The Advanced Combustion Engineering Research Center (ACERC)

High Pressure Coal Combustion

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Objectives

Measure coal combustion characteristics at:

- High pressure (1-30 atm)
- High temperature (up to 1300°C)
- High heating rate (10^5K/s)

Rationale

- No reliable data at high pressures and high temperatures
(lots of TGA data, but not much at practical conditions)
- Form of rate expression is still debated in literature
(nth order vs. Langmuir-type expressions)

Industrial Relevance

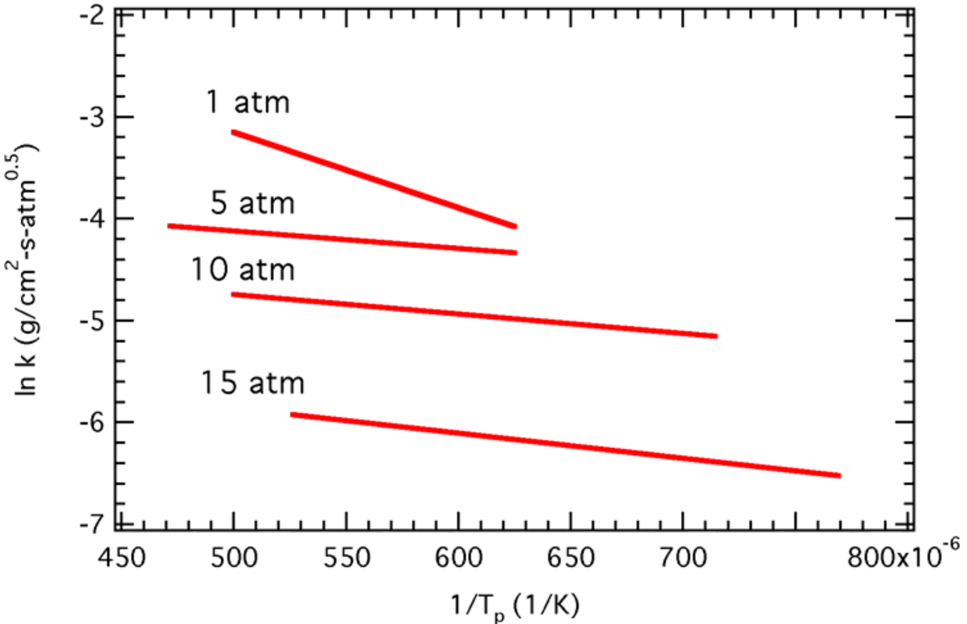
- Oxygen-blown gasifiers/combustors (IGCC and PFBC)
- Pulverized Coal Injection (PCI) into tuyeres of blast furnaces
- Enhanced oxygen combustion systems

Previous High Pressure Work at BYU

- Monson and coworkers
  - High pressure drop tube
  - Chars generated at 1 atm
  - Char reaction rates at 1-15 atm in 5-21% O_2
  - Activation energy as a function of pressure
- Hecker and coworkers
  - Chars generated in FFB at 1 atm
  - High pressure TGA work (n = 0.7)
- Hong and coworkers
  - Simple Langmuir rate expression with Thiele modulus
  - Explained several sets of data, including Monson's burnout data (but not measured T_p's)

Monson Data

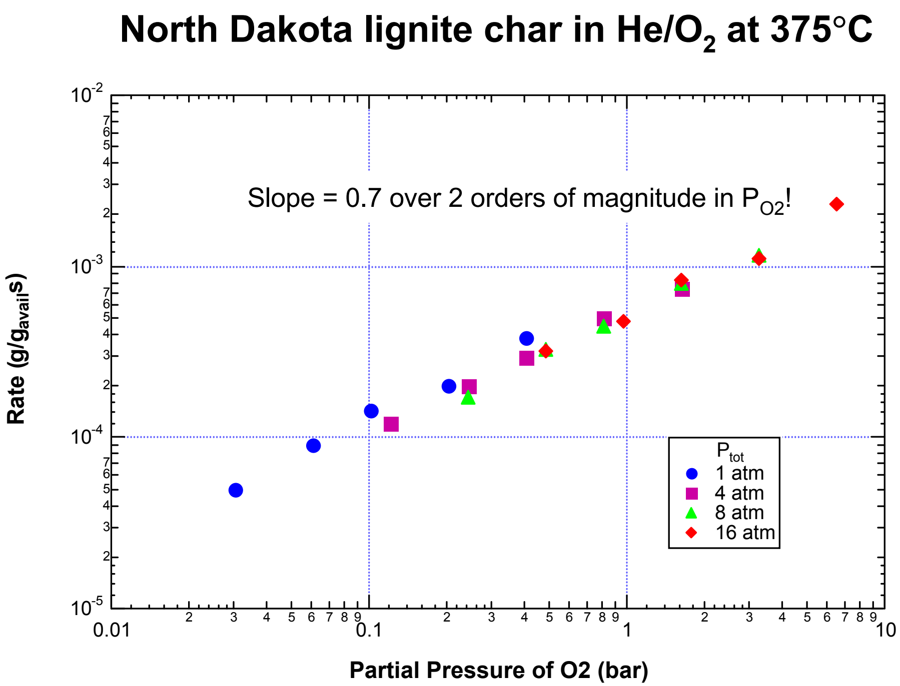
(Data fit with n=0.5)

