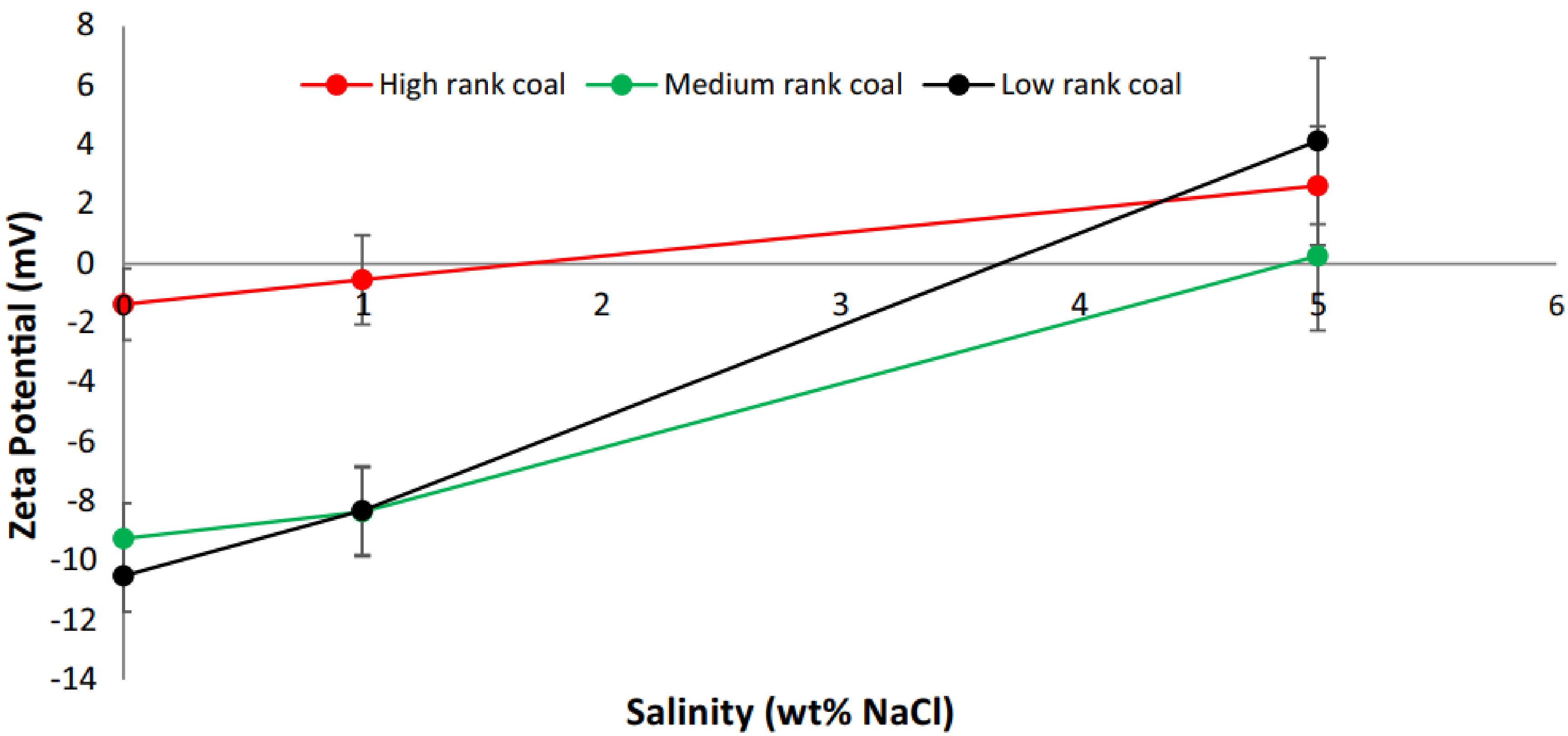
Coal samples	Moisture (%)	Ash (%)	Volatility (%)
Sample 1	1.06	16.31	8.62
Sample 2	0.86	11.60	33.16





