

**MACT Control for Industrial Boilers**  
CIBO – August 3-5, 2004

**Mercury, HCl, Metals and Particulate  
Control in a  
Dry Absorption System**

*Beaumont Environmental Systems*

Presentation that introduces Flash Drying and present the approach to mercury control using that system.

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**Building a Simple MACT System**

- **Mercury**
  - **Need a Baghouse**
  - **Need some Cooling**
  - **Need a Simple Sorbent**
- **HCl**
  - **Need a Simple Sorbent**
  - **Metals**
  - **SO<sub>2</sub> Later**
- **Particulate**
  - **Baghouse**
  - **SO<sub>3</sub> Control**

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Mercury capture is ALMOST always improved by cooling.; lime addition "freezes" mercury oxidation by acids but is a stronger bonding site than AC, especially with ESP; therefore lime addition where LOI is high can be implemented with or without cooling with impunity.

For bituminous coal, most applications will have ample flyash LOI, HCl and SO<sub>3</sub> such that a baghouse alone can achieve near 90% mercury control. Cooling can be added for condensable PM control and lime for additional mercury and SO<sub>3</sub> control, but acids will only be added for very low chlorine/low sulfur coals to achieve 90% mercury control.

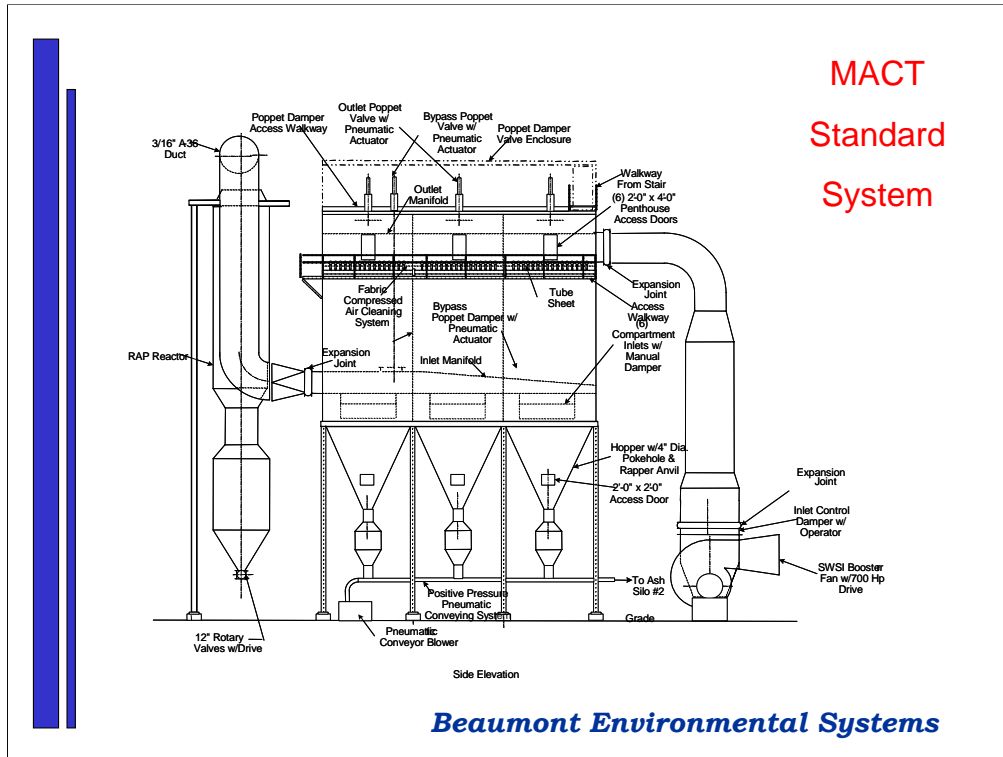
For subbituminous/lignite coals, acid addition and gas cooling will be necessary to achieve 90% mercury control with a baghouse, but lime addition will likely not be required due to alkaline ash. Carbon addition by modified combustion or sorbent addition may be needed for >90% mercury control, but the reactor design will minimize the consumption of additional sorbents by intense mixing of fly ash and flue gas.

Mercury removal with ESPs is more difficult to predict and are fuel and site specific. But gas cooling and conditioning will always significantly improve PM and mercury control in an ESP. With subbituminous/lignite, we cool only if we either add carbon or acids or both, or use oxidants to make acids.

HCl is removed by lime at almost any temp, gas cooling is not necessary.

Metal PMs occur generally as submicron sulfate particles that will grow (hydrate) if gas is cooled, so cooling dramatically aids metals capture.

SO<sub>2</sub> removal always benefits from water addition/gas cooling.



A typical RAP/Dap system applied to a boiler..

In the DAP we only cool and possibly add pebble lime on a once thru basis..

In the RAP where SO<sub>2</sub> is removed we use pneumatic transfer from the baghouse back to the DAP silo.

We can furnish the DAP and later upgrade to the RAP..

### Boiler Design Criteria (Before Cooling -or- Lime Addition)

Stoker		PC Fired	
<b>Particulate at BH Exit - Estimate</b>			
350	Temp (F)	350	Temp (F)
10	MWe	100	MWe
3500	MMBTU/hr	1000	MMBTU/hr
0.005	ACFM/Mwe @ 450	0.005	ACFM/Mwe @ 450
	grains/acf		grains/acf
31,154	at 350	311,538	at 350 acfm
20,385	at 70 (SCFM)	203,846	at 70 (scfm)
1.3352	lbs/hr Part	13.3516	lbs/hr Part
0.0134	lbs/mmBTU	0.0134	lbs/mmBTU
0.0083	grains/dscf	0.0083	grains/dscf
<b>Looking at SO3</b>			
78,678	Lbs Steam	786,782	Lbs Steam
2.00	% Sulfur	1.25	% Sulfur
2	<b>Stoker</b>	1	<b>PC Fired</b>
15.00	ppmv SO3	4.69	ppmv SO3
3.75	SO3 Absorbed	1.17	SO3 Absorbed
11.25	SO3 Remaining	3.52	SO3 Remaining
0.0365	Lb/MMBtu Cond	0.0114	Lb/MMBtu Cond
<b>Outlet including Condensibles</b>			
0.0498	Lb/MMBtu OUT	0.0247	Lb/MMBtu OUT
<b>SCR or SNCR Sneakage Must be Added</b>			