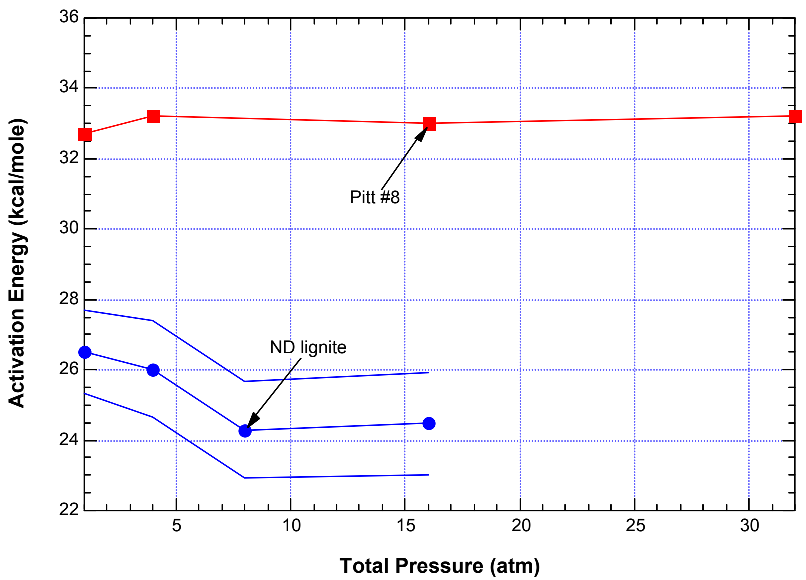


Pressure (atm)	E (kcal/mole)
1	14.8
5	3.4
10	3.8
15	4.9

The decrease in E with P_{tot} does not seem reasonable

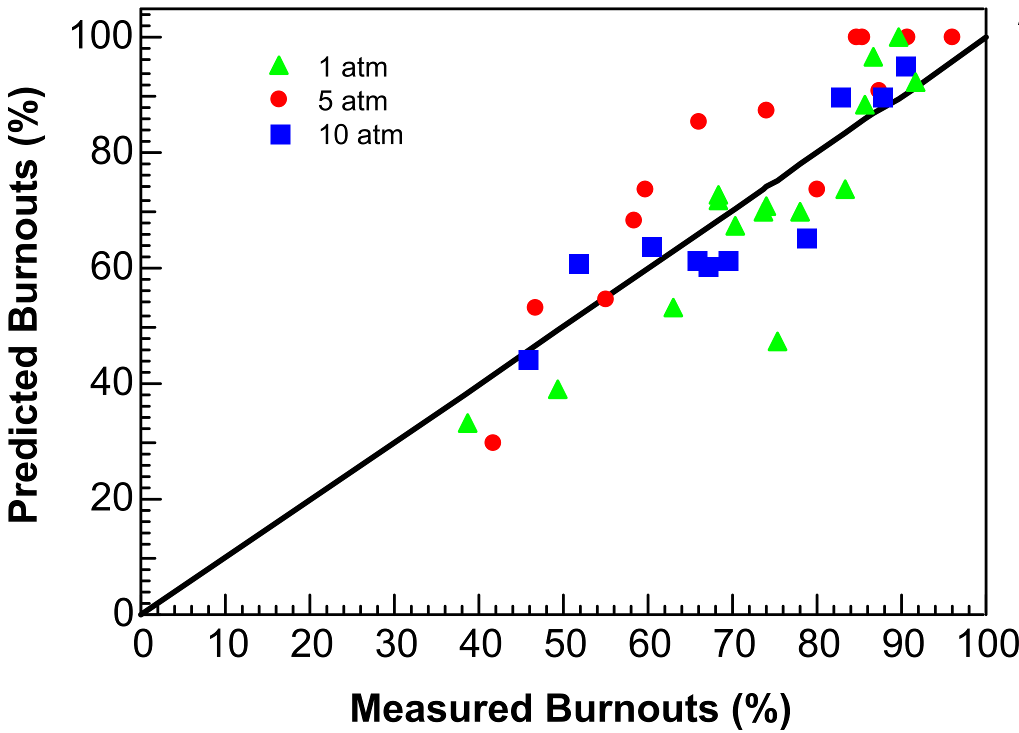
Hecker HP-TGA data





The HP-TGA data do not seem to support the findings of Monson

Hong modeling efforts



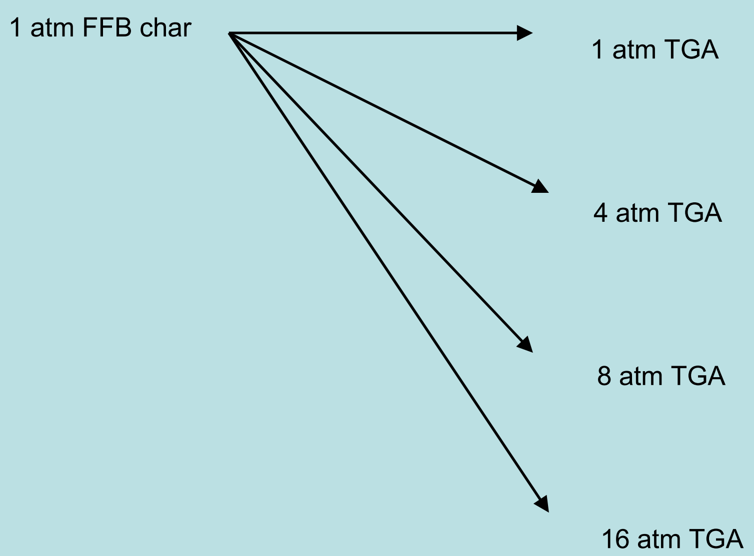
$$r'''_{obs} = \eta \frac{k_1 C_s}{1 + KC_s}$$

$$M_T = L\sqrt{\frac{\nu_O k_1}{2D_e}}\frac{KC_s}{1+KC_s}[KC_s - \ln(1+KC_s)]^{-\frac{1}{2}}$$

- Langmuir rate with Thiele-type modulus
- Fit five sets of data, including Monson's
- Could not explain Hecker's HP-TGA data (constant n=0.7)

