

# The Pressurized Entrained Flow Reactor at GA Tech

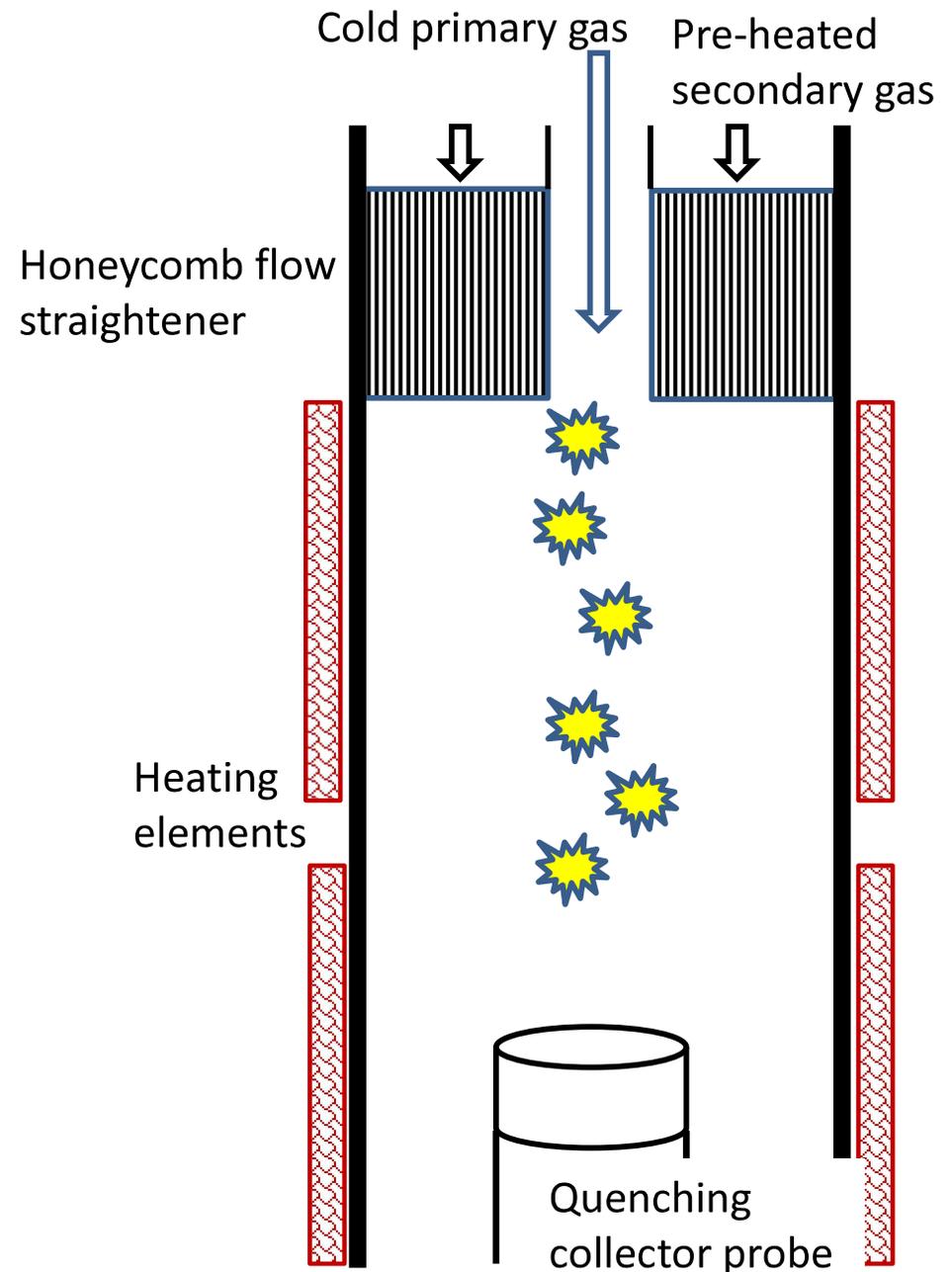
Entrained flow reactors (also known as *drop tube furnaces*) have been used to study high temperature kinetics and fundamental chemistry of solid and liquid fuels for many years. Atmospheric pressure versions are by far the most common (GA Tech has one as well). They offer tight control over particle (or droplet) temperature, gas composition, and residence time. If pressure is to be varied then the entire reactor is usually housed in a pressure vessel. Pressurized EFRs (PEFRs) are somewhat rare due to complexity of operation. This one is the largest PEFR in use by any university for research purposes. It is housed in the Carbon-Neutral Energy Solutions Building.