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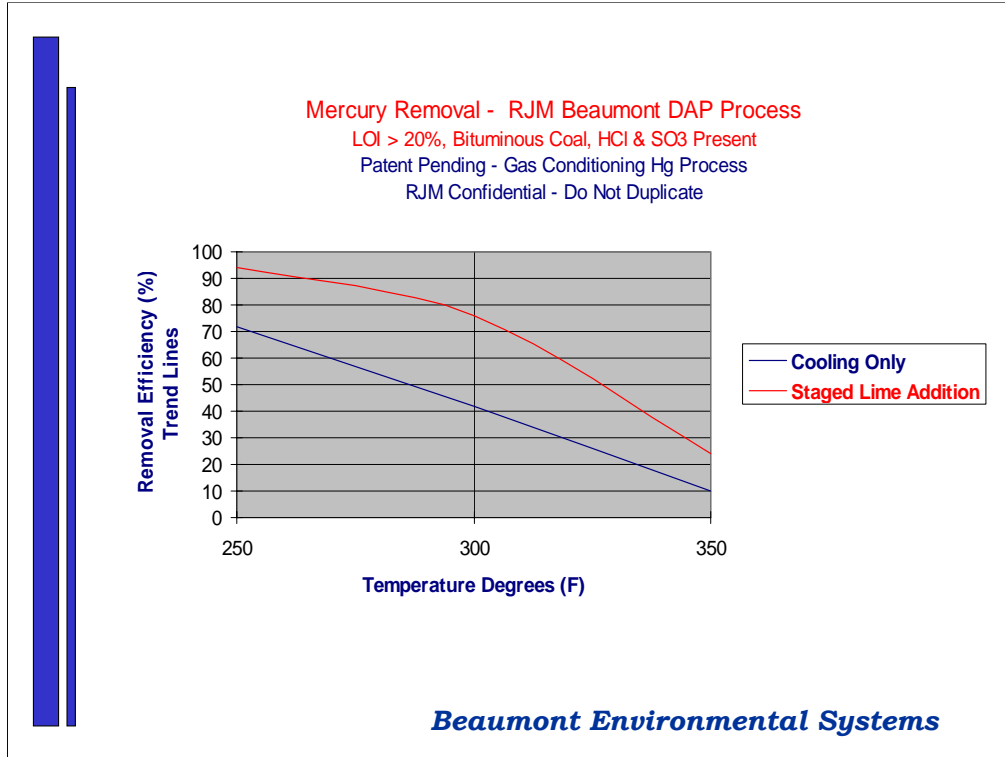
First we must look at particulate. Each boiler is unique, two typical boilers are shown above.

Assuming: WE ARE DESIGNING FOR 0.025 Lbs/MMBtu both of the above boilers would need to reduce particulate.

Cooling will allow reduction of the condensibles.

Baghouse could be designed for lower particulate outlet using membrane filter bags or use an Electro-Pulse for additional particulate removal.

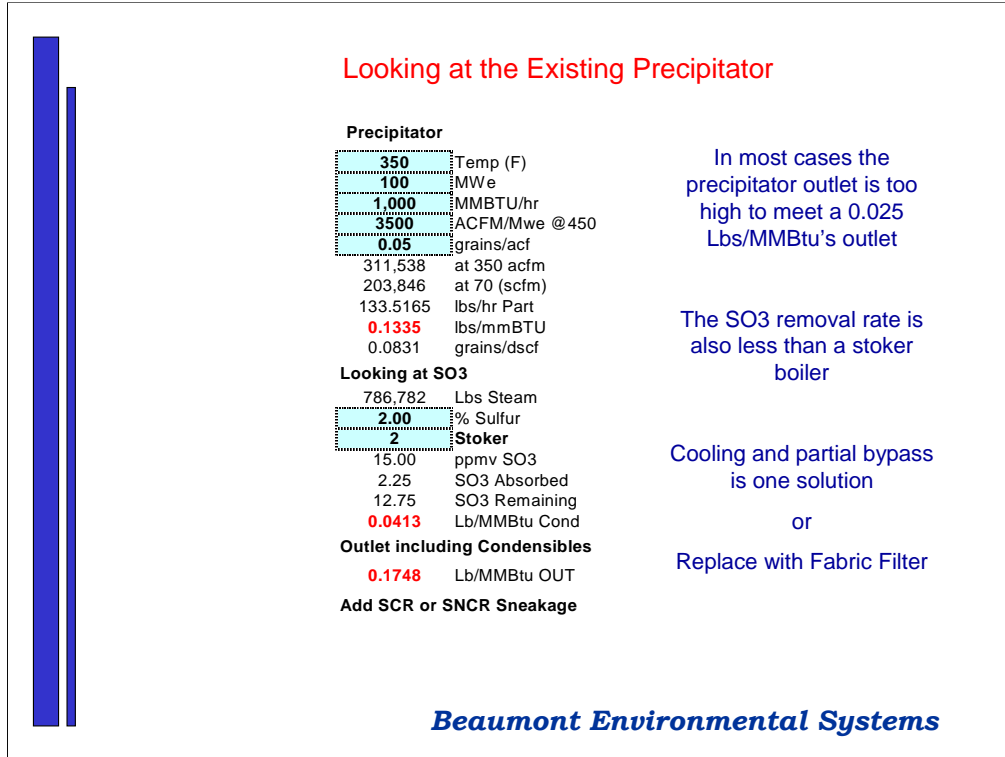
We must look at mercury to shed additional light on the optimum approach.



A plot the illustrates the improvement that occurs with the addition of lime to the baghouse.

We can add lime as slurry in the cooling water –or- by adding as a dry material after cooling water addition in the DAP.

Adding water and lime separately allows mercury capture on available LOI carbon prior to any neutralization by the lime.