High Temperature, High Pressure Chars

Previous Approach



New Approach

1 atm drop tube char → 1 atm TGA

6 atm drop tube char → 6 atm TGA

10 atm drop tube char → 10 atm TGA

15 atm drop tube char → 15 atm TGA

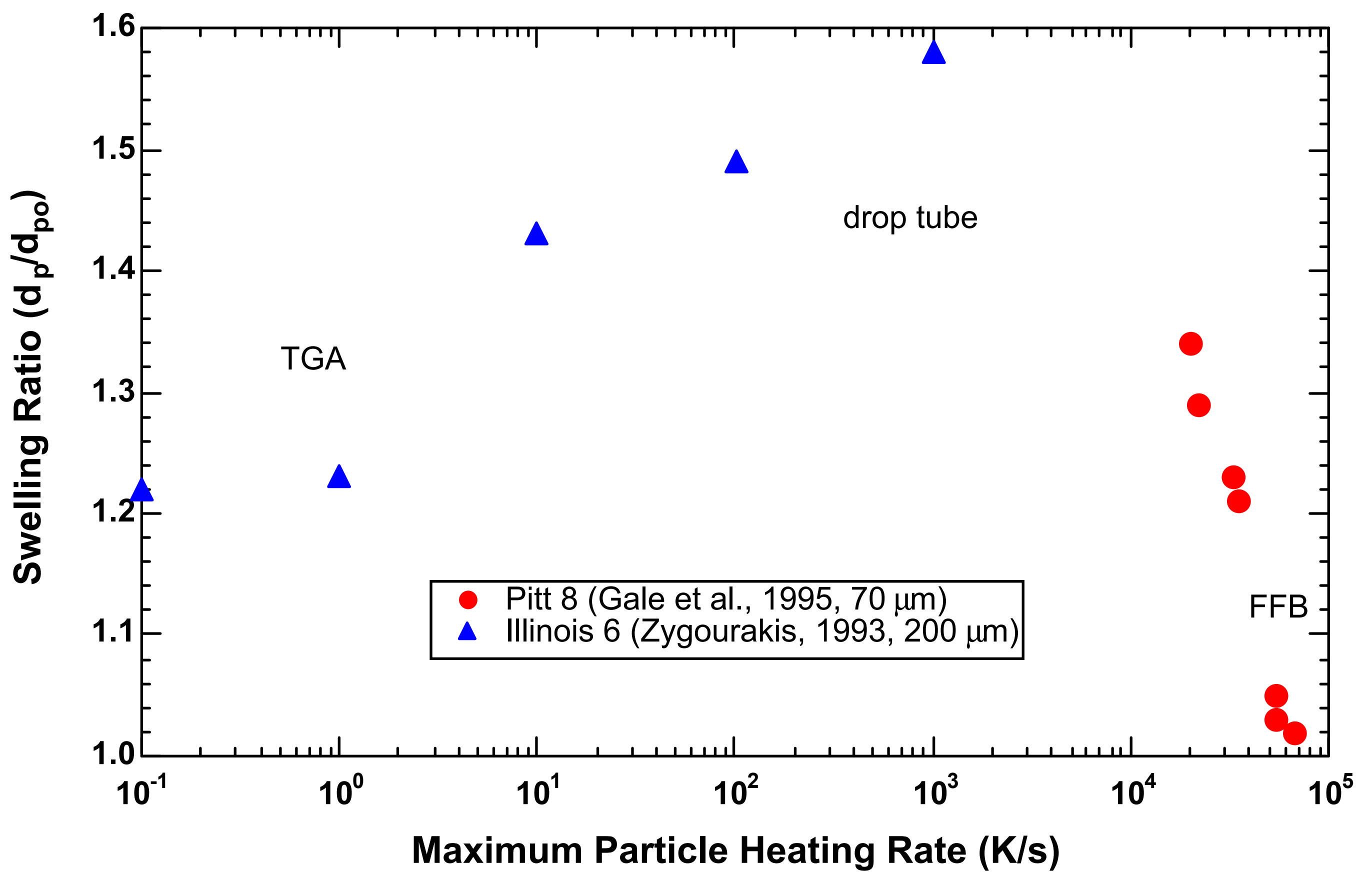
Why?

char density and diameter = f(P_{tot}, heating rate)

intrinsic char reactivity = f($T_{final,}$ heating rate)??

Swelling vs. Heating Rate at 1 atm

- Heating rate significantly affects swelling properties during pyrolysis of bituminous coals at atmospheric pressure (Gale et al., Comb. Flame, 1995)
- **High pressure experiments at moderate heating rates may show too much swelling**



Flat Flame Burner (FFB) in HP drop tube

- Advantages:
  - Char preparation at high temperature and heating rate (~1500 K, 10^5 K/s)
  - Adjust stoichiometry for %O_2 in post-flame zone
  - Fast heat-up and shut-down times for ease of use
- Disadvantages:
  - Fuel-rich operation at pressure produces soot from CH_4
  - Axial temperature profile not constant

Status

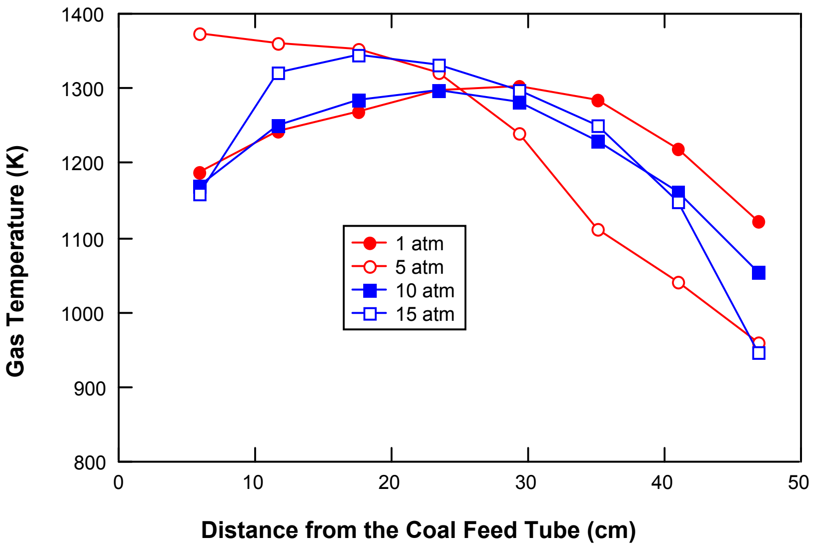
- Operational water-cooled FFB
- First set of chars produced
  - Pittsburgh #8 hva bituminous coal (~75 μm)
  - Wyodak subbituminous coal (45-75 μm)
  - Knife River lignite (<45 μm)
  - Koonfoutain South African bituminous coal (63-75 μm)
- Beginning analysis of chars