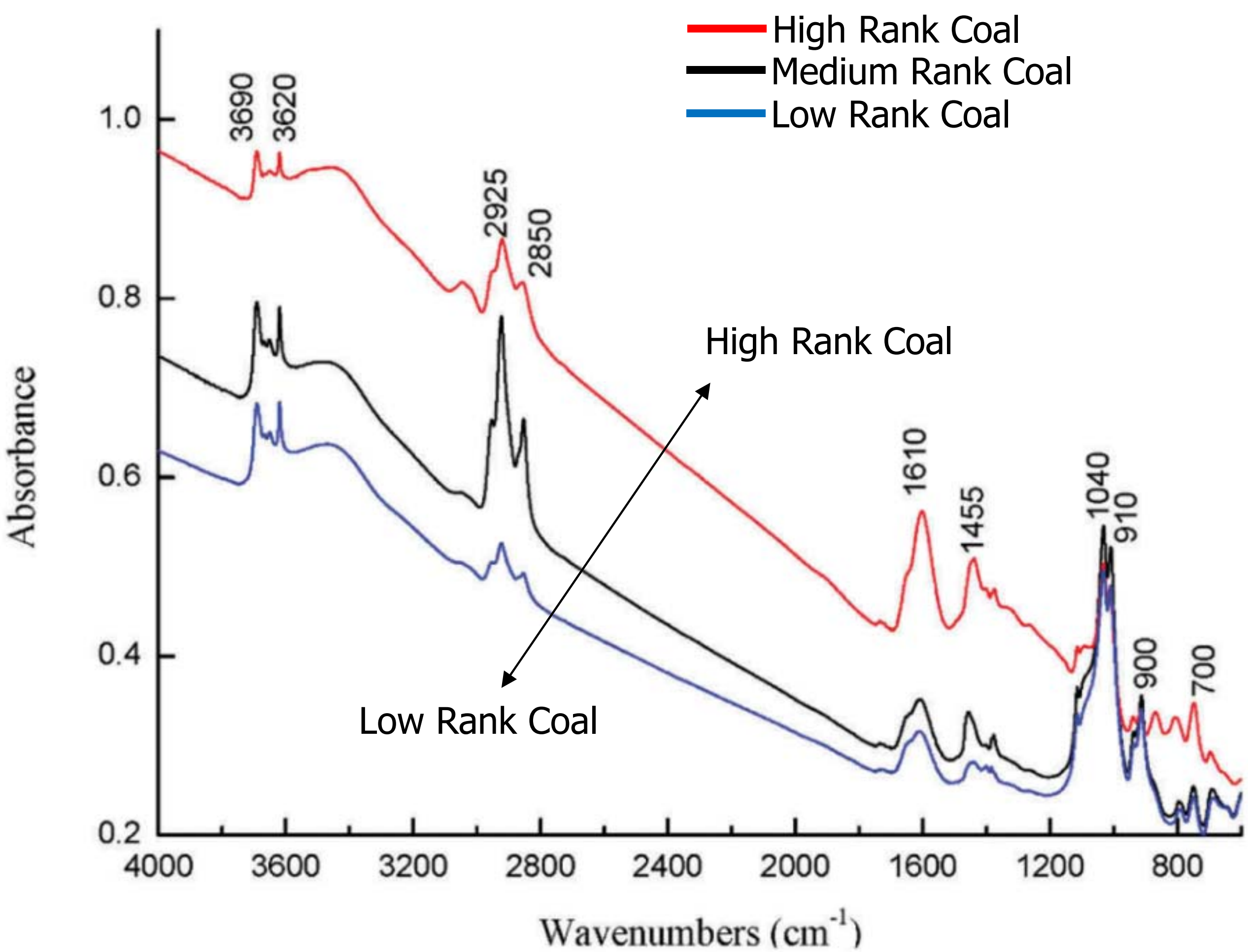
Chen et al. 2011

Effect of Coal Rank



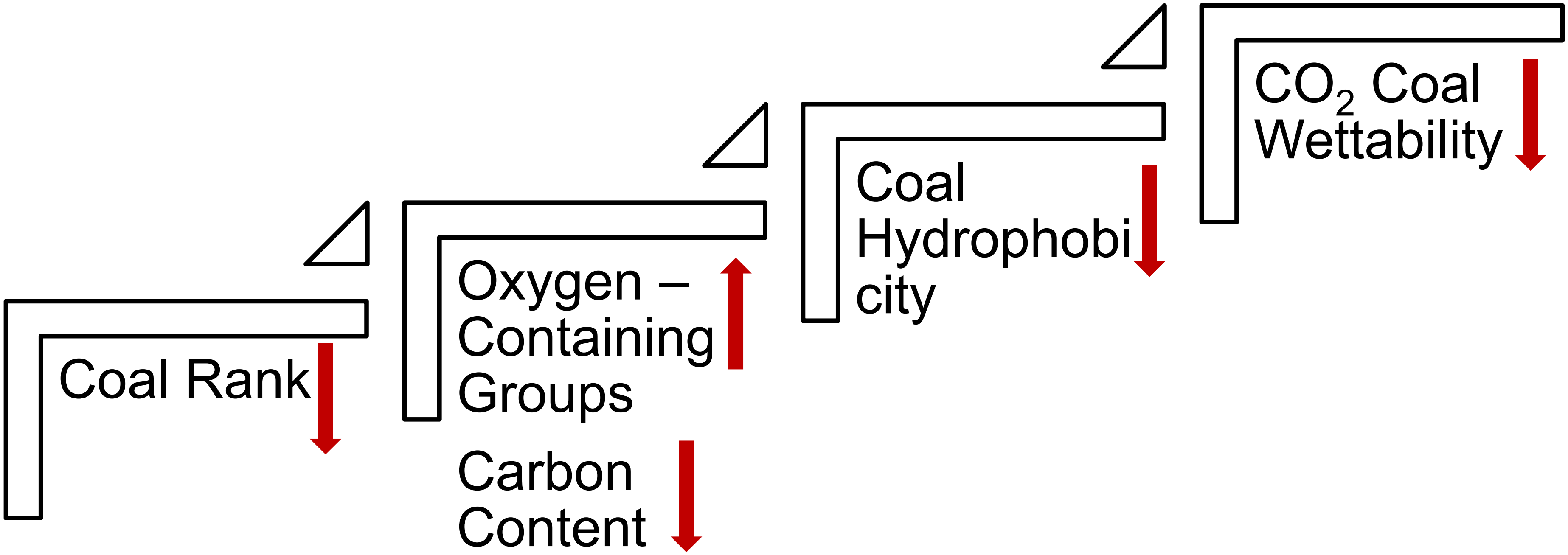
Arif et al. 2017

Effect of Coal Rank



Wavenumber	Group
3690-3620	-OH group
910-1040	Si-O-Si
2925-1455	CH_2
2850	CH_3
700-900	C = C

