Multi-Pollutant – Control Capabilities – 8/13/03

Presented By

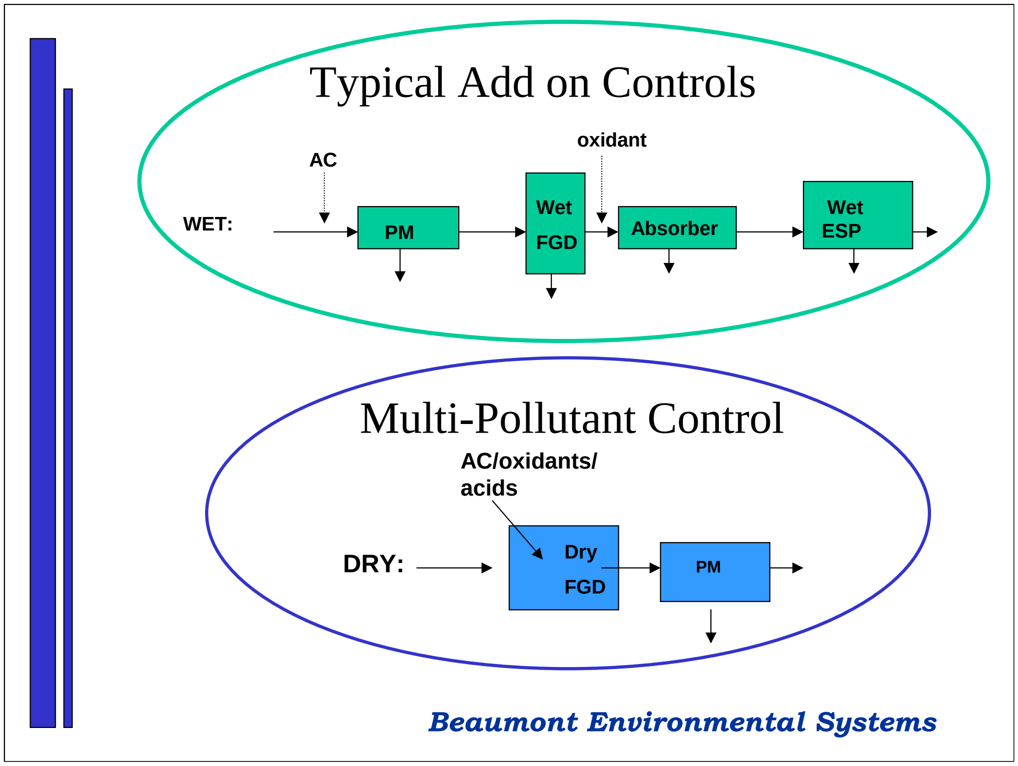
Will Goss

&

Charles Sedman

Beaumont Environmental Systems

Will Goss
Beaumont Environmental Systems
108 Lintel Drive
McMurray, PA 15317
willgoss@adelphia.net
724 941-1743



Using a Wet system may have up to four control devices, three wet discharge points, and one dry discharge point.

A Multi-Pollutant dry system has two controls, one discharge point.

What is **Multi-Pollutant** Control

- Control for Combustion Processes
  - Typically Boilers
- Minimum Number of Components
  - Flash Dryer + Fabric Filter
- Flexibility to meet Future Requirements
  - Inlet Conditioning
- Cost Effective Design
  - Capital + operating Costs
- Dry Safe Disposal Material
  - Does Not Leach

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The control of boilers has expanded over the years to include SO_2, NO_x, Mercury, H_2SO_4 and other Air Toxics in addition to closer attention to particulate. In addition the required removal efficiency of the pollutants has been rising, making it important to select control equipment that can be expanded or improved to accommodate future requirements.

Mercury and particulate control has become of more importance as part of the Multi-Pollutant control system.

We will address the selection options available.

Beaumont Environmental Systems offers a true multi-pollutant system using a flash dryer combined with a pulse type filter.

What to Control?

- Temperature
- H_2SO_4
- HCl
- SO_3
- SO_2
- NO_x
- Mercury
- Other Toxic Metals (NESHAP)
- Ash
- Fine Particulate