Initial Tests

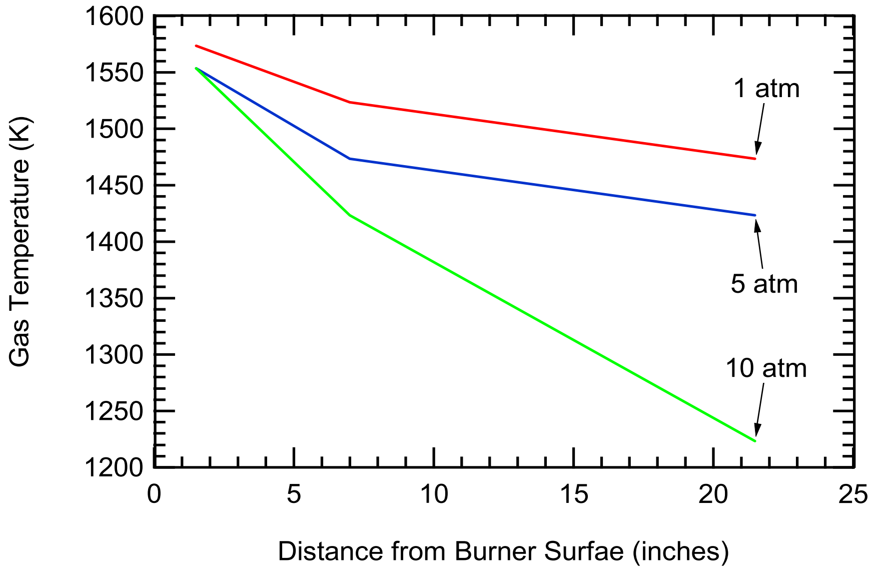
	Pressure			
	1 atm	6 atm	10 atm	15 atm
Pittsburgh #8 hva bit	x	x	x	
Knife River lignite	x	x	x	
Wyodak sub	x			
Koonfoutain bit	x			

Temperature Profile Comparison of HP-FFB and HPDT

High-pressure Drop-tube

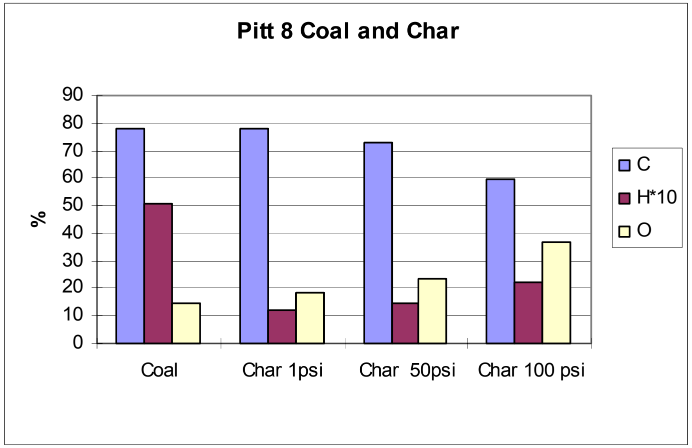


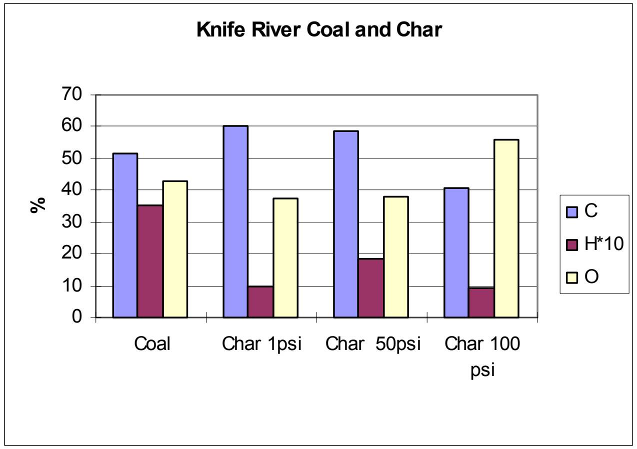
High-pressure FFB

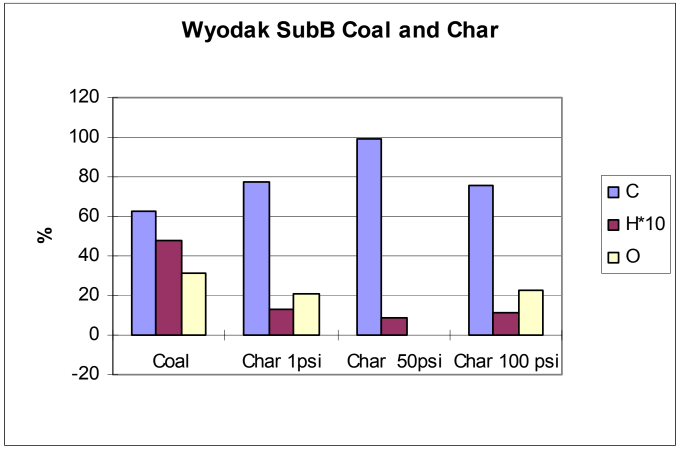


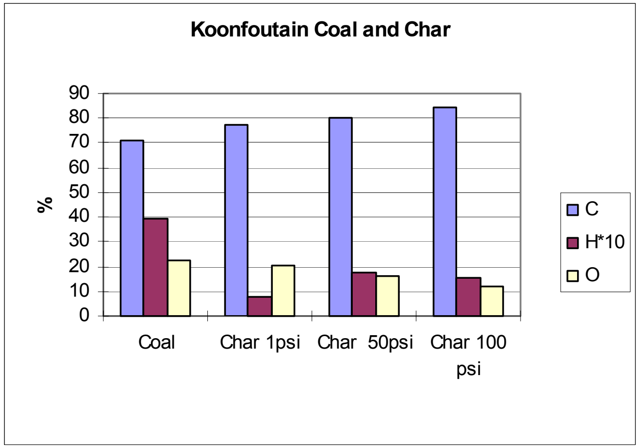
☞ **New HP-FFB has much higher particle heating rate than drop tube (10^5 K/s vs 10^4 K/s)**