Effect of Coal Rank



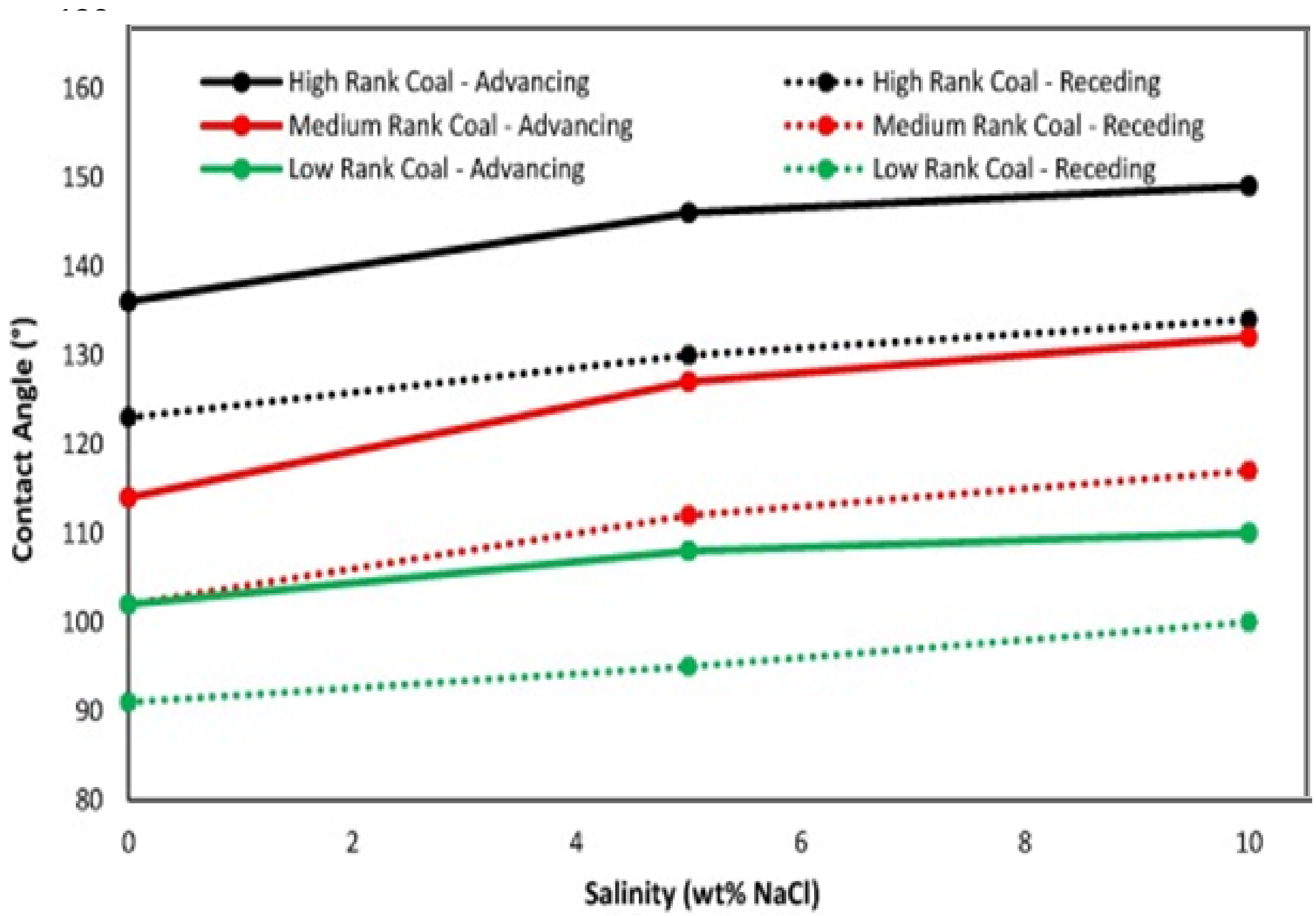
Effect of Water Salinity

- Coal-seam water usually has low salinity and varies between 800 to 28000 ppm.

Location			TDS mg/L
Australia	Bowen Basin	Durham Ranch	**5968**
		Fairview	**1201**
		Upper seam	**6207**
		Lower seam	**6528**
US		Black Warrior Basin	**4402**
		San Juan Basin	**28783**
		Uinta Basin	**11876**
		Maramarua	**837**