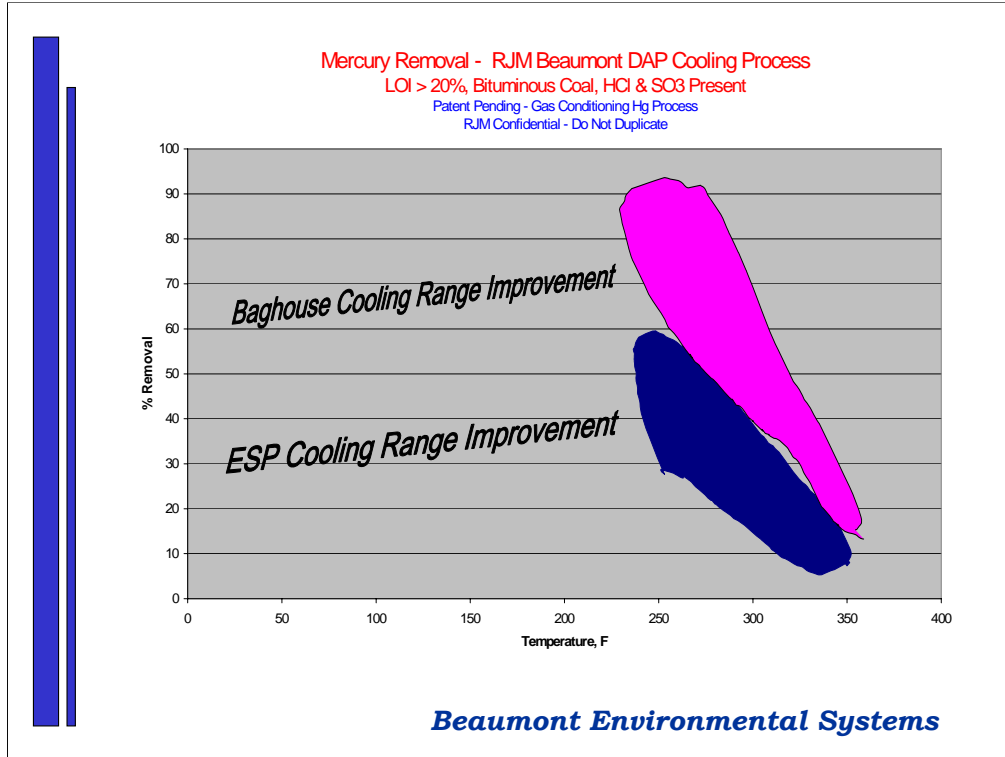


The chart above shows the split in particulate load for a boiler equipped with an electrostatic precipitator.

Unless the precipitator is quite large and has an efficiency in the 99+% range it may need to be converted to a fabric filter.

Cooling and lime addition may be considered.

Bypassing and treating a portion of the flue gas flow may also be considered.



1. With high LOI ash, HCl and SO<sub>2</sub> both drive mercury to oxidized state
2. With high LOI ash, temperature becomes very important (no surprise)
3. When LOI is low, temperature is not as important, but HCl and SO<sub>2</sub> remains important..

Also, oxidized and particulate mercury vapor are indistinguishable, therefore are include together in our discussions.

Here are estimates of mercury oxidation/capture (guarantees) we are looking at for stokers (LOI above 20%) burning bituminous coals (we're assuming both HCl and SO<sub>3</sub> are present in the gas prior to lime addition):

ESP with lime injection to freeze reaction and bind mercury:

350F 20% oxidation/particulate x 50% capture or - **10% control**

300F 50% oxidation/particulate x 70% capture or - **35% control**

250F 75% oxidation/particulate x 80% capture or - **60% control**

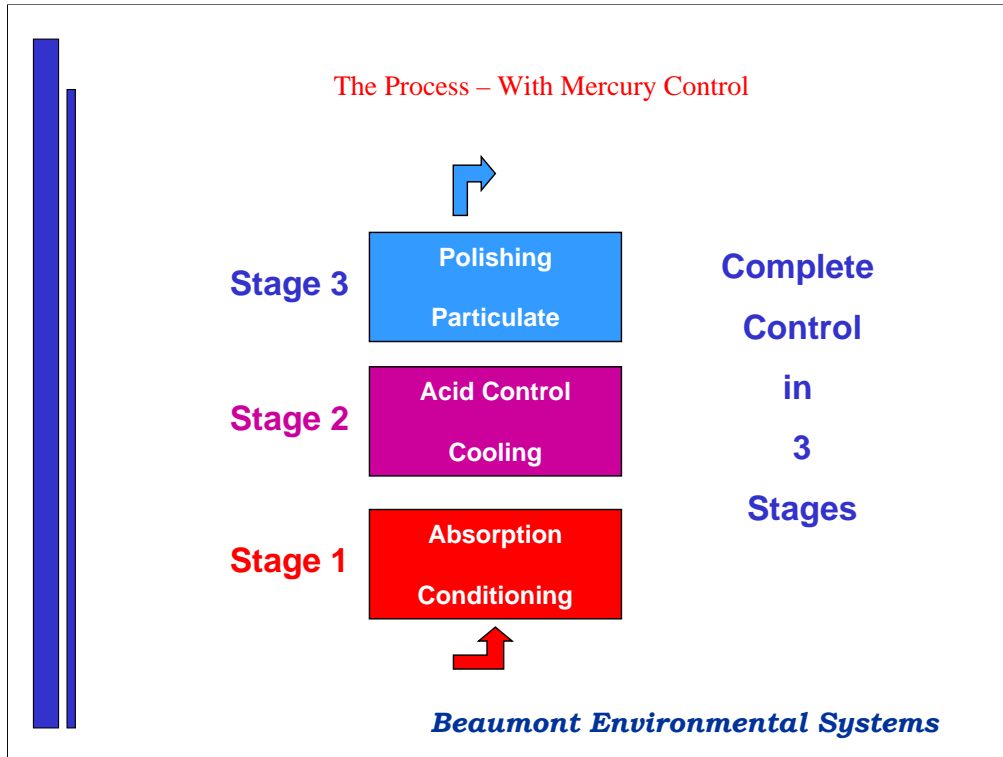
Baghouses with lime injection:

350F 20% oxidation/p x 80% capture or - **15% control**

300F 70% oxidation/p x 95% capture or - **65% control**

250F 91% oxidation/p x 99% capture or - - **90% control**

The capture of oxidized and particulate mercury with baghouse is near 100% below the acid dew point because of calcium sulfite hemihydrate and hydrated lime in the filter cake..



In the optional first stage, we cool and condition the ash for oxidation of the elemental Mercury.

In stage two, where we normally provide SO<sub>2</sub> removal by flash drying, we utilize the recycle of ash and sorbent to continue Mercury removal while also dealing with acids.