Elemental Compositions of Chars



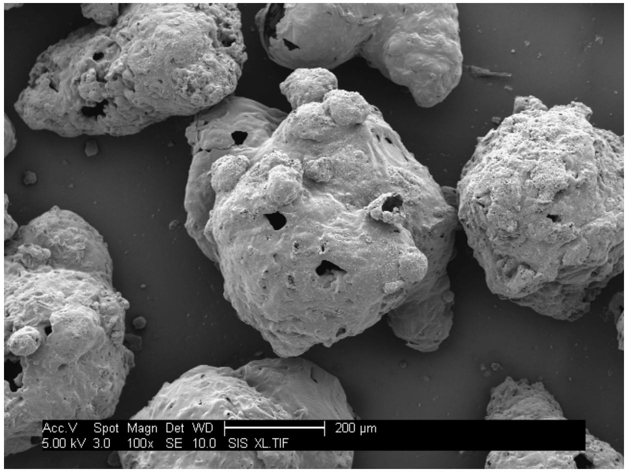




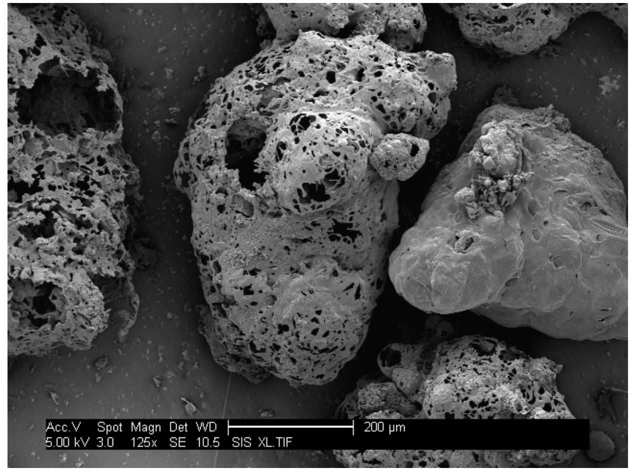


- Hydrogen content of chars is low enough to represent industrial conditions

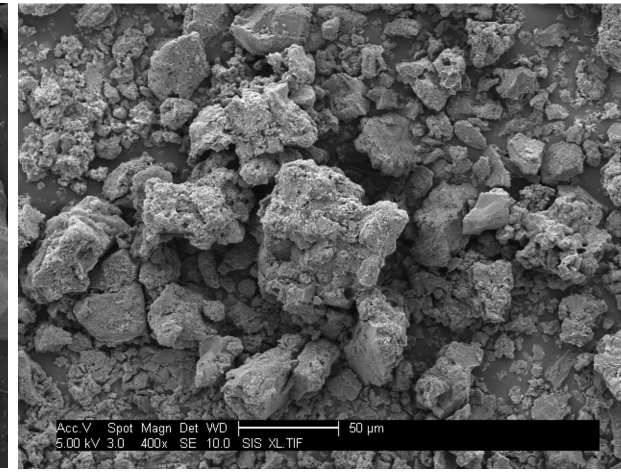
SEM Photos of Pitt #8 Chars



Pitt # 8 char (P=1 ATM)



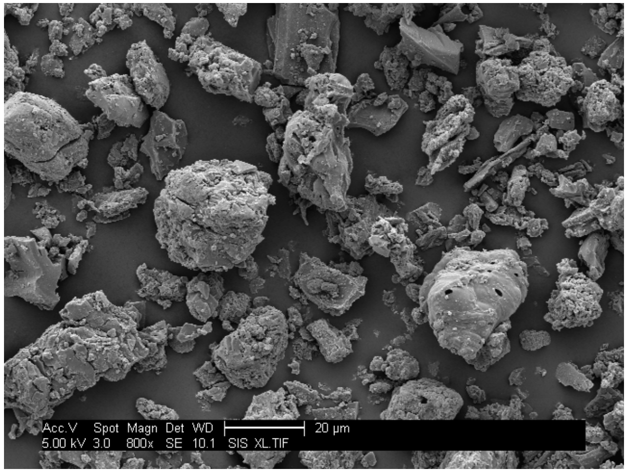
Pitt # 8 char (P=6 ATM)

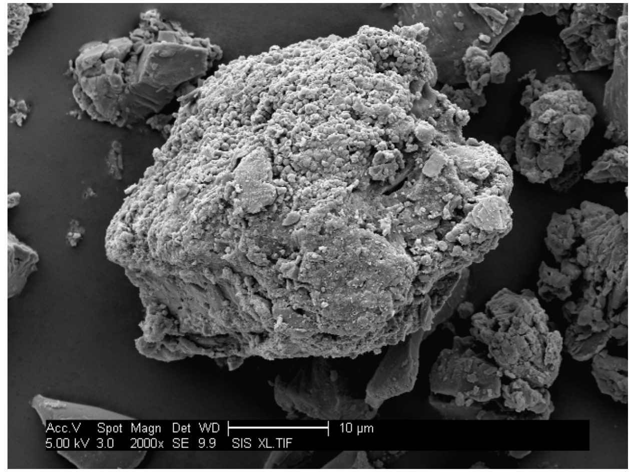


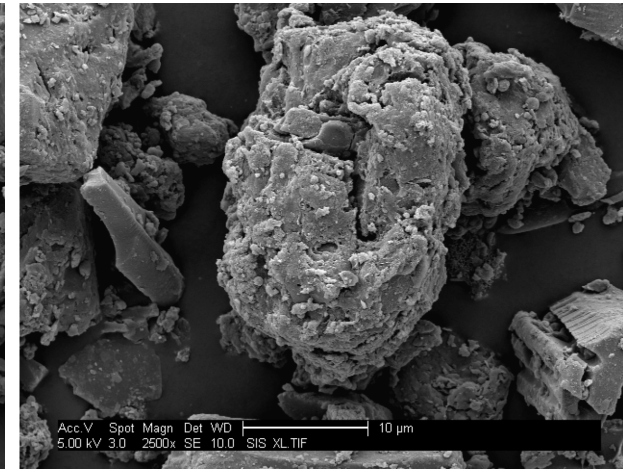
Pitt # 8 char (P=10 ATM)

- Increased pyrolysis pressure increased
  - tar precursors left in char due to vapor pressure effects
  - resistance for the volatiles to transport from the interior to the exterior
- With more volatiles retained in coal particles, char made from higher pressure showed higher fluidity
- SEM photos of char made from HP-FFB, medium pressure (6 ATM) showed popped bubbles
- On 10 ATM char, pressure hold the volatile, no distinct large holes.