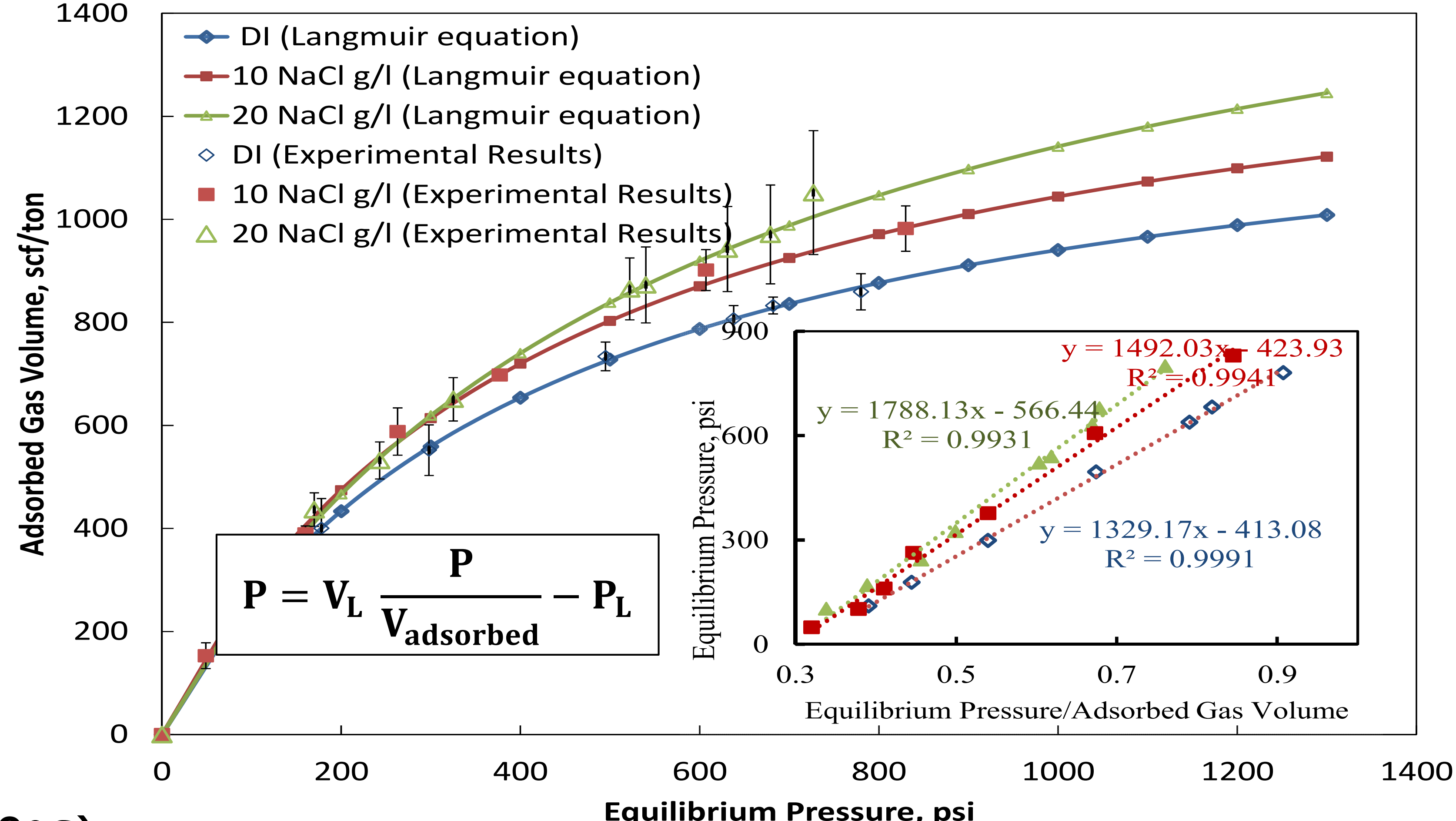
Salinity of Coal Seam Associated Water (Hamawand et al., 2013).

