Reinhold Environmental Ltd.

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Alternate Technology for Enhanced SO_X/NO_X Capture by Limestone-Urea Injection

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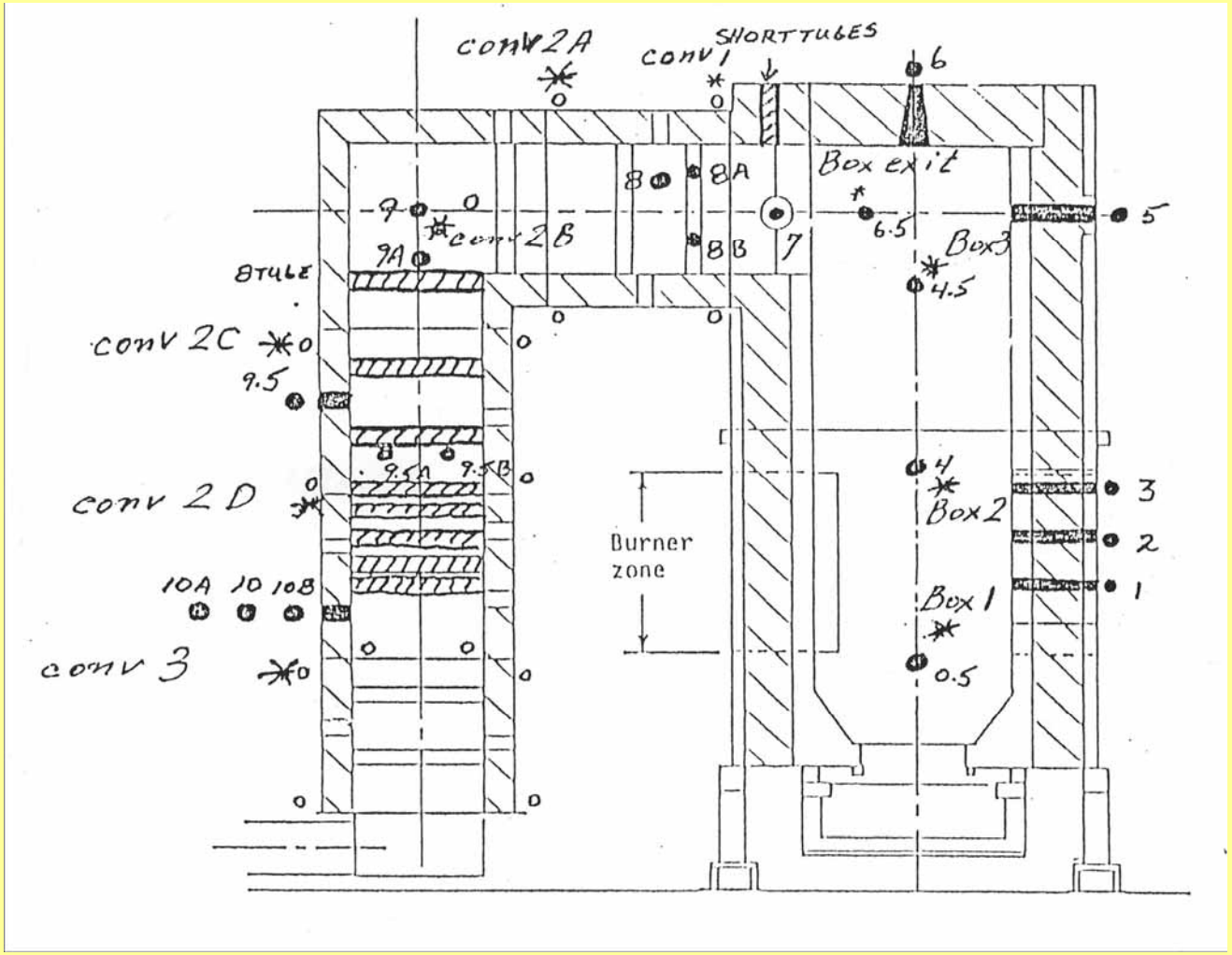
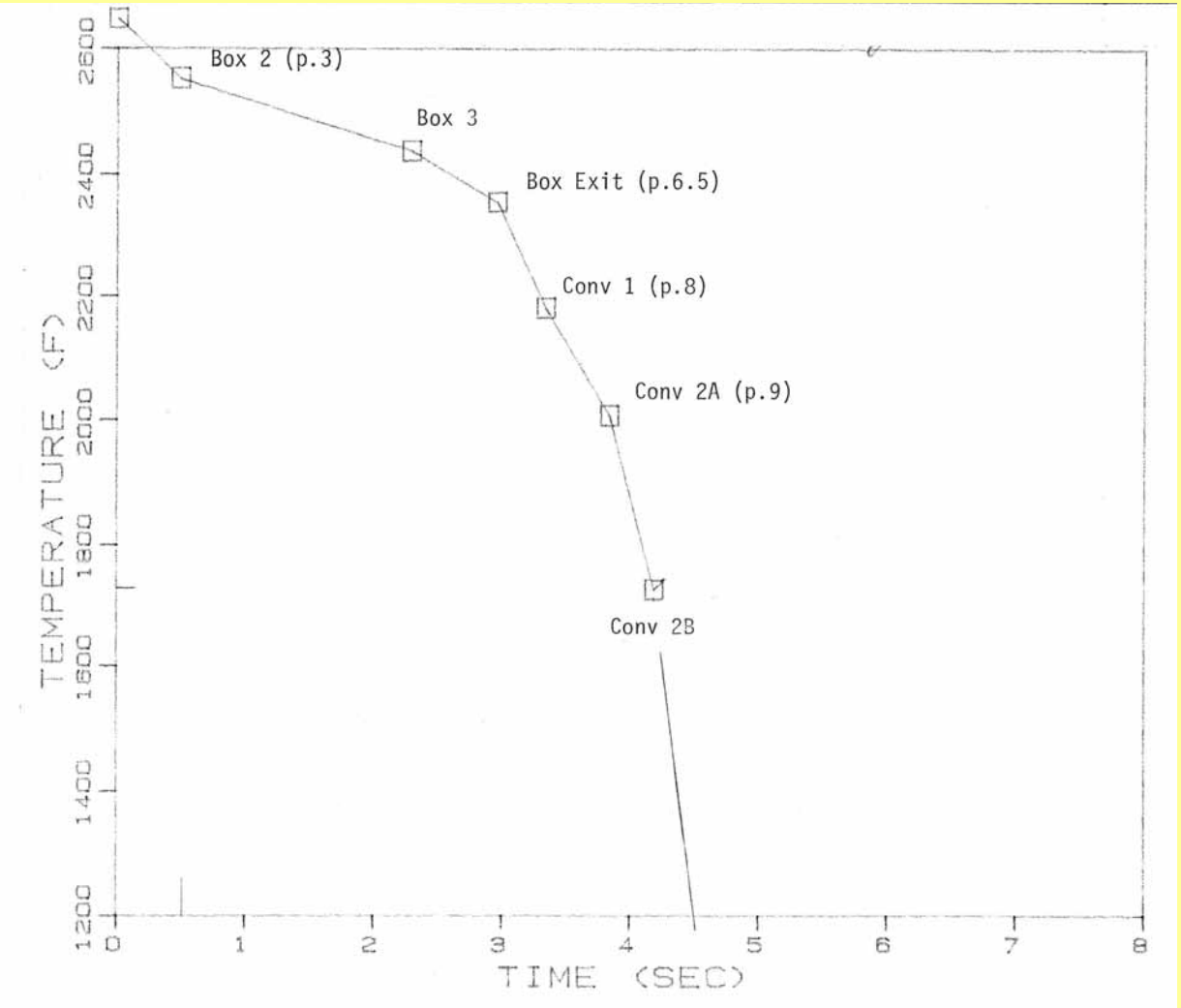
Limestone Sorbent Injection in a Pilot Scale Furnace