Finally the flue gas moves to stage three, the fabric filter, where particulate is removed and sorbent for Mercury polishing can be added if necessary.

## Sorbent Properties and System HgCl<sub>2</sub> Capacities

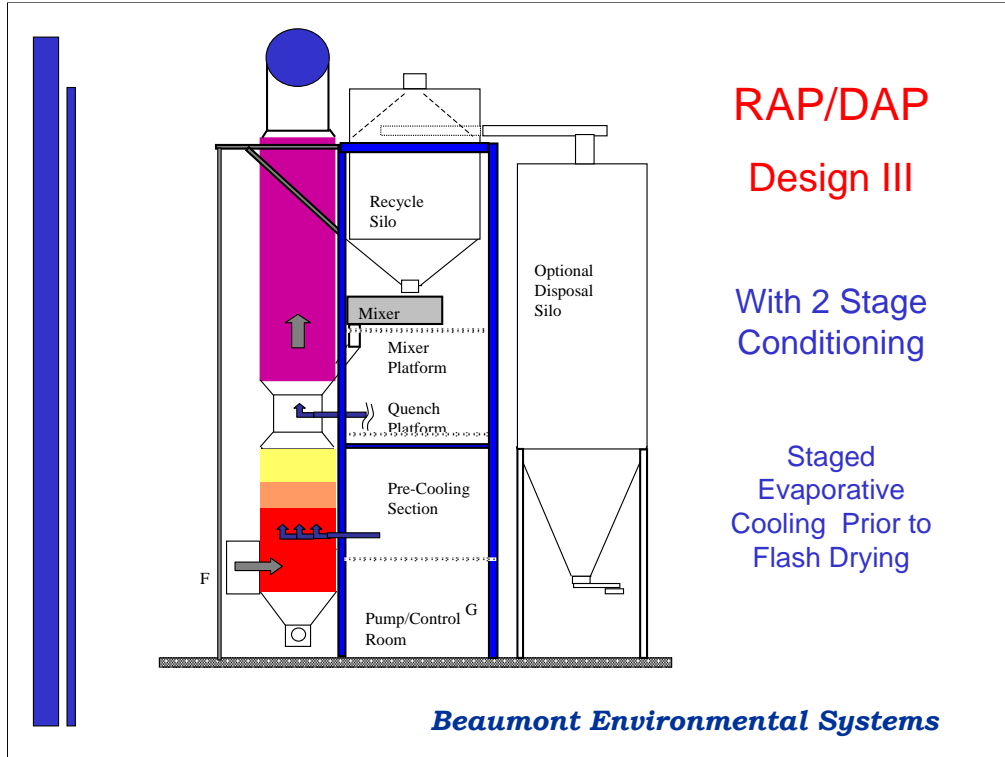
Sorbent	pH	BET Surface Area (m <sup>2</sup> /g)	Avg. pore diameter (D)	D <sub>50</sub> (µm)	Porosity	Surface Basicity (mmoles/m <sup>2</sup> )	HgCl <sub>2</sub> Capacity (mg HgCl <sub>2</sub> /g)		
							q <sub>60</sub>	q <sub>100</sub>	q <sub>140</sub>
Ca(OH) <sub>2</sub>	11.95	14.510	248	6.25	0.156	0.033	0.4469	0.2020	0.0800
CaO	11.95	4.525	5840	7.01	0.065	0.017	0.4471	0.0538	0.0153
CaCO <sub>3</sub>	9.64	0.9042	4130	23.69	0.006	n/a	0.4594	0.0509	0.0111
CaSO <sub>4</sub> ·xH <sub>2</sub> O	7.4	6.605	198	29.09	0.069	n/a	0.3595	0.1152	0.0039
NaHCO <sub>3</sub>	8.35	14.305	500	53.9	0.161	n/a	0.2416	0.1467	0.0358
Na <sub>2</sub> CO <sub>3</sub>	10.98	0.9582	221	300	0.006	0.032	0.2814	0.0551	0.0188
NaOH	12.01	0.2546	252	300	0.001	2.530	0.0000	0.0978	0.0085
Na <sub>2</sub> SO <sub>4</sub>	6.65	0.2031	74.4	88.94	0.001	n/a	0.1847	0.0424	0.0090
K <sub>2</sub> CO <sub>3</sub>	10.98	0.5718	111	300	0.003	0.124	0.4102	0.0409	0.0090
K <sub>2</sub> SO <sub>4</sub>	7.37	0.4448	110	30.64	0.002	n/a	0.2047	0.0253	0.0028
Mg(OH) <sub>2</sub>	10.21	10.91	315	9.61	0.152	0.002	0.2900	0.0370	0.0024

(n/a) means that there was no color change of the indicator, suggesting a weak, basic sorbent and that the indicator was unsuitable, so titration was not performed).