SEM Photos of Knife River Lignite Chars







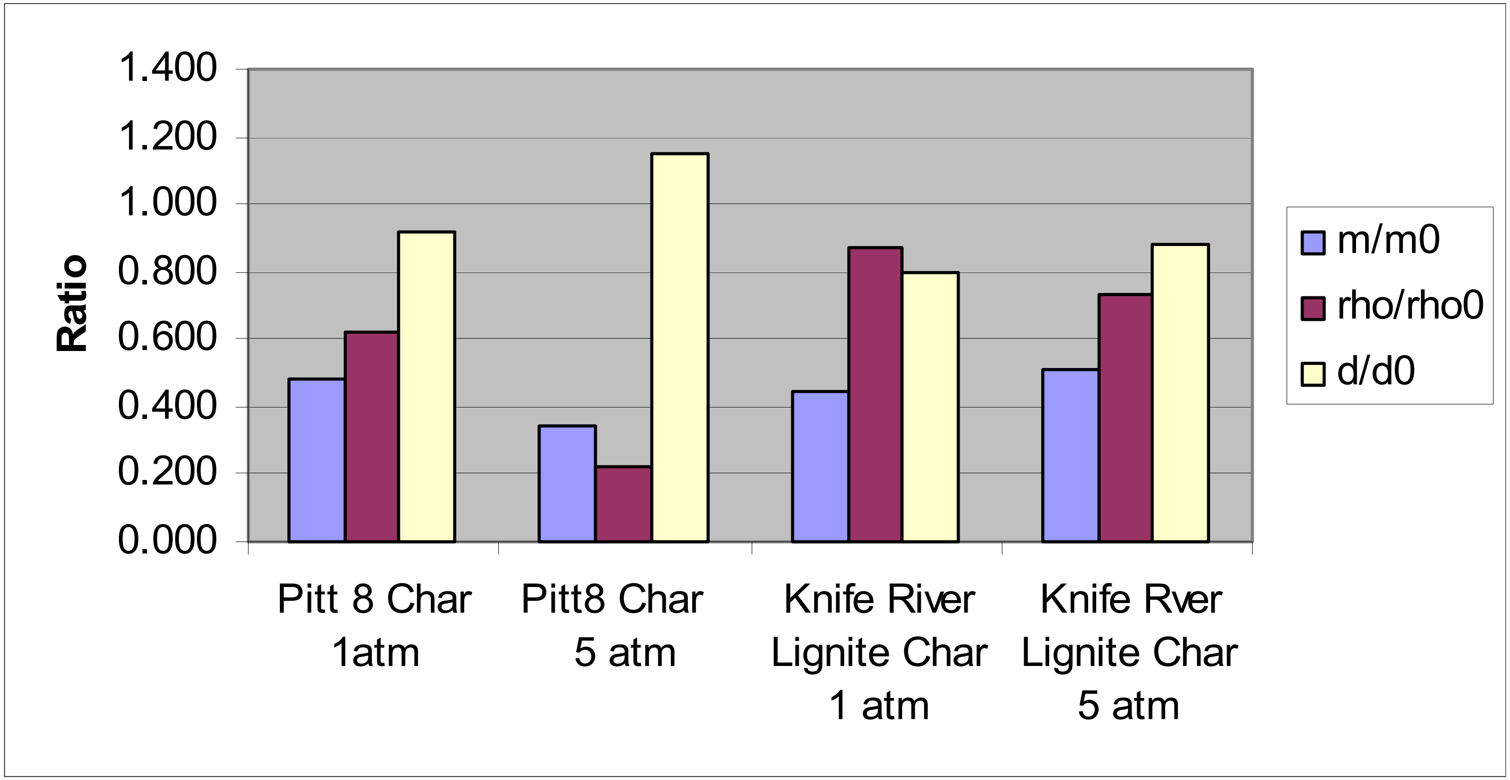
KRL char (P=1 ATM)

KRL char (P=6 ATM)

KRL char (P=10 ATM)

- No clear effect of pressure for this coal
- Effects of char formation pressure on morphology greatest for bituminous coals