- Limestone injection in a pilot scale furnace with capacity 1.3 MMBTU/hr
- Furnace operated on natural gas doped with H_2S (simulation of Illinois Coal #6)
- Sorbent – El Dorado dry limestone ground down to 40-50 microns
- Model the temperature-time profile for the full scale coal fired utility boilers U.S. design with capacity 200 MW to 500 MW

Location of Ports and Wall Thermocouples



Temperature – Time Profile
Dry Limestone P.3, P.5, P.8, P.9
No. 1, 3, 4, 5, 6, 7



Baseline Particle Temperatures

- **Sorbent injection over the burner zone**
- **Temperatures at injection: 2500 to 2280°F (1400 to 1250°C)**
- **Radiation heat transfer dominates**
- **Time to achieve 2300°F (1245°C) particle temperatures:**

11 Micron	**0.9 MSEC**
45 Micron	**15 MSEC**

Characteristic Time-Temperatures

- **Sorbent process times**
  - **Calcination: 0.2 to 0.3 seconds**
  - **Sulfation: 0.35 to 0.4 seconds**
  - **Total calcination and sulfation: 0.7 seconds**
- **Sorbent process temperatures**
  - **Calcination: 2200 to 1800°F**
  - **Sulfation: 2000 to 1750°F – limestone**
  - **Sulfation: 2000 to 1300°F - dolomite**

Dry Sorbent Baseline Results

	Sorbent Injection							
N	Port Location	Direction	SO_2 Reduction (%)	Ca/S Ratio	Ti-Tg (°F)	τ_i-τ_g (sec)	SR	SO_2 Input (ppm)
1	3	Coflow	35.85	2.52	2535 – 2000	3.35	1.19	3975
3	5	Coflow	35.87	2.59	2400 – 2000	1.6	1.18	3875
4	8	Counter flow	34.21	2.40	~2400 – 2000	<0.5	1.21	3950
5	8	Cross flow	34.36	2.40	2190 – 2000	~0.5	1.21	3950
6	9	Counter flow	45.33	2.40	~2100 – 2000	<0.5	1.20	3975
7	9	Coflow	15.28	2.40	2000	--	1.20	3950

Sorbent Deactivation

- **Critical temperature – 1950 to 2000°F**
- **Time for particle deactivation – 1 to 15 MSEC**