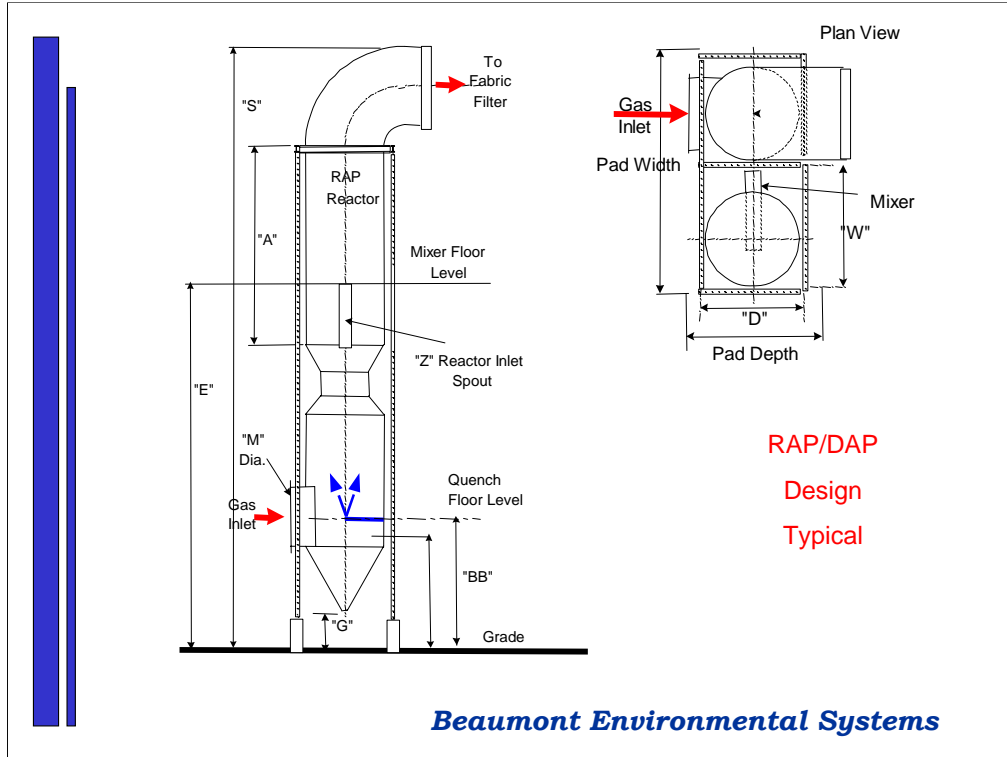
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The physical and chemical characterization of sorbents are shown above along with the system's 24 h mercury capacity, q<sub>T</sub>, for reaction temperatures, T, of 60 and 100 °C and the 17 h mercury capacity for 140 °C. The empty reactor capture is appreciable; at 60 and 100 °C, these amounts are equal to 41% (0.1361 mg) and 66% 0.0523 mg), respectively, of the average gross sorbent capture.

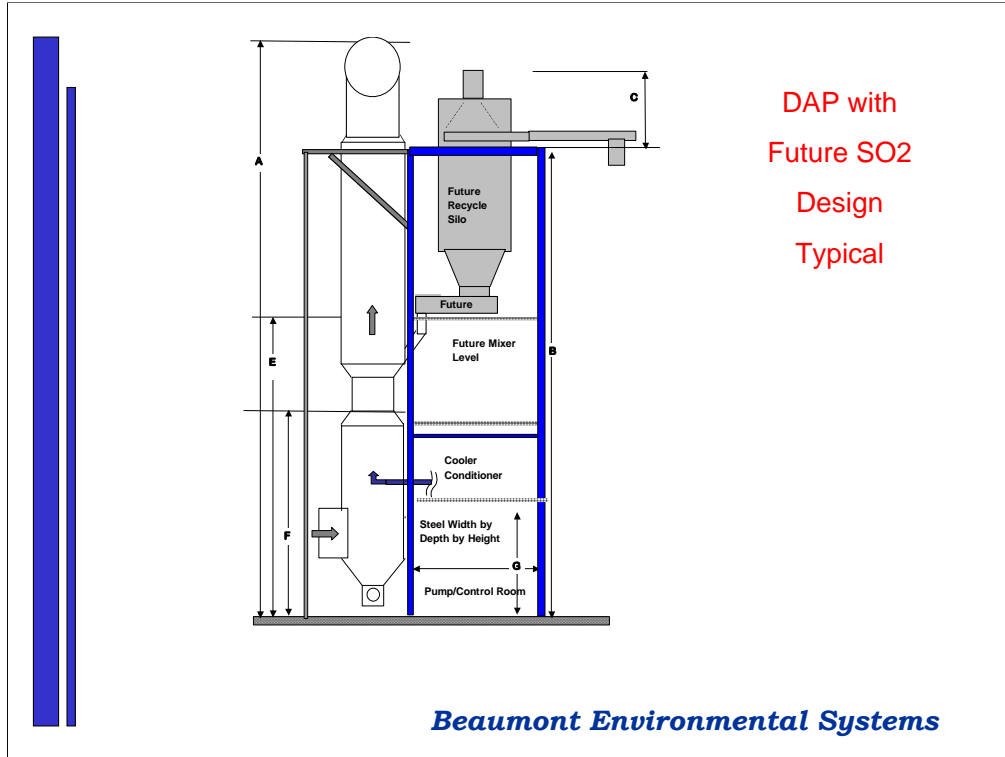
The lime reactivity jumps dramatically between 212 and 140F due to water sorbed (hydration by flue gas moisture); hydrated lime shows less improvement because it already has hydrated water. This table is important in showing why you would use **hydrated lime** rather than pebble lime for dry injection, and **why lowering the temperature** is important for any lime sorbent to be effective on mercury. The table also shows, curiously, that limestone is as effective as lime for all temp ranges and hydrated gypsum actually better than lime at 212F. but not at 284F (where gypsum loses hydrated water).



To enhance Mercury oxidation with bituminous coals we can pre-condition the incoming flue gas and ash. We attempt to overcome the lack of acid ( $\text{SO}_3$ ) in the flue gas of lower-sulfur fuels for elemental mercury oxidation. Added acid can be absorbed on ash acts as a landing zone for elemental Mercury.




Typical side and plan view sketch for the Reactor used in the DAP or RAP process.



The figure shows the typical arrangement for a DAP that may be upgraded in the future for SO<sub>2</sub> control.

The main steel shown in blue must be sized for future loading and large enough to fit in the mixer.