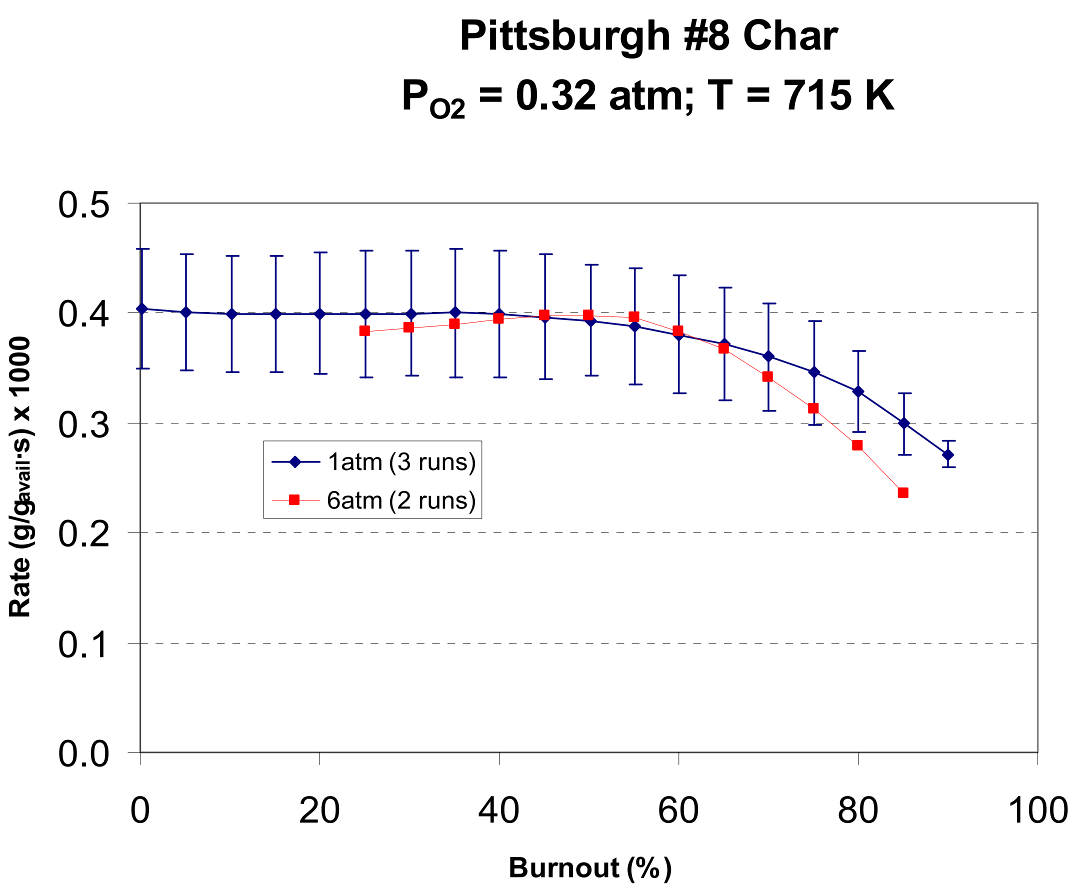
Preliminary Swelling Data



- Mass release from ash tracer (soon to use Al and Ti tracers)
- Tap densities measured, ratio eliminates packing factor
- Shrinkage indicated for 3 of 4 samples
- Increased swelling with pressure for Pitt #8 char, but not as much as in lower heating rate experiments

Pitt 8 TGA Reactivity Data

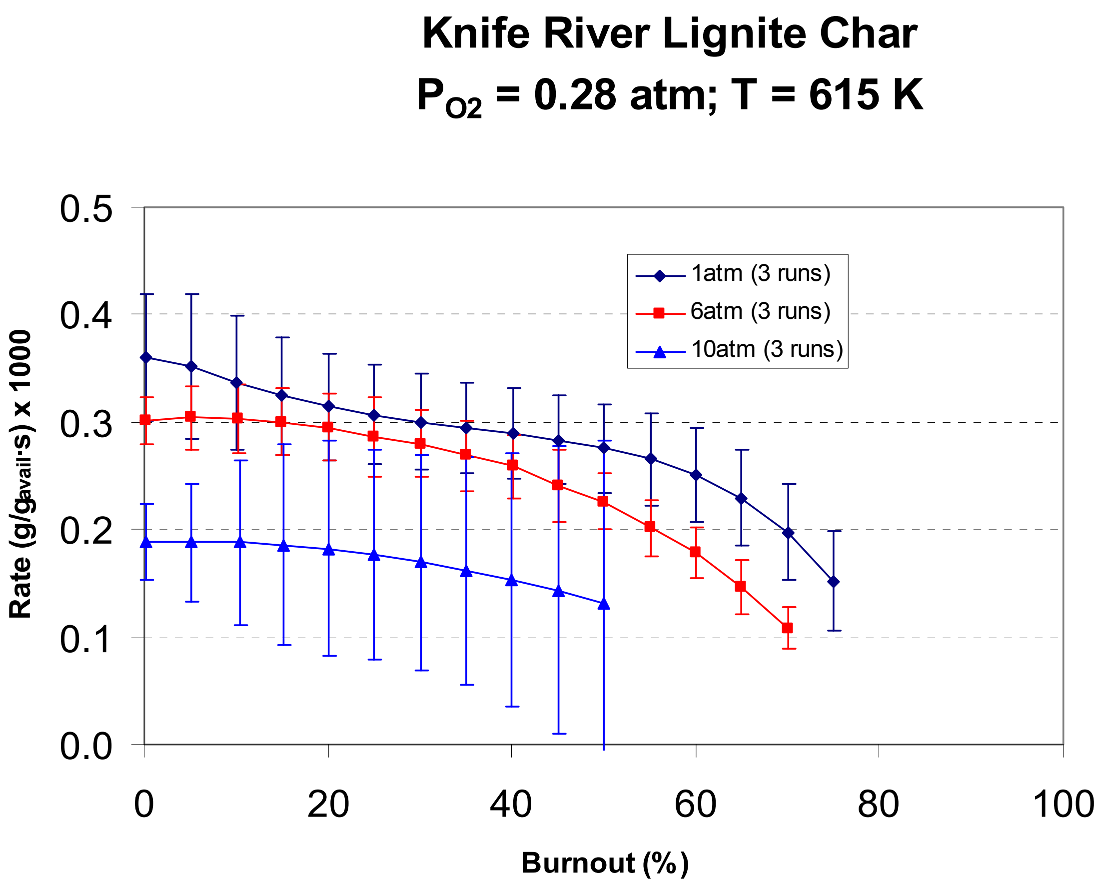
(3-5 mg samples, P_{tot} = char formation pressure)



- TGA (intrinsic) reactivity relatively constant until 60% burnout
- Only late burnout reactivity changes for high pressure char

Lignite TGA Reactivity Data

(3-5 mg samples P_{tot} = char formation pressure)



- TGA (intrinsic) reactivity not constant like the Pitt 8 char
- High pressure char has 15% lower reactivity at these conditions
- Lignite reactivity much higher than Pitt 8, so TGA temperature lowered to get intrinsic rates

The Advanced Combustion Engineering Research Center (ACERC)

- **Founded by the NSF in 1986**
  (Founding Director: L. Douglas Smoot)
- Brigham Young University & University of Utah
- **Initial Mission:** Clean and Efficient Use of Fossil Fuels

  Initial research was aimed at improving the comprehensive 3-D entrained flow coal combustion model (PCGC-3)
- **NSF base support** funding (~$2 M/yr) for first 11 years
- **Results:**
  - Industry using CFD now
  - Many students placed in industry
  - Numerous publications and computer software products

Current ACERC Mission

To develop advanced combustion technology through fundamental engineering research and educational programs aimed at the solution of critical national problems

ACERC Leadership

Thomas H. Fletcher
Director
Chemical Engineering
BYU

JoAnn Lighty
Associate Director
Chemical & Fuels Engineering
U of Utah

Larry Baxter
Associate Director
Chemical Engineering
BYU

Current Research Interests

Industries

- Electric power
- Chemical processes
- Forest products
- Transportation
- Cement
- Glass
- Military (safety)

Fuels

- Coal
- Biomass
- Black liquor
- Petroleum coke
- Live fuels
- Natural gas
- Jet & diesel fuel
- Metallurgical coke
- Soot
- Foams
- Model hydrocarbons