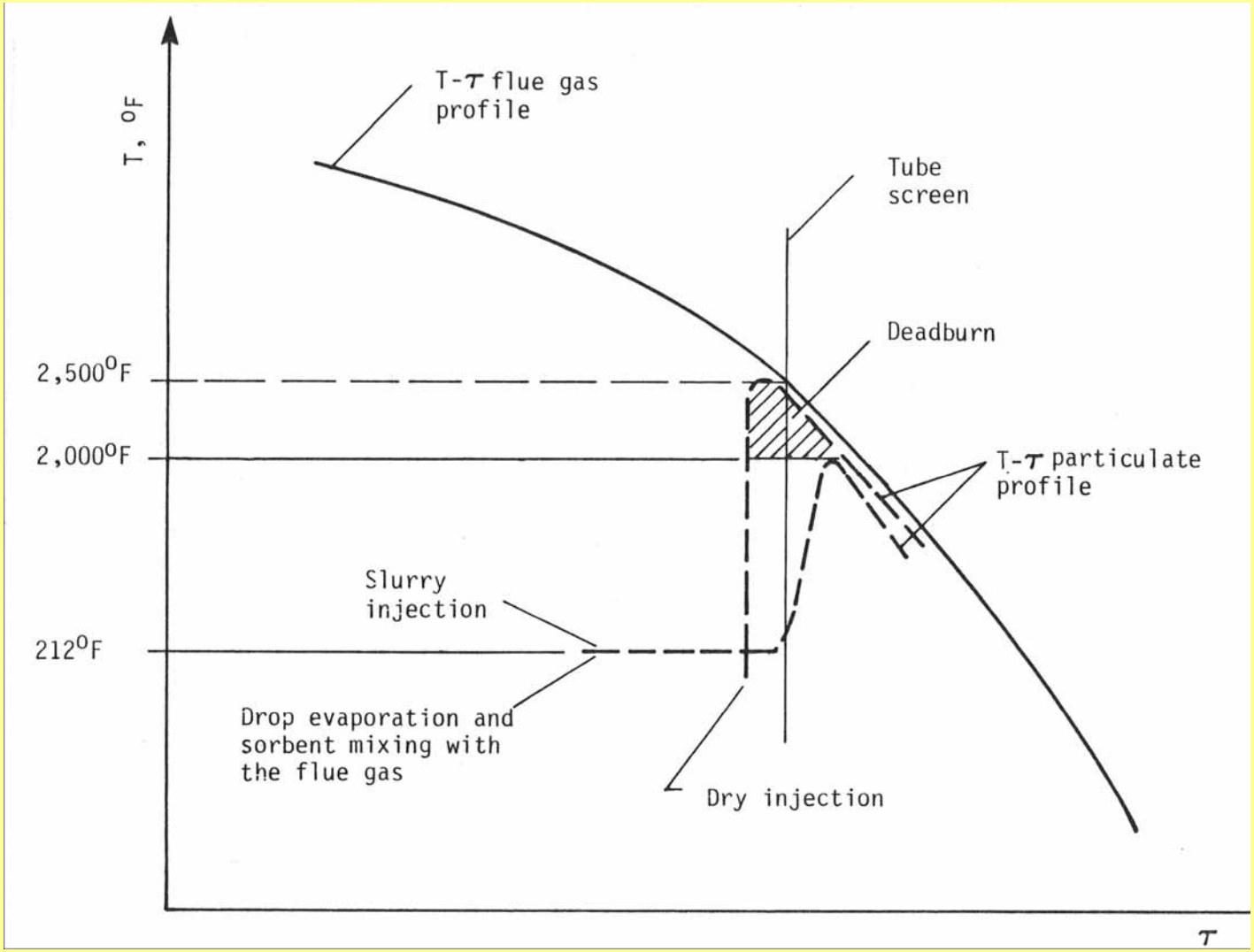
Enhanced SO_2 Capture

- **Inject water/limestone slurry (2:1) jet supported by air**
  - **Upper Furnace**
  - **Good penetration and distribution**
  - **Good mixing (~1 sec residence time)**
- **Suppress sorbent deactivation**
  - **Low particle temperatures during evaporation**
  - **Water drop evaporation time: 0.8 – 1 sec**
  - **Achieve desirable sorbent particulate temperature zone - 2000°F (behind the tube screen and first row superheater tubes)**

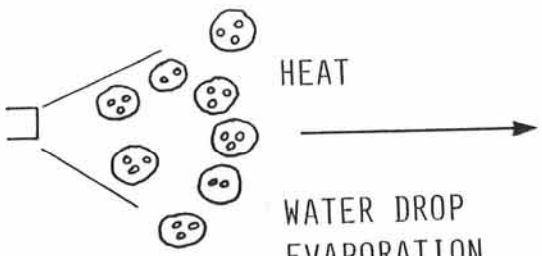
Slurry Injection Advantages

- Suppress deadburning
- Enhanced mixing
- Desired temperature window hit in inaccessible areas
- Ash interaction avoided
- Opportunity to use water as an additional additive-carrying medium