**Acid Gas Control Using Flash Drying**

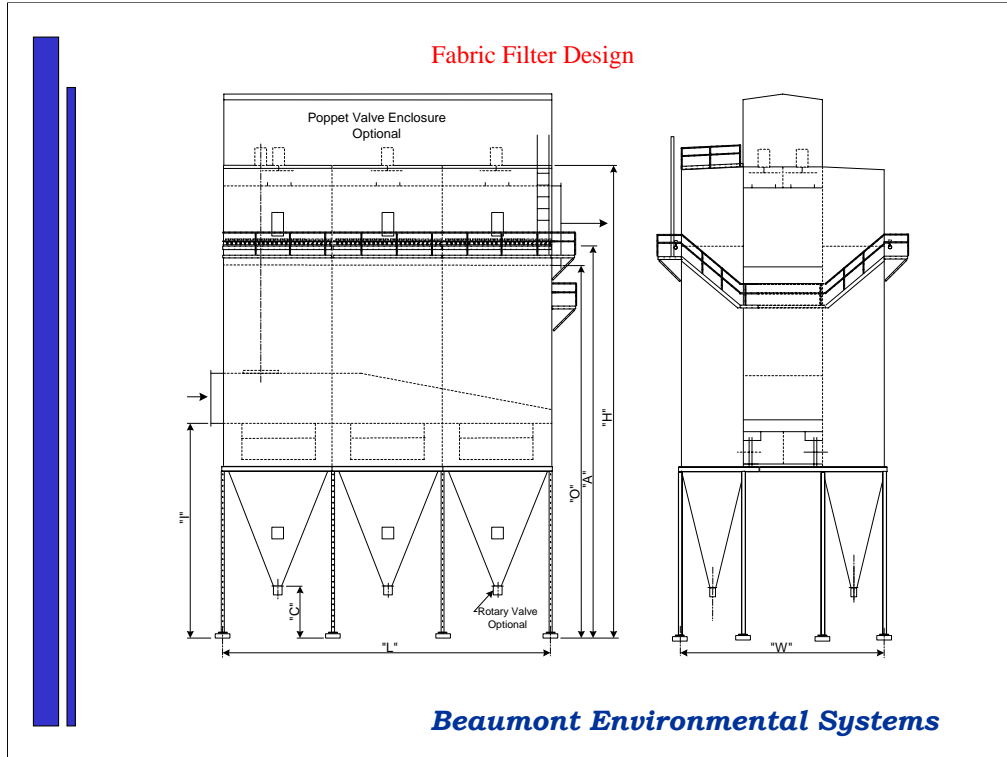
- **SO<sub>2</sub>, SO<sub>3</sub> and HCl up to 99%**
- **Higher outlet temperatures (>200°F)**
  - **protects against corrosion**
  - **eliminate plume -or- reheat**
  - **Protects against wet stack**
- **Smallest FGD Footprint**
- **Backend NO<sub>x</sub> Polishing**

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For most coals the SO<sub>2</sub>, SO<sub>3</sub> and HCL are easily controlled using Flash Drying in the RAP reactor.

Compared with older technologies we are able to fit into smaller spaces, and offer better removal rates at lower lime utilization.

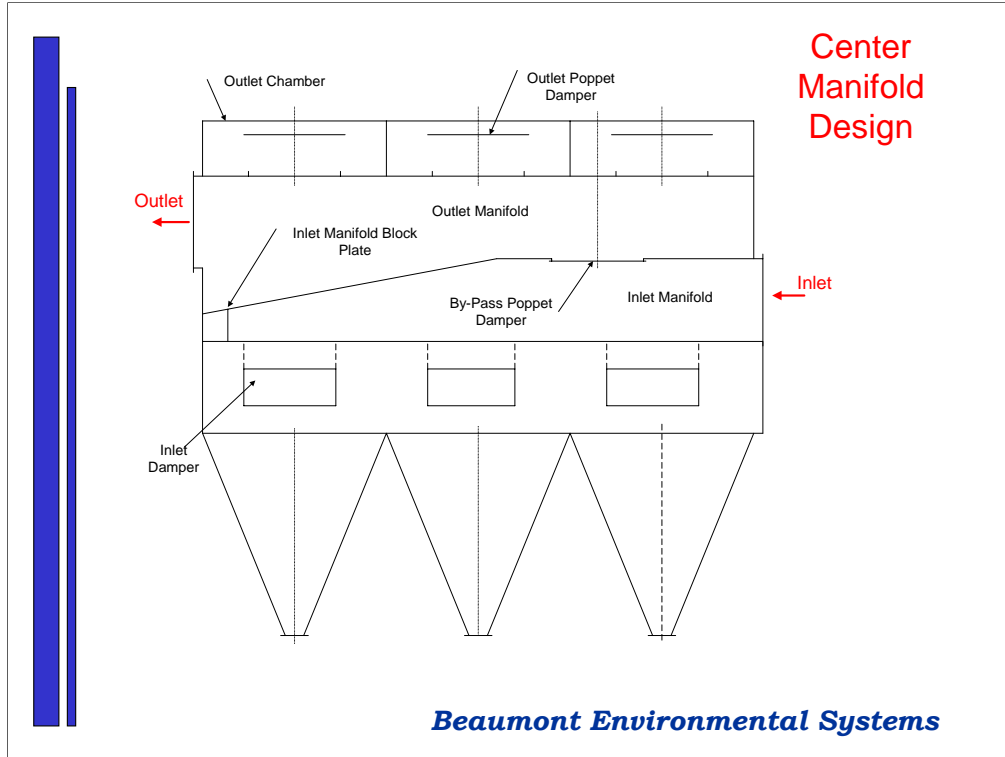
Indications are that some level of NO<sub>x</sub> polishing can be accomplished with additional oxidation added via oxidants or oxidized sorbents added upstream of the particulate collector.



A typical Pulse type baghouse. The unit incorporates side wall entry for gas flow distribution.