Subjects

- Organic reactivity
- Ash
- Soot formation
- NO_x, SO_x
- Heat transfer (convective, radiative)
- CFD
- Parallel computing

22 Professors Involved

• Calvin Bartholomew	ChE
♠ Larry Baxter	ChE
• Merrill Beckstead	ChE
• Jeffrey Bons	ME
• Mark Clement	CS
♠ Eric Eddings	ChFE
♠ Tom Fletcher	ChE
• Fernando Fonseca	CE
• Hugh Hales	ChE
• Bill Hecker	ChE
♠ JoAnn Lighty	ChFE
• Matt Linford	Chem
• Warren Lucas	CE
• Mardson McQuay	ME
• Justin Peatross	Phys
• Dave Pershing	VP
• Ron Pugmire	ChFE
• Adel Sarofim	ChFE
• Doug Smoot	ChE
• Quinn Snell	CS
♠ Dale Tree	ME
• Brent Webb	ME

♠ = Executive Committee

Who Really Does The Work

- ~ 30 Graduate Students
- ~ 45 Undergraduate Students
- ~ 5 Research Faculty (at U of Utah)
- Visiting Scientists

ACERC secretaries – Jessica Higginbotham, Trang Tran

Range of Research Interests in ACERC

Field Tests/Demonstrations
- **Data Maps for Code Evaluation**
- **New Concepts**

Comprehensive Modeling
- **Incorporate Latest Submodels**
- **Accessible to Industry**

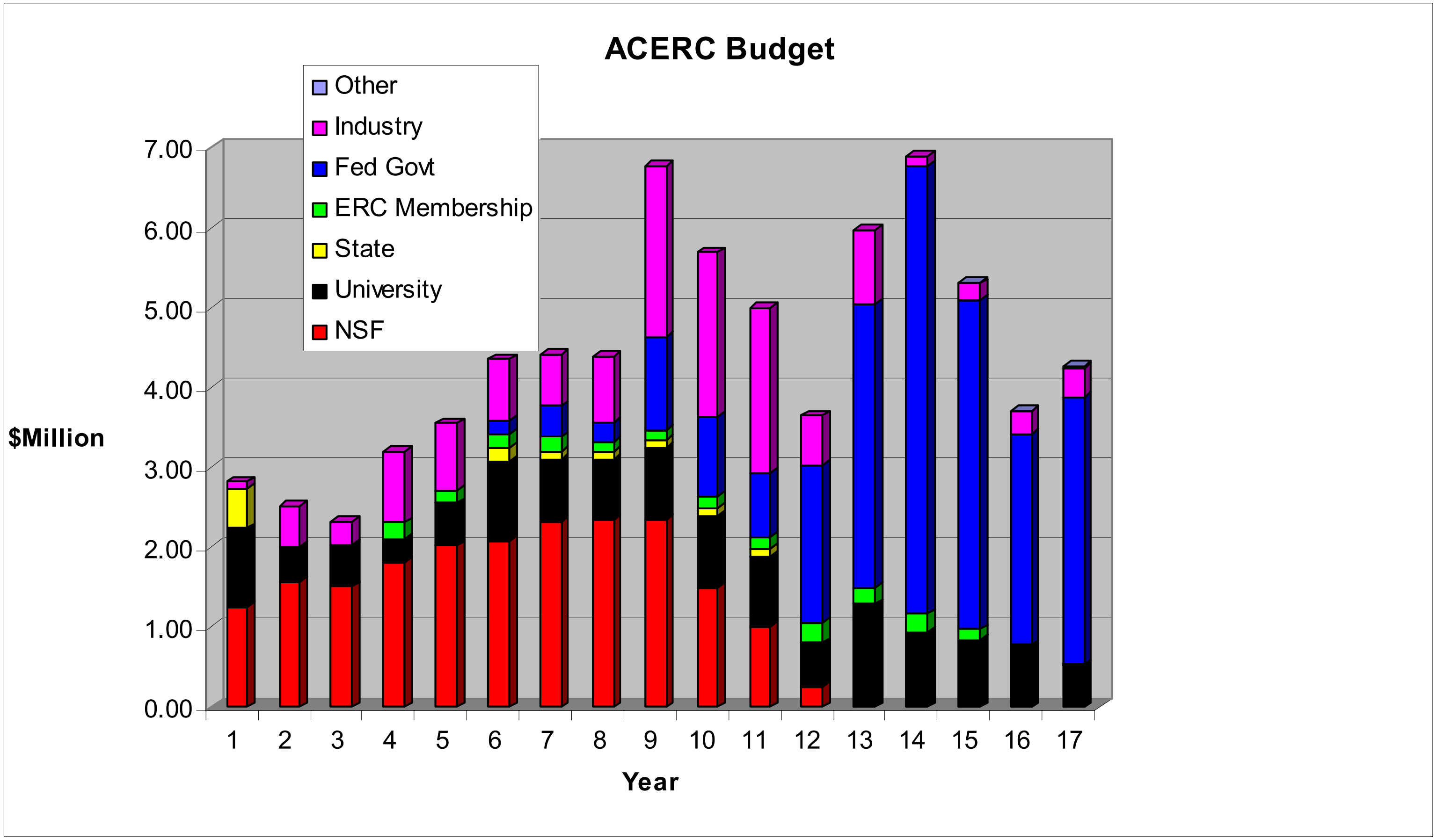
Bench and Pilot Scale Testing
- **Probe Measurements**
- **Laser Diagnostics**
- **Submodel Development**

Fundamental Scientific Research
- **Chemistry**
- **Mechanisms**
- **Ideas**

Types of Reactors
- **Entrained Flow**
- **Fluidized Bed**
- **Fixed Bed**
- **Rotary Kiln**
- **Suspended drops & particles**
- **Levitated particles**

Scale of Reactors
- **Single Particle**
- **1 g/hr**
- **5 lbs/hr**
- **40 lbs/hr**
- **1 MW**
- **150 MW (small industrial)**

ACERC Research Funds 1987-2002



Over $75 million in research over 17 years!

Next Annual ACERC Conference: Feb. 12-13, 2004 in Provo, UT (see www-acerc.byu.edu)