The fuel to be tested is ground to a powder and fed into the reactor through a water-cooled fuel injector probe. This keeps the fuel cool right up until the injection point. A small amount of inert gas (known as the *primary gas*) flows in with the fuel.



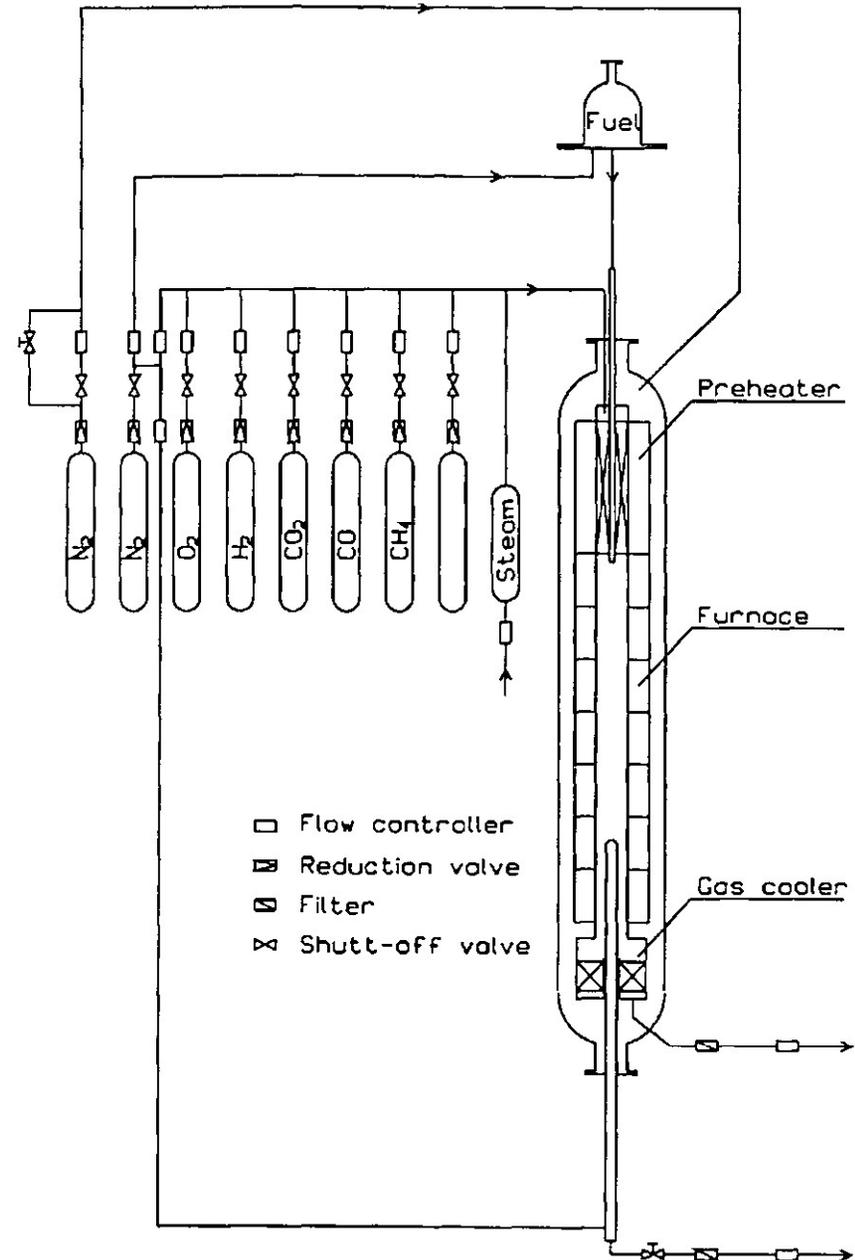
# Fundamental Studies of Pyrolysis, Gasification, and Combustion