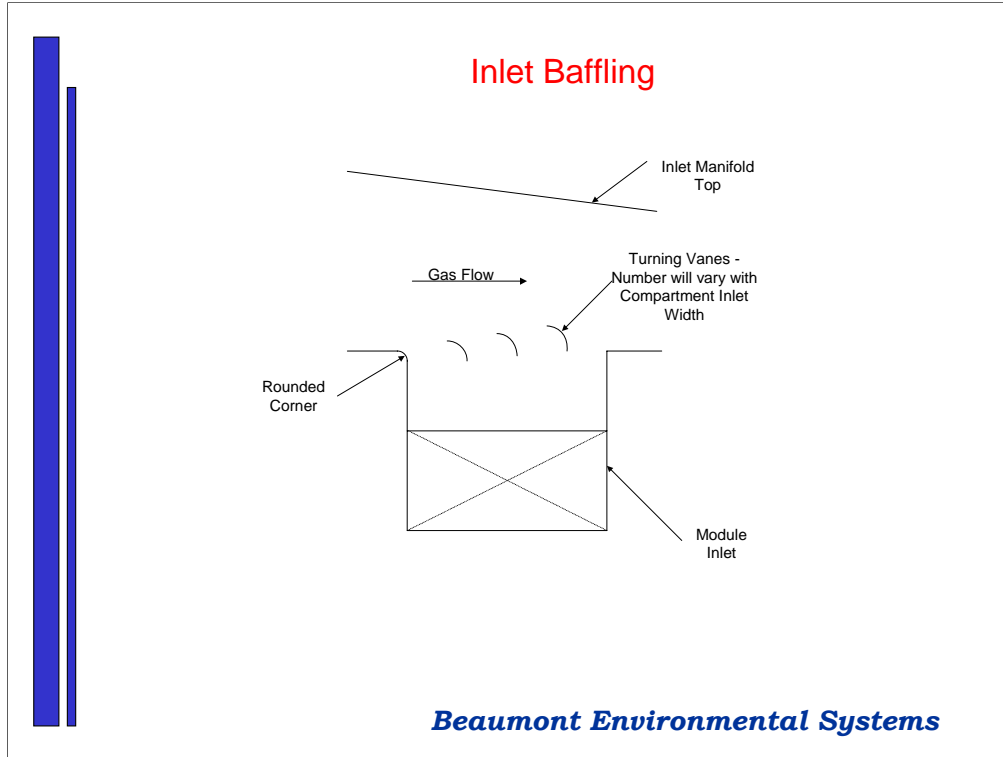


The filter fabric, in itself, does not provide the efficient removal of particulates. It is necessary to establish and maintain a dust cake to attain high efficiency particulate removal rates and provide for extended fabric life. A portion of the dust cake is permanently attached to the filter fabric and is never removed. This permanent dust cake is established early in the life of filter fabric, therefore, care is required in the start-up and initial operation of the fabric filter. Diatomaceous earth, coal fired fly ash or other acceptable materials are utilized to pre-coat the filter fabric prior to the first introduction of gases as a preparatory step in establishing a good ash cake and also to protect the filter fabric from unburned hydrocarbons, sparks and other undesirable elements. Fabric cleaning is not initiated until a predetermined pressure drop is established across the filter fabric and dust cake. Once fabric cleaning is established most of the dust will be cleaned from the bags. Slowly, over time, a permanent dust cake is established. Filter bags that have established a permanent filter cake weigh 5 to 10 times the original unused filter fabric.



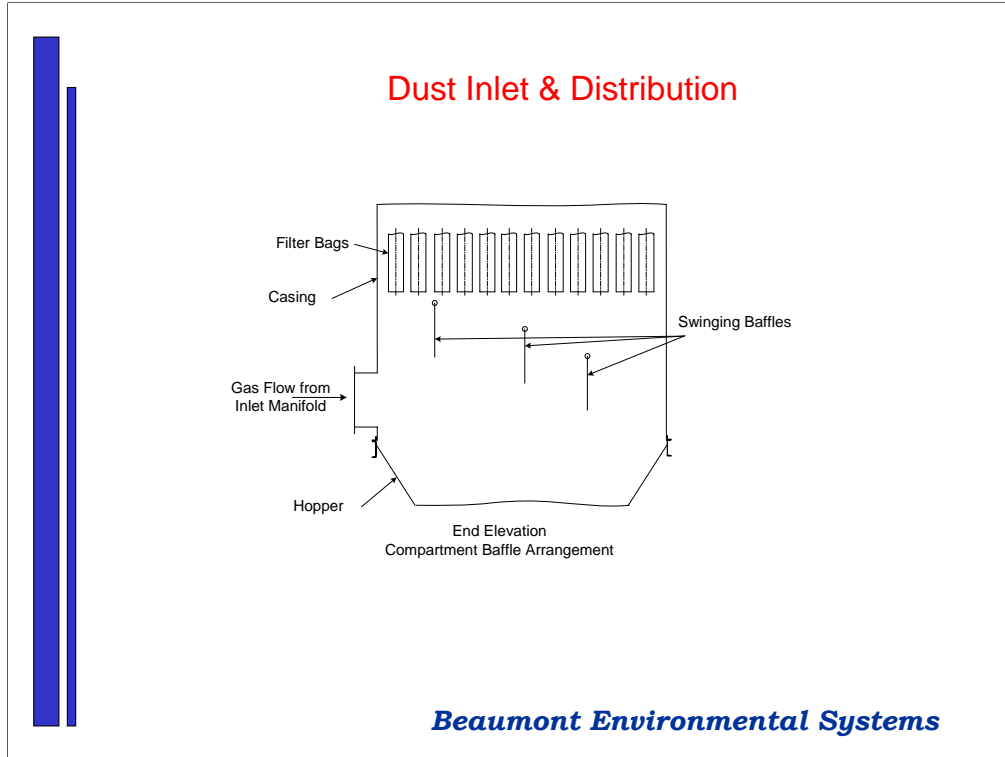
Beaumont has devised a design based on their years of experience that provides optimum distribution of both gas and dust within the fabric filter. We have found that if the gas/dust is closely controlled from the initial entrance into the fabric filter inlet manifold then optimum uniform distribution can be achieved to each compartment and each bag.

Dust tends to settle towards the bottom of the duct/manifold more than gas due to its greater density. Proper selection of gas velocity assists in maintaining the dust more uniformly disbursed in the gas stream. A tapered inlet manifold is utilized to maintain the proper gas velocity as a constant as gas/dust is distributed to compartments located along the manifold.