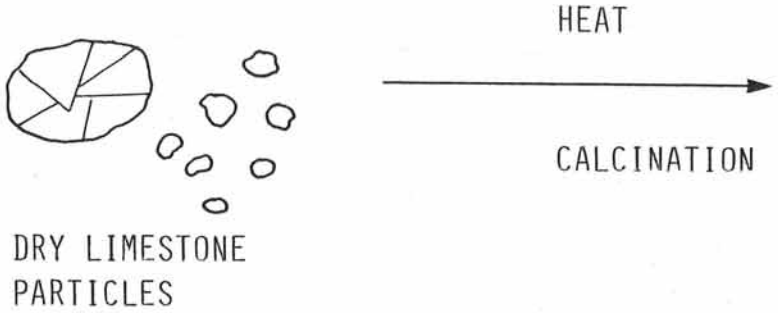
Sorbent Injection Process



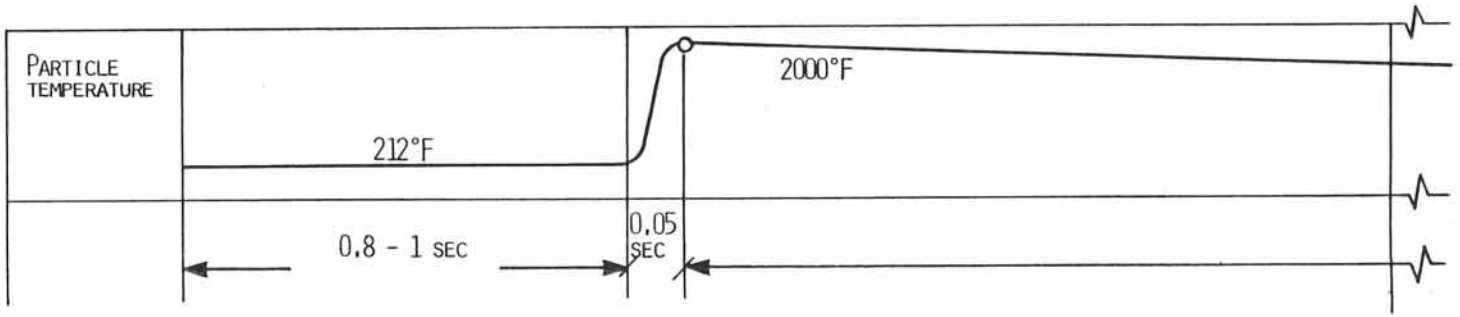
Enhanced SO_2 Capture



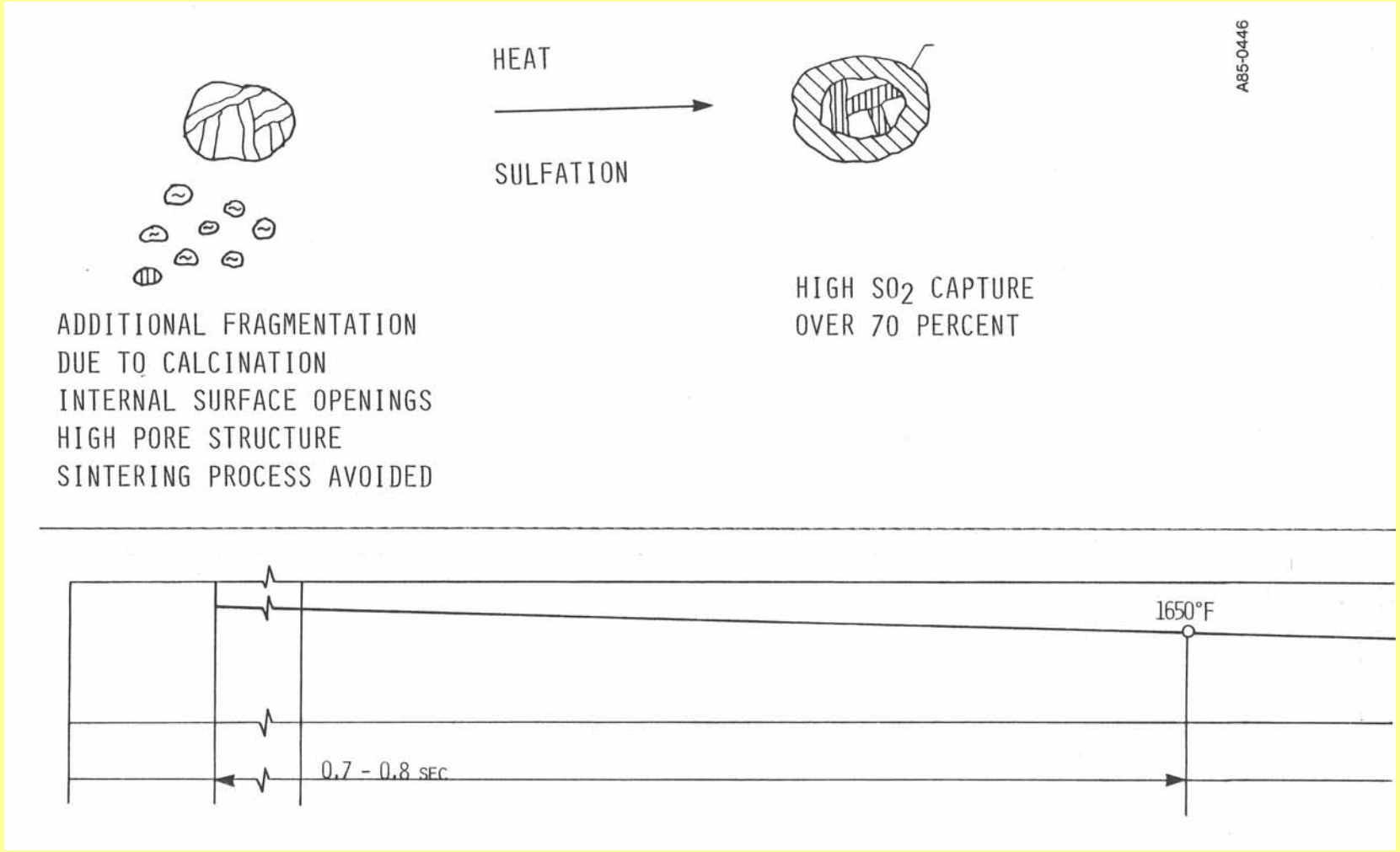
LIMESTONE-WATER SLURRY ATOMIZATION
GOOD MIXING WITH FLUE GAS FLOW



PARTICLE DISINTEGRATION DUE TO INCREASED
VAPOR PRESSURE IN THE PORE STRUCTURE



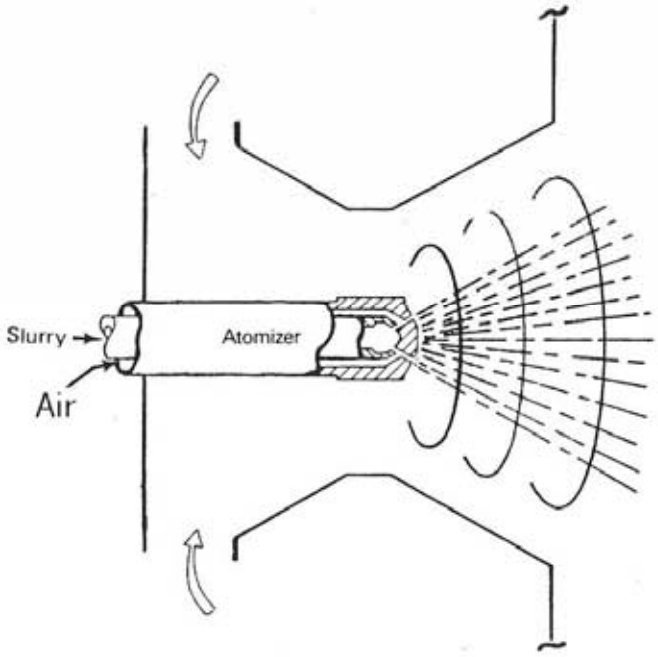
Enhanced SO_2 Capture



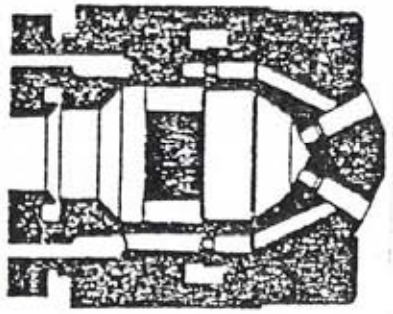
Time to Heat Up Water Drops to Reach Boiling Surface Temperature						
Drop Diameter δ, μ	200	300	500	800	1000	1500
Time τ, SEC	3.24×10^{-3}	7.29×10^{-3}	2.03×10^{-2}	5.18×10^{-2}	8.1×10^{-2}	1.82×10^{-1}
Evaporation Time of Water Drops Injected in a Gas Flow						
Drop Diameter δ, μ	200	300	500	800	1000	1500
Time τ, SEC	0.021	0.048	0.133	0.339	0.530	1.193
Gas Flow Temperature 2192°F (1200°C)						