- Particles are carried in with cool (about 50C) primary gas steam.
- Particles heat rapidly ( $\approx 10,000\text{C}/\text{sec}$ ) by radiation from the tube walls and convection from hot secondary gas.
- Aerodynamically small particles will be carried through with the gas, thus controlling the residence time.
- Small particles can be assumed isothermal, which simplifies kinetic studies. Reaction tube ID = 82mm.
- Reactions occur in hot gas but are effectively stopped if temperature is cut in half.
- Reactions are rapidly extinguished in a moveable water-cooled, N<sub>2</sub>-quenched collector probe. Effective heated length 15 to 170 cm.



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The majority of the gas is preheated to the reactor temperature and passed through a honeycomb ceramic structure to produce a uniform gas velocity profile at the point where the fuel is introduced. This is the top of the reaction section. Both the preheat and reaction sections of the reactor are heated electrically with Super Kanthal elements. We typically operate at 600-1100°C but the elements can reach temperatures as high as 1500°C. As the fuel enters the reaction section it is rapidly heated by both radiation from the tube wall and convection from the hot secondary gas. Particle heating rates as high as 10,000°C/sec can be achieved in these reactors with particles of 100 microns or smaller. By keeping the flow in a laminar regime the fuel particles flow down the center of the reactor. The gas environment can be either inert (for pyrolysis) or reacting (for gasification or combustion).