Effect of Water Salinity



Arif et al. 2017

Effect of Water Salinity

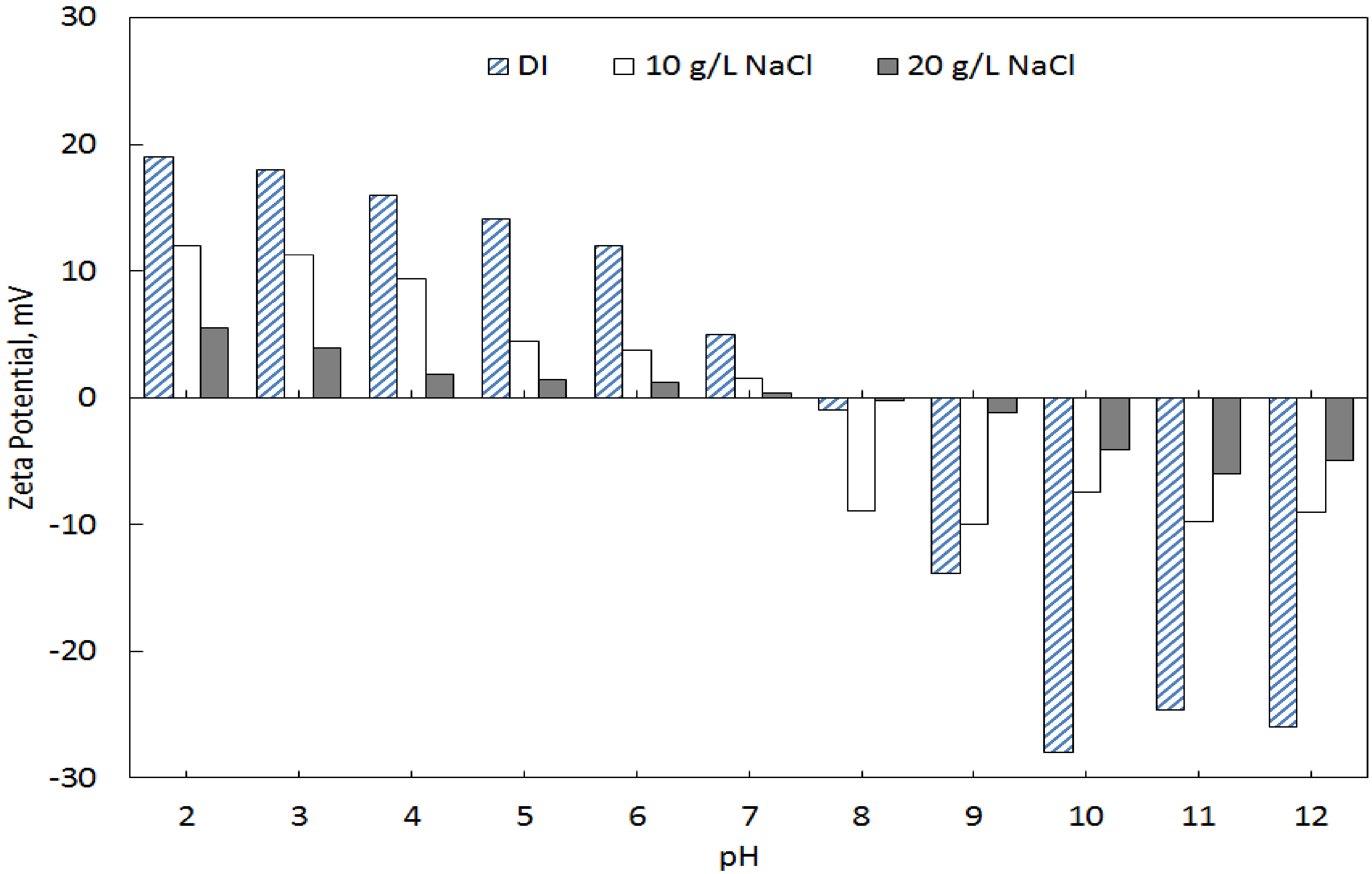


$$P = V_L \frac{P}{V_{adsorbed}} - P_L$$

(40°C)