Slurry Atomization and Injection

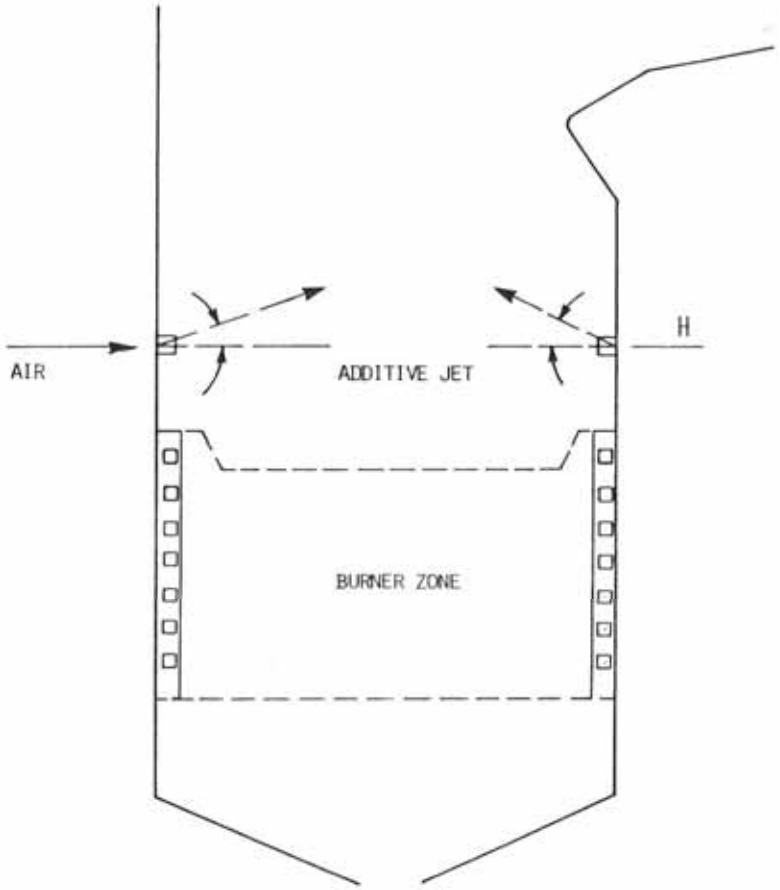
FGR 5 to 10 Percent

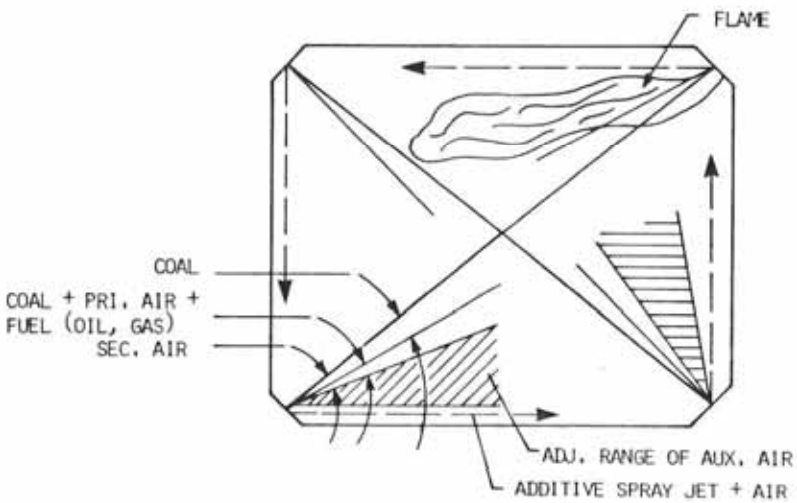


Compressed Air 45 to 60 psi
Slurry 30 psi

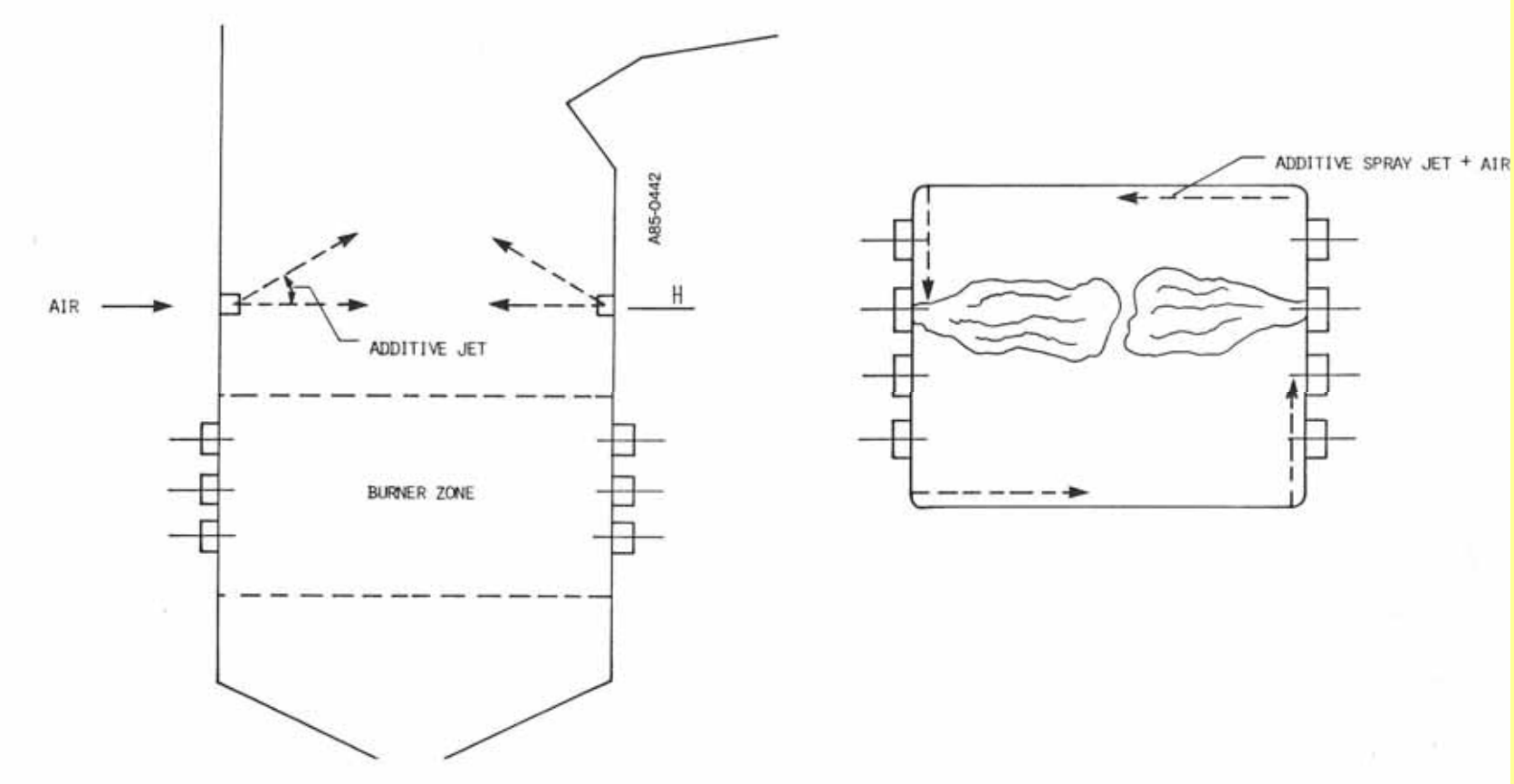


T-Fired Boiler





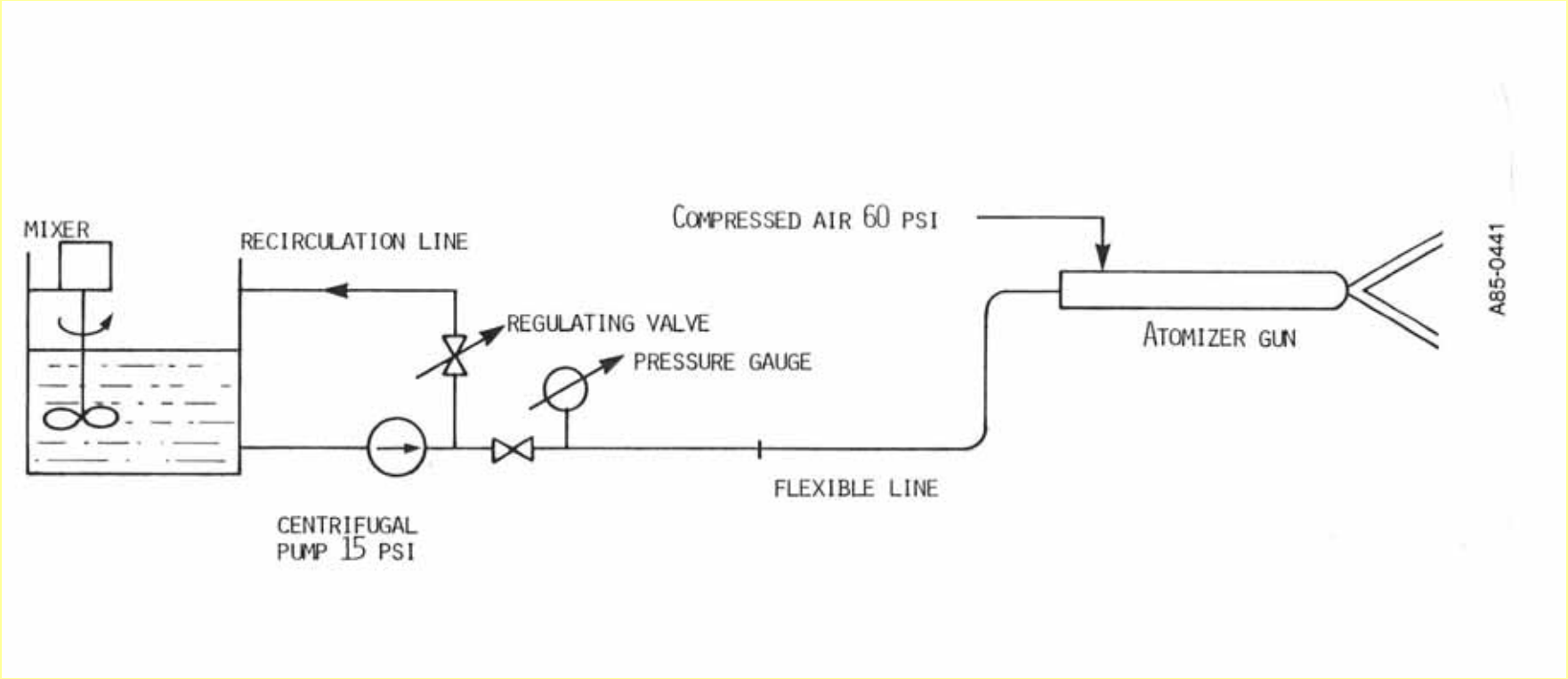
Wall-Fired Boiler



Preliminary Limestone – Water Slurry Tests

- Natural gas doped with H2S (Illinois Coal #6 Simulation)
- 1.3 MBTU/hr T-fired furnace
- Sorbent: Fine El Dorado limestone
- Slurry: 1:2 ratio sorbent/water
- Injection: Different ports in the furnace – Y-jet atomizer
- Mixing problem with flue gas avoided