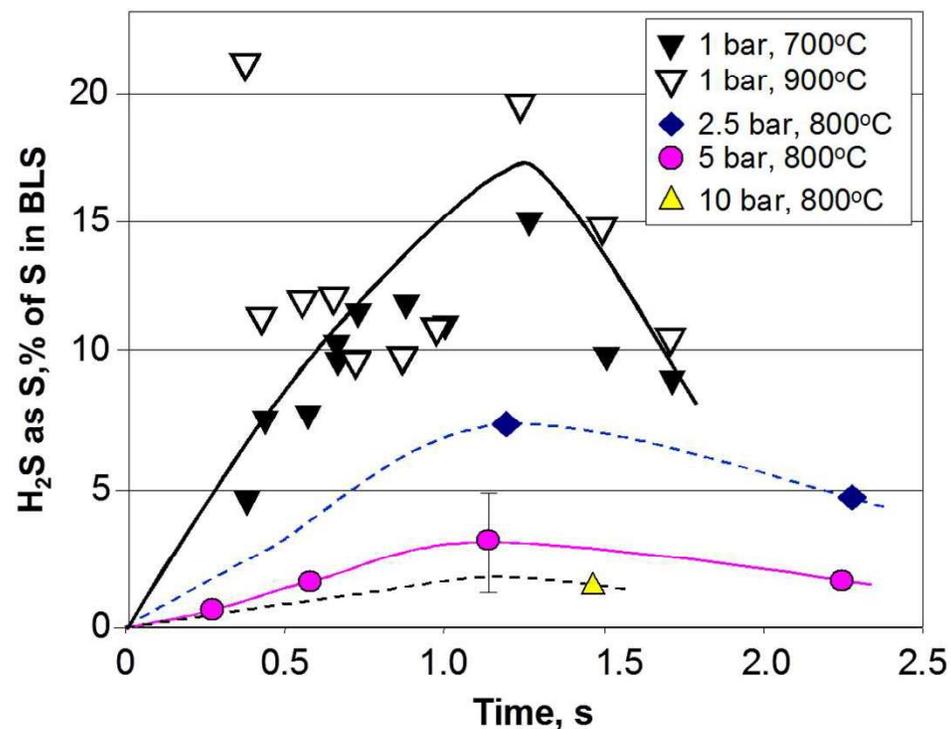
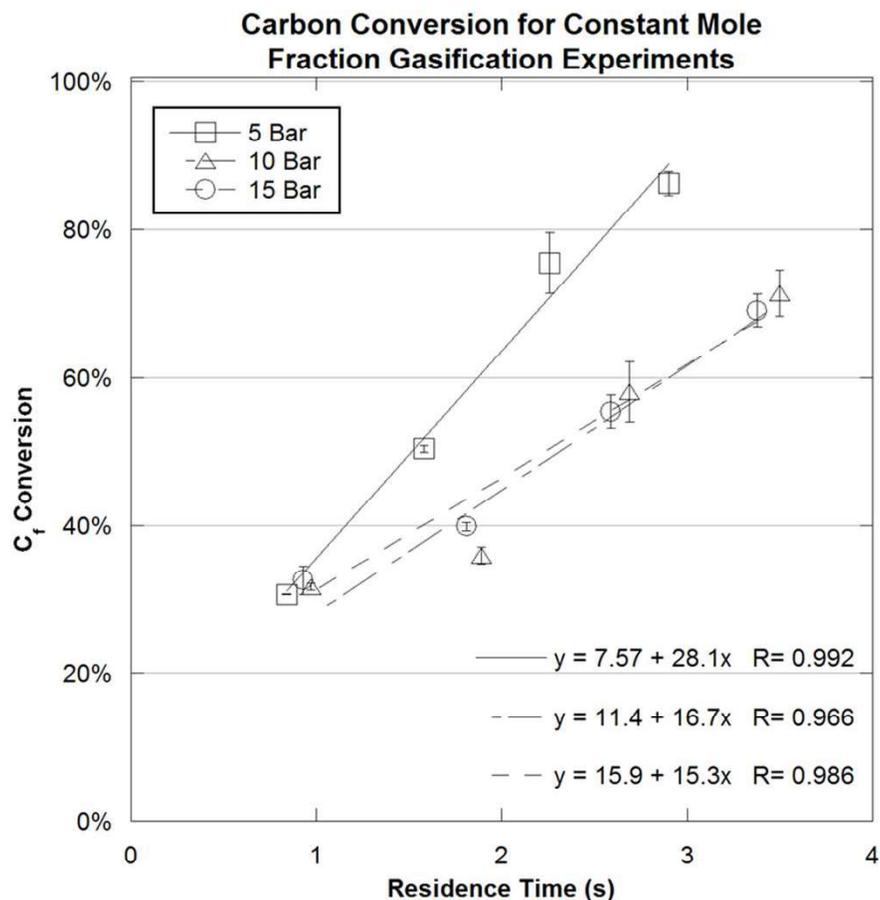
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At the bottom, both the gas and entrained particles enter a collector probe. This probe is water-cooled for rapid cooling and designed to introduce cool inert gas to the hot gas just inside the tip. The collector probe can be moved up and down along the axis of the reactor to vary the path length, and thus residence time, of the fuel particles. Gas velocity can also be varied to control residence time. Past feedstocks include various woods, pulverized coals, switch grass, bagasse, corn stover, recycle paper sludge

The reacted particles (“char”) are collected in a small cyclone, while condensation aerosols (“fume”) pass through and collected in a glass fiber filter. The exhaust gases can be analyzed on-line by FT-IR, NDIR for CO/CO<sub>2</sub>, H<sub>2</sub>, or Chemiluminescence for NO<sub>x</sub>. Gas bag samples can be collected for later GC or GC-MS analysis.