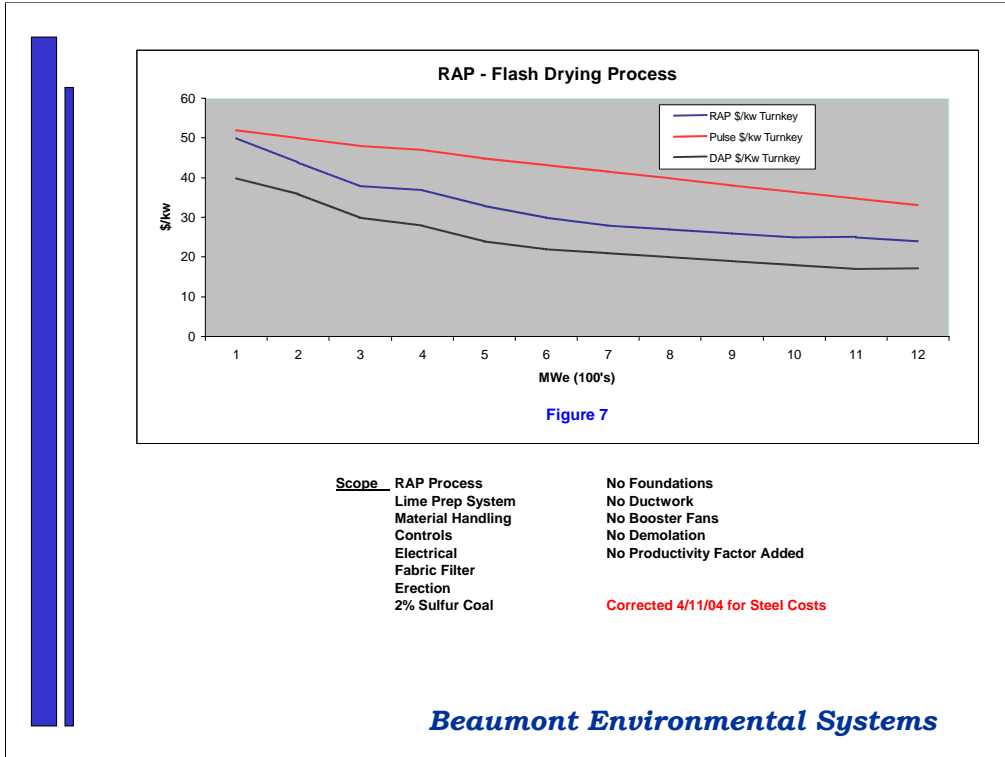


The constant gas velocity assists in maintaining a uniform dust/gas mixture. Curved baffles are utilized at the gas/dust entrance to the compartment from the inlet manifold. These baffles are located low in the inlet manifold, where dust particles tend to accumulate, and act as impingers to force the dust into the compartment inlet. Gas is also channeled into the compartment inlet. Without the impingers the dust particles will continue along the inlet manifold to the rear compartments due to their mass and inertia.

The upstream side of the compartment inlet is rounded to prevent gas separation as the gas/dust turns the 90° required to direct the mixture from the inlet manifold to the compartment. The gas and dust would create a circular, whirling motion as it enters the compartment if the impingers and rounded edge were not utilized. This condition would force the gas and dust to one side of the compartment inlet and create an uncontrollable distribution of the dust and gas. It would also create pockets of high gas velocity that can be very detrimental to bag life due to dust impingement and bag movement.

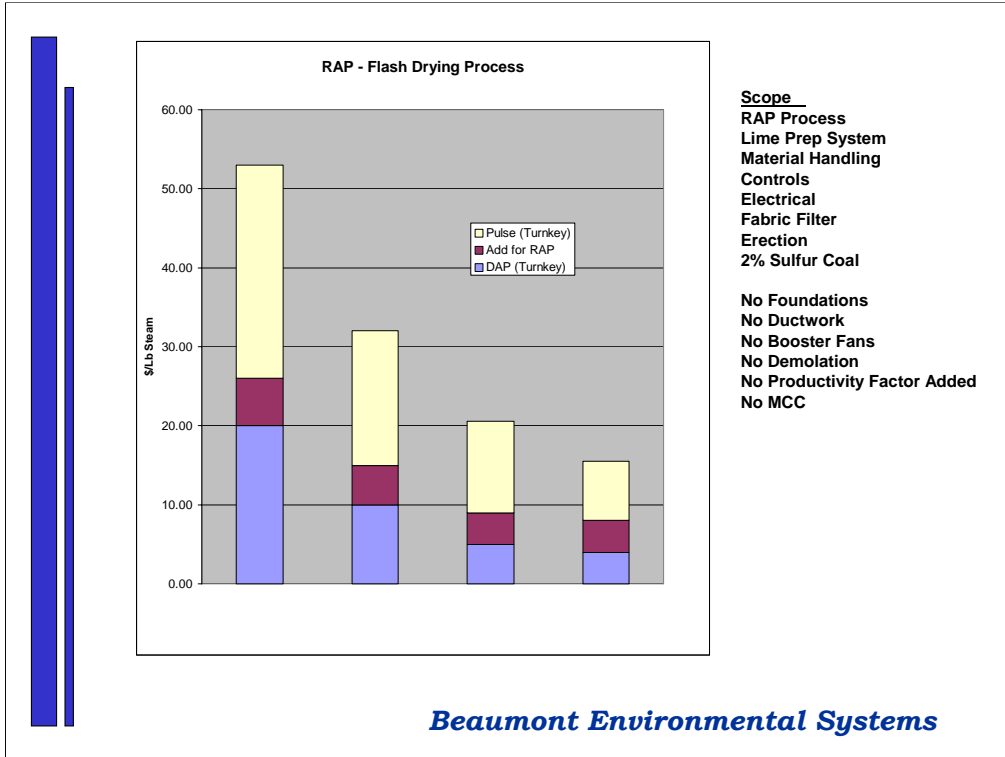


A large area is provided beneath the filter bags to reduce the gas and dust velocity to a low level and allow the gas/dust to expand over the compartment cross sectional area and to the filter bags. Several swinging baffles are provided below the filter bags to assist the gas/dust distribution and expansion process. The baffles can be easily adjusted, if necessary, in the field to optimize the gas/dust distribution to the filter bags. The bags are spaced wider than normal in both directions to provide channels for coating the bags and later cleaning on-line.



The above chart shows costs for larger utility type boilers.

The curves include costs for the DAP process, the RAP process and for the Pulse type Fabric Filter.



The above chart shows costs for industrial boilers.

The curves include costs for the DAP process, the RAP process and for the Pulse type Fabric Filter.



## Beaumont FGD (RAP) History

1989 Airpol (Part of Wheelabrator)

1990 Airpol (Part of FLS Miljo)

First Reactor Type Spray Dryer (TVA-Clean Coal)

City of Hamilton 50 MWe

Polish FGD Utility Scrubber (DOE)

Tai Sugar (2 installations - Oil Fired Boilers)

1996 Airpol Closed/Consolidated to FLS Miljo

Rail Calcining - Houston Industries

1997 Beaumont Opened

Medical College of Ohio (Flash Dryer)

Flash Dryer Pilot - Southern Research Institute

Medical College of Ohio (LoTOx)

2002 Beaumont

Patent Issued RAP

EPA Electro-Pulse

EPA Flash Dryer

Mercury Patent Pending

***Beaumont Environmental Systems***

BES Beaumont has been under consistent management since 1989.

Development of semi-dry scrubbers, reactors and flash dryers as well as fabric filters have been designed and developed during this period.