Limestone Slurry Experimental Equipment

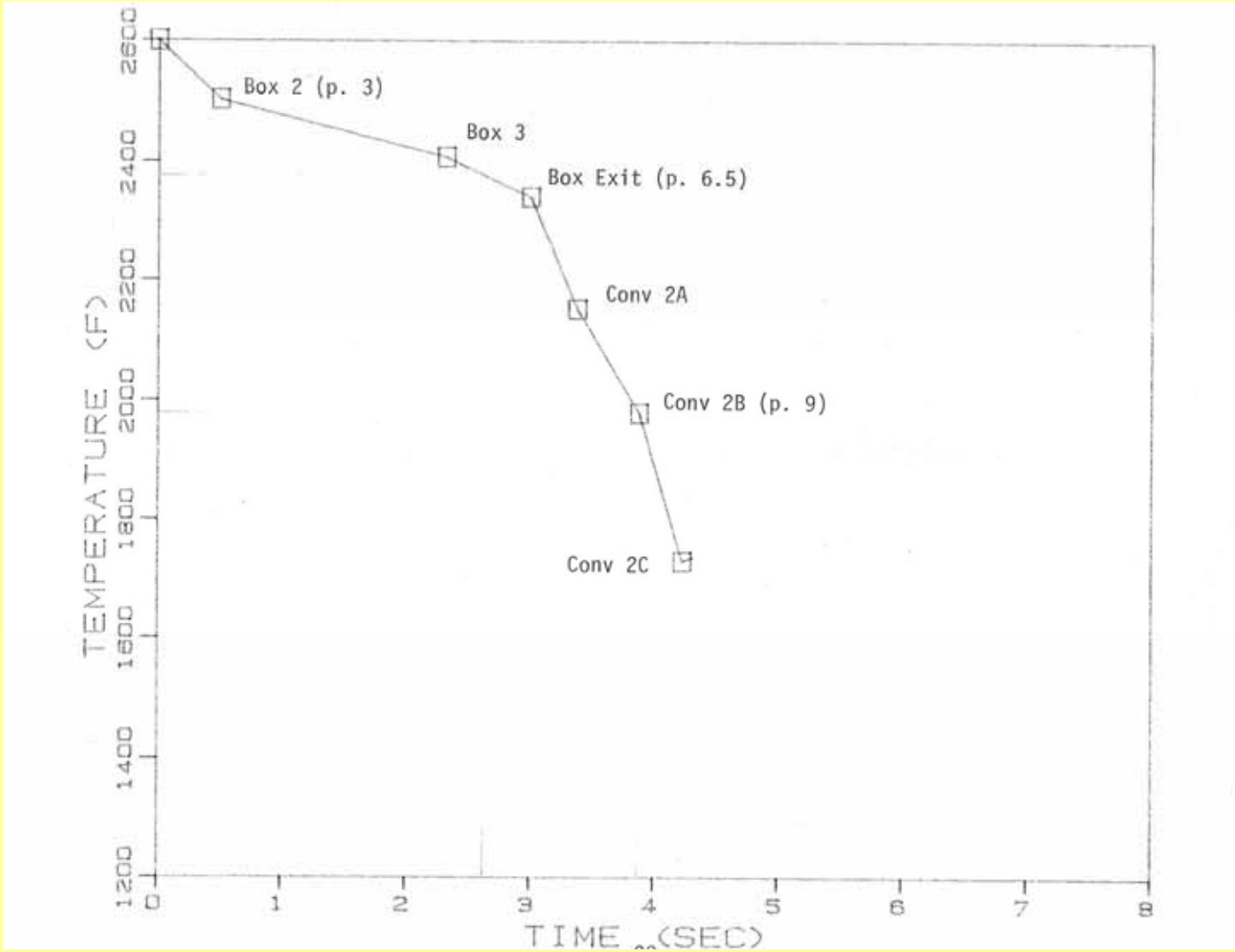


Slurry Results

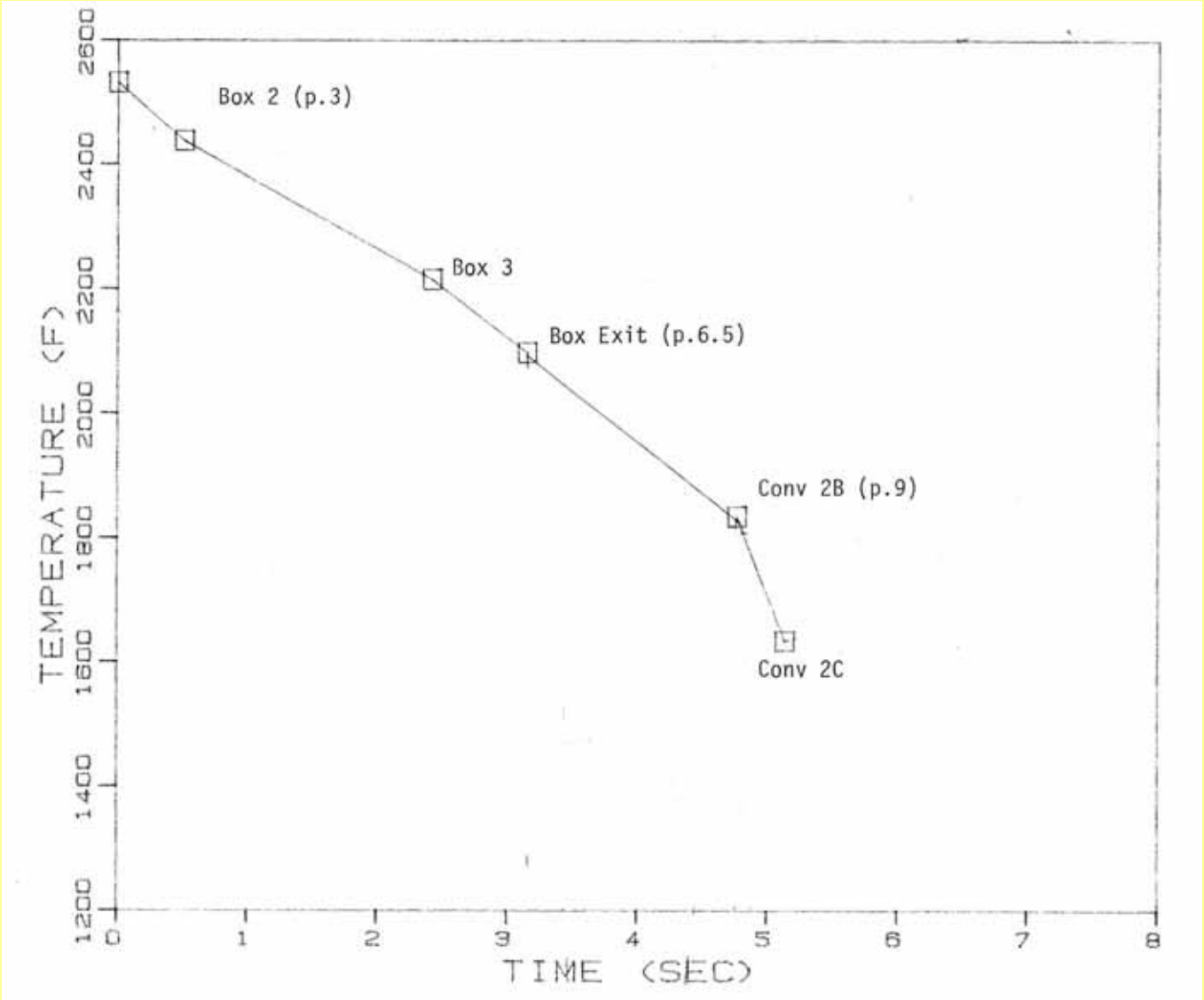
	Slurry Sorbent Injection							
N	Port Location	Direction	SO_2 Reduction (%)	Ca/S Ratio	Ti-Tg (°F)	τ_i-τ_g (sec)	α	SO_2 Input (ppm)
1	5	Coflow	72.58	2.69	2160 – 1830	2.0	1.20	3875
2	5 Moved Injector 2” Ahead	Coflow	76.50	2.69	2160 – 1830	2.0	1.21	3875
3	5	Coflow	35.82	2.57	2380 – 1980	1.3	1.18	3975
4	5	Coflow	38.42	2.57	--	--	1.18	3975

Natural gas doped with H2S (simulation of Illinois Coal #6)
Sorbent: 1 & 2 – El Dorado limestone slurry 1:3
3 – El Dorado dry limestone
4 – El Dorado dry limestone P3, equivalent water P3 to 1:3