P_L Langmuir adsorption pressure, psi
V_L Langmuir adsorption volume, scf/ton

Effect of Water Salinity



Discussion

Effect of Salinity

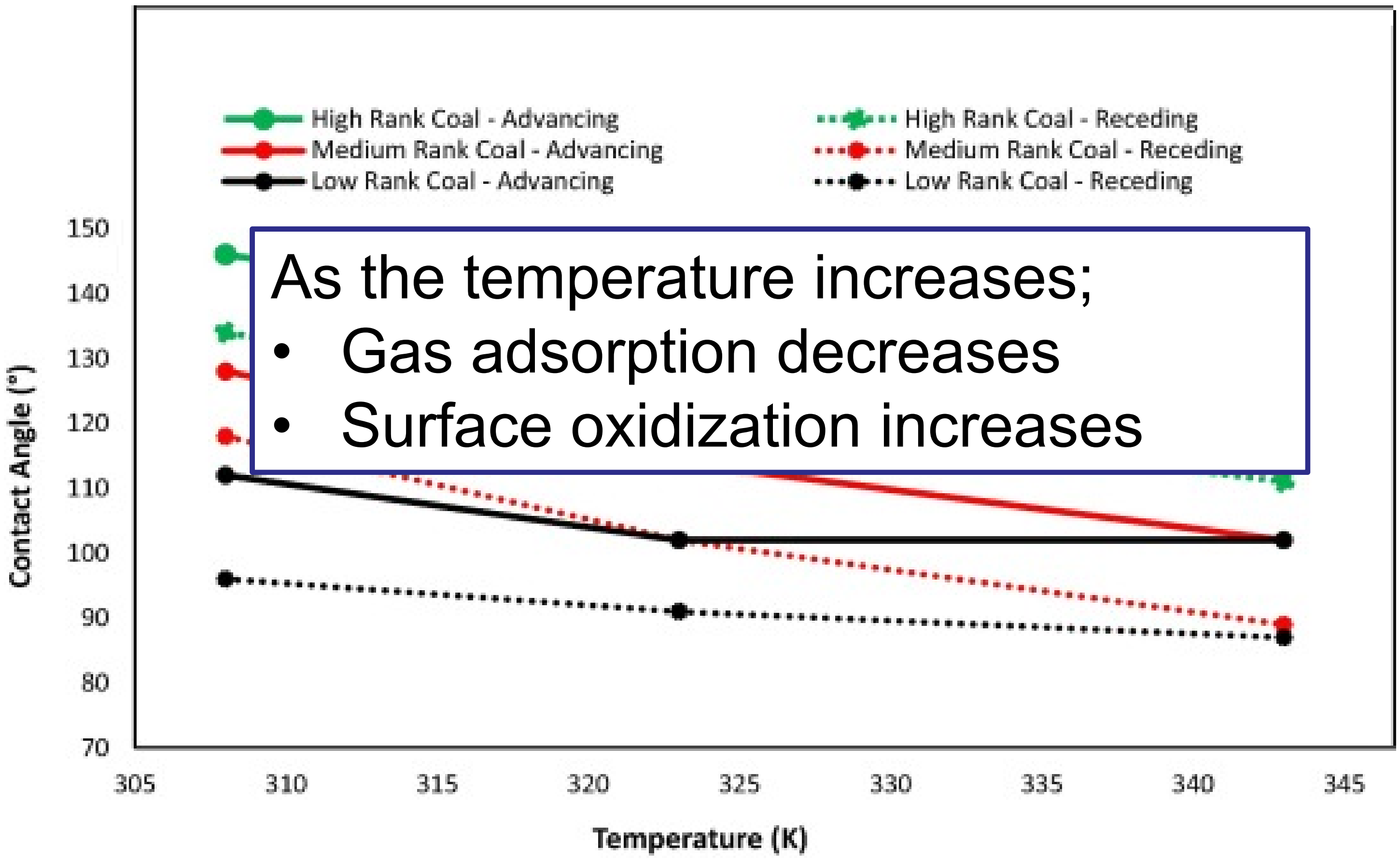
- As the salinity increase

1. CO_2 adsorption on the coal surface increases → Gas interfacial tension to the solid (γ_{SG}) decreased significantly

$$CA \uparrow = \cos^{-1}\left(\frac{\gamma_{SG} \downarrow - \gamma_{SL}}{\gamma_{GL}}\right)$$

2. It compresses and destabilizes the hydrated layers (double layer) surrounding the coal surface, causing a reduction in the absolute value of the zeta potential, and making the coal surface more hydrophobic.