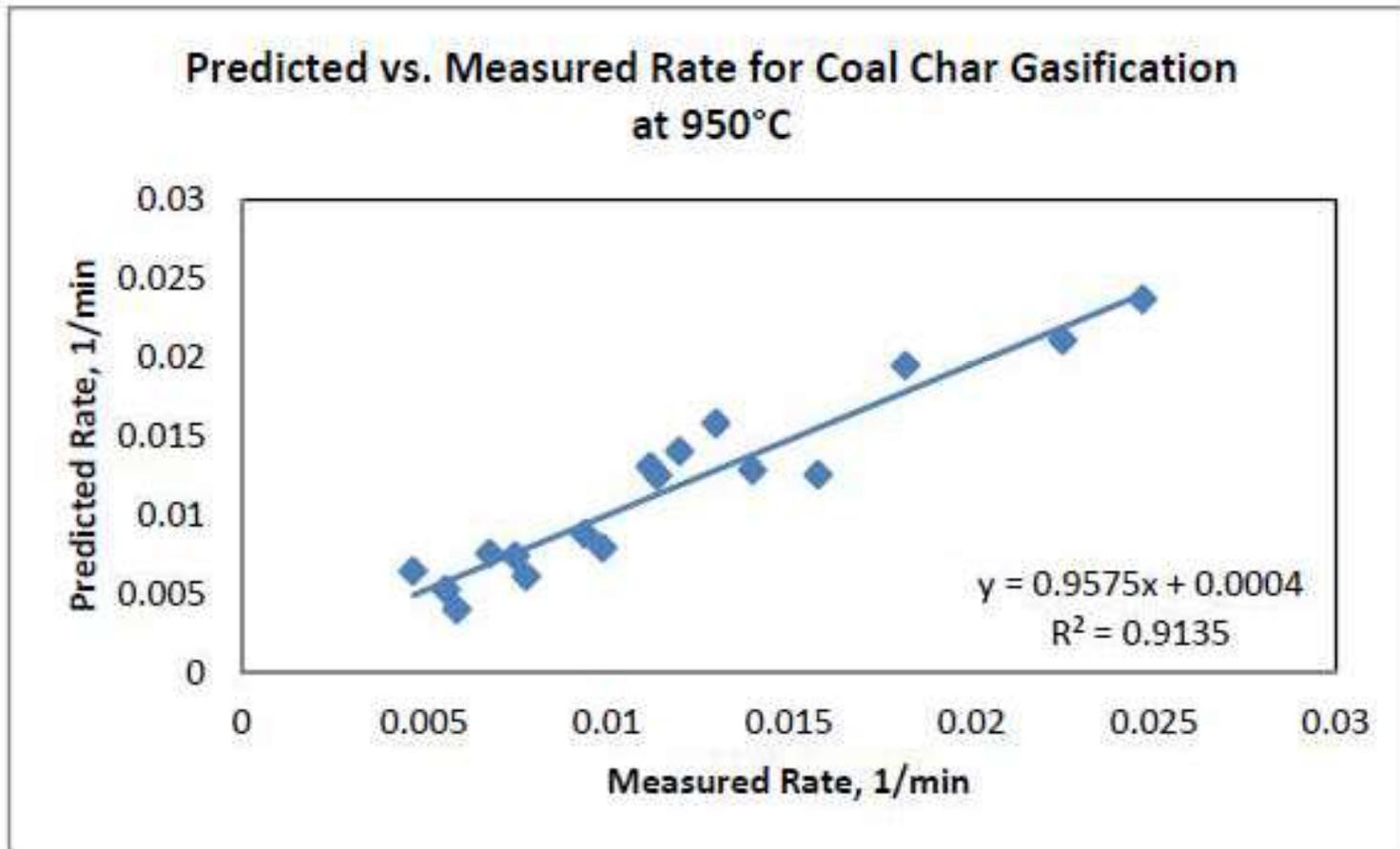
- The particle residence time can be varied from about 0.2s to over 30s but will depend on particle size and density.
- Typical temperatures vary from 600C to 1200C but can go as high as 1500 by switching to pure alumina reaction tubes.
- Typical operational pressure can vary from 3 to 20 bar. Much higher pressures are possible with some minor modifications, however convective heat losses become quite large and the maximum temperature drops with increasing pressure.
- Feed gases include N<sub>2</sub> and Ar (for pyrolysis), air, O<sub>2</sub>, CO<sub>2</sub>, CO, H<sub>2</sub>O, and H<sub>2</sub> for gasification or combustion.

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A wide variety of studies are possible with these reactors. The left figure shows kinetic data for gasification of black liquor in CO<sub>2</sub> and water vapor (from PhD dissertation “Pressure Effects on Black Liquor Gasification, Chris Young 2006). The right figure shows the fraction of sulfur that forms H<sub>2</sub>S during pyrolysis of black liquor (Sinquefield, et.al, 2001).

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Another example of kinetic data taken with the PEFR, for lignite coal char gasification. Taken from DOE Project DE-FE0005339 final report “Development of Kinetics and Mathematical Models for High Pressure Gasification of Lignite-Switchgrass Blends,” (2016)

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