Baseline for 1, 2, and 3



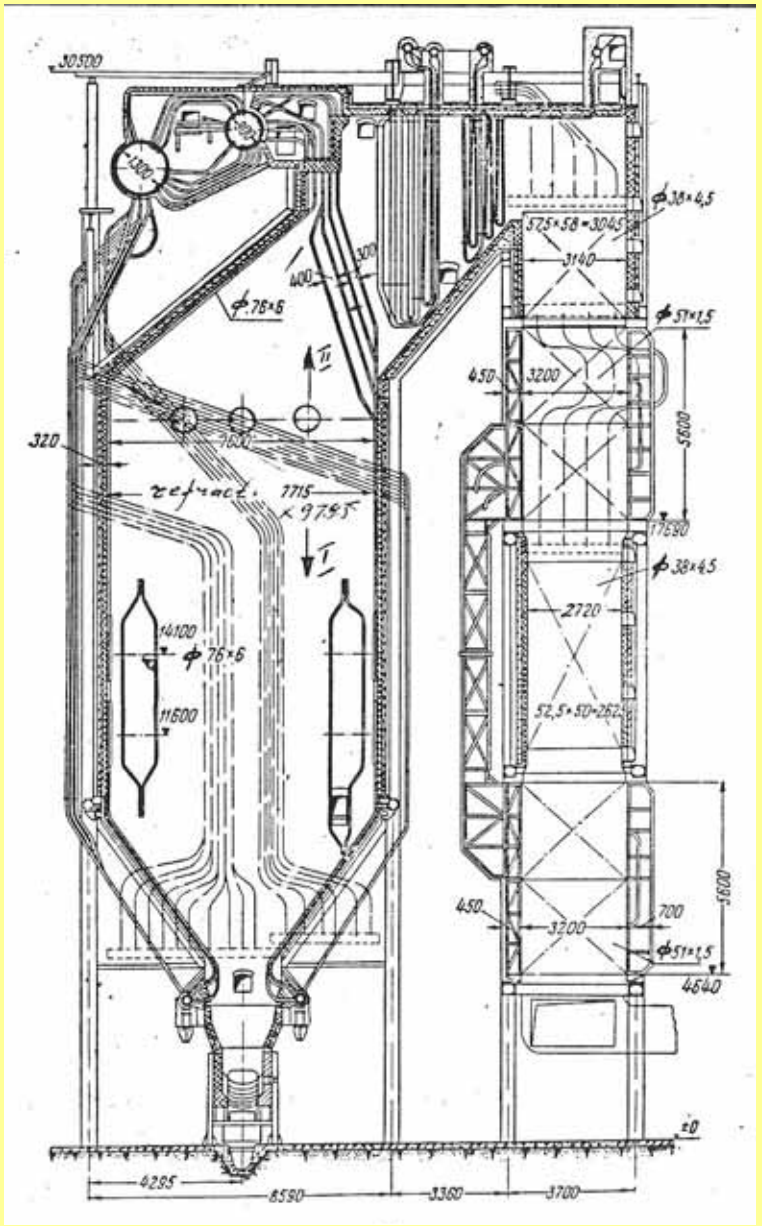
Slurry 1:3, 5, Tests 1 and 2



Boiler Performance Impact

- No impact on the steam parameters and SH/RH performance
- No impact on boiler capacity
- Insignificant boiler efficiency decrease because water injection
- No influence on combustion stability
- Primary SH/RH and economizer erosion evaluation
- FD and ID capacity and pressure evaluation
- ESP/Baghouse capacity and performance evaluation

Industrial Steam Boiler 500,000 lb/hr, 1485 psi, 950°F



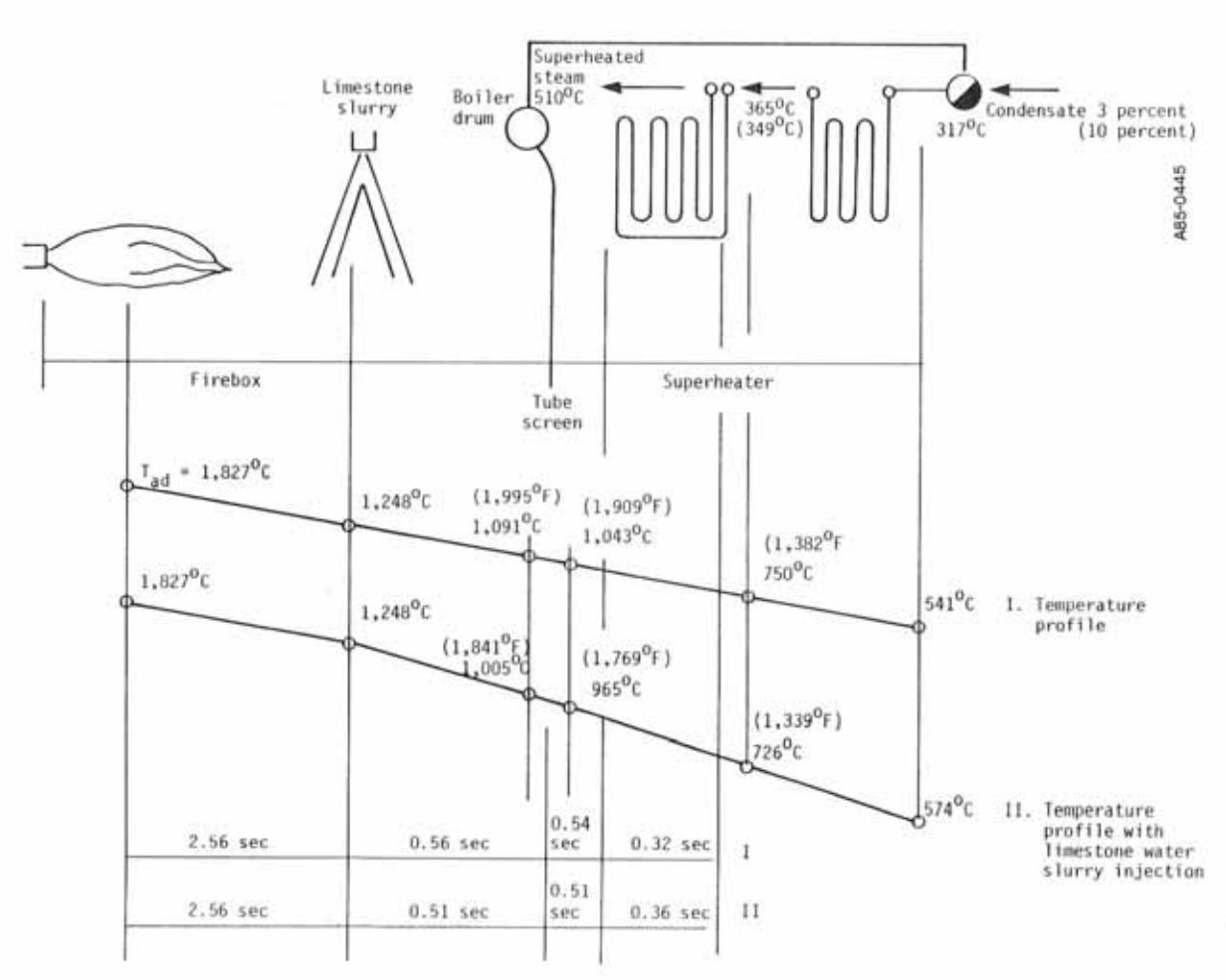
Boiler Parameters

- **Capacity**
  - **230 T/hr (507,000 lb/hr) steam**
- **Pressure**
  - **After superheater – 101 ATM (1485 psi)**
  - **Boiler drum – 110 ATM (1620 psi)**
- **Temperature**
  - **Superheater steam – 510°C (950°F)**
  - **Feeding water – 215°C (419°F)**

Boiler Parameters – Cont.

- **Coal – Subbituminous Coal**
  - **W – 11.0%**
  - **A – 40.1%**
  - **S – 3.8%**
  - **C – 38.6%**
  - **H – 2.6%**
  - **N – 0.8%**
  - **O – 3.1%**
  - **Vol – 30.0%**
  - **LHV – 3650 KCAL/KG (6570 BTU/lb)**

Boiler Profiles with and without Slurry Injection



Flue Gas NO_X Control with Urea Injection

- Urea injection technology based on EPRI patent, now expired and is public domain
- In the small scale furnaces with good mixing of urea with the flue gas 80% NO_X reduction achieved
- In a real boiler not more than 40% NO_X reduction achieved because the mixing problem

Flue Gas NO_X Control with Urea Injection – Cont.

- APTECH system provides a good mixing of urea with main flue gas flow in the right temperature window
- Urea temperature window – 1500°F to 1900°F
- Ca based sorbent temperature window – 1600°F to 1850°F
- Expected NO_X reduction with APTECH system – up to 75%