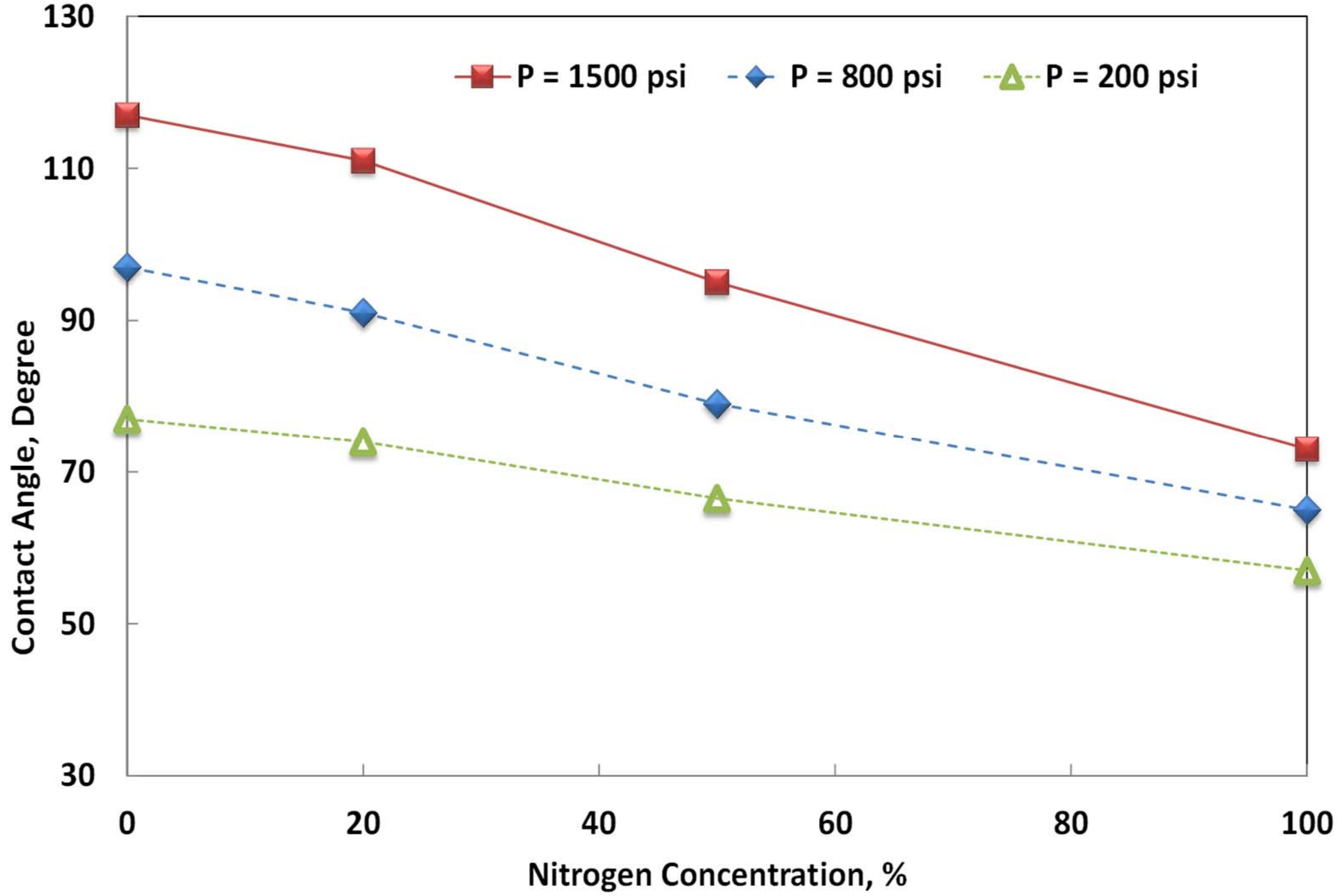
Effect of Temperature



As the temperature increases;

- Gas adsorption decreases
- Surface oxidization increases

Effect of Gas Composition



Summary

- CO_2 can be sequestrated in coal seams to enhance the coalbed methane production (ECBM) in addition to CO_2 storage. The efficiency of this process greatly affected by the coal formation properties and the operation conditions as following;

1. As the coal rank increased from lignite to anthracite, gas adsorption capacity increases and the coal become more hydrophobic.
2. With increasing pressure, coal became more hydrophobic as a result of lower pH value and high CO_2 adsorption.
3. Adsorption capability decreases and the coal becomes more water-wet at high formation temperature.

Summary

4. As the formation water salinity increases, the coal becomes more gas-wet and the adsorption isotherm increases.
5. The presence of N_2 in the injected gas decreases the coal wettability to gas.

For carbon sequestration and ECBM application, the storage capacity of CO_2 in coal increased as the formation water salinity, coal rank, and the formation pressure increased. The gas storage as free gas increases, where the displacement efficiency increases as the coal become more CO_2 wet. Also, the adsorbed gas phase increases due to the CO_2 adsorption isotherm increase.

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Thank You

Questions

Coal Rank

COAL RANK	CARBON CONTENT (%)	VOLATILE MATTER (%)	CALORIFIC VALUE (kJ/kG)	MOISTURE CONTENT (%)
PEAT	60	>53	16800	>75
BROWN COAL	60 – 71	53 – 49	23000	35
SUB-BITUMINOUS COAL	71 – 77	49 – 42	29300	25 – 10
BITUMINOUS COAL	77 – 87	42 – 29	36250	8
ANTHRACITE	77 – 87	29 – 8	>36250	<8

$$J = -D\frac{d\varphi}{dx}$$