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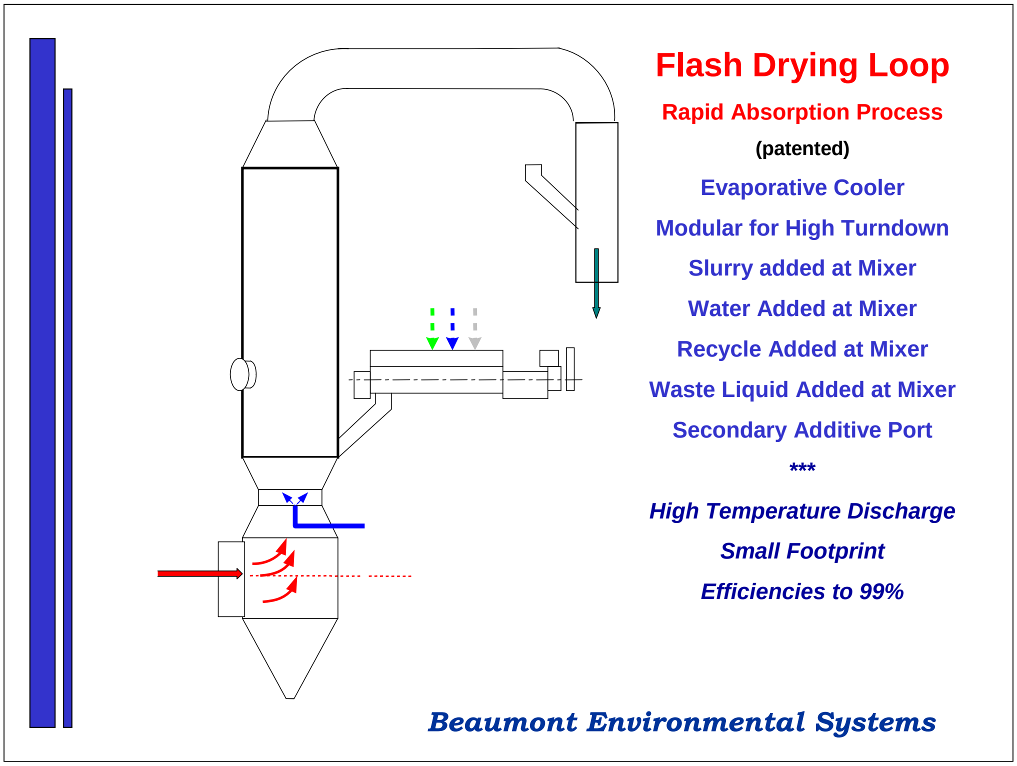
We are able to control all the regulated particulate, gases and metals following a NOx system for a coal fired boiler. Some NOx polishing can also be addressed in the final filter using oxidized sorbents

Indications are that some level of NOx polishing can be accomplished with additional oxidation added via oxidants or oxidized sorbents added upstream of the particulate collector.



The latest in the evolution of dry/semi-dry systems uses the patented flash drying process.

The above features were added and patented to improve the older reactor type semi-dry system. In addition to the many improvements, the flash drying concept has improves efficiency, utilization of lime and allowed a higher outlet temperature.

Acid Gas Control Using Flash Drying

- SO_2, SO_3 and HCl up to 99%
- 90% to 95% SO_2 removal
- Higher outlet temperatures (>200°F)
  - protects against corrosion
  - eliminate plume –or- reheat
  - Protects against wet stack
- Smallest FGD Footprint
- Backend NOx Polishing

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For most coals the SO2, SO3 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 NOx polishing can be accomplished with additional oxidation added via oxidants or oxidized sorbents added upstream of the particulate collector.

What is Flash Drying

- Sorbent added outside of the reactor
- Liquids are added in the Mixer they coat recycle material, in a thin film
- Advantageous to have fine recycle material recycled from Fabric Filter
- This flash drying process has improved the lime utilization, raised the removal efficiency's, and allows for high temperature discharge to the stack.

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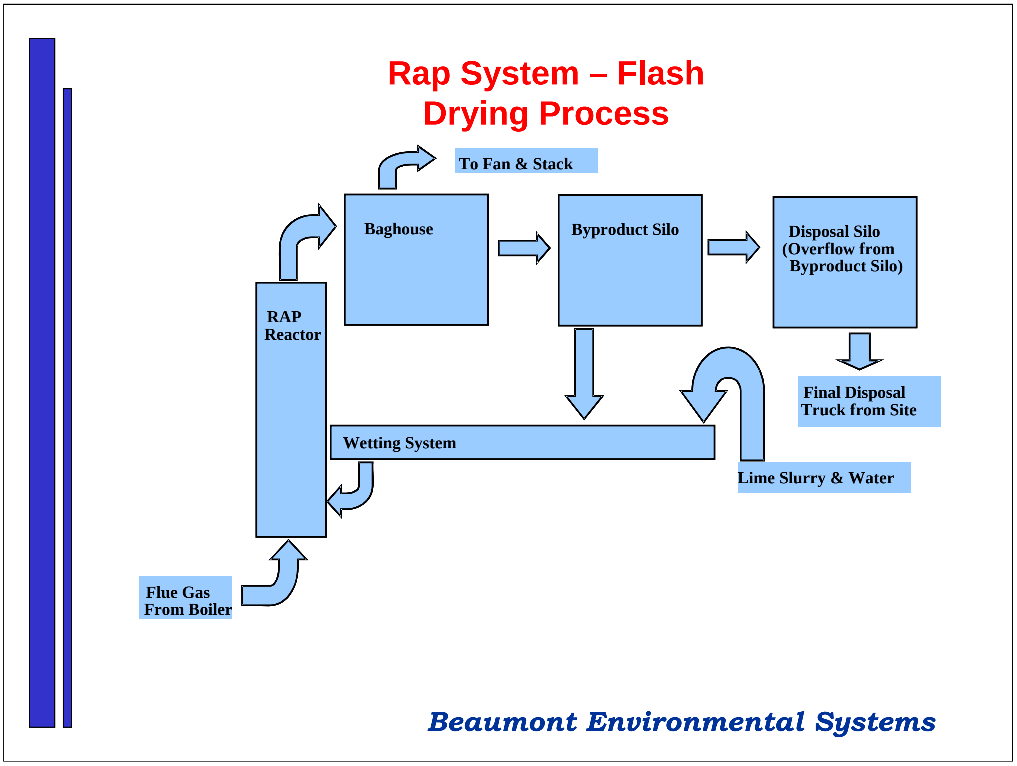
Flash drying is accomplished when the sorbent as a slurry and water is added outside of the reactor and then the mixture is added into the reactor where the hot gases flash off the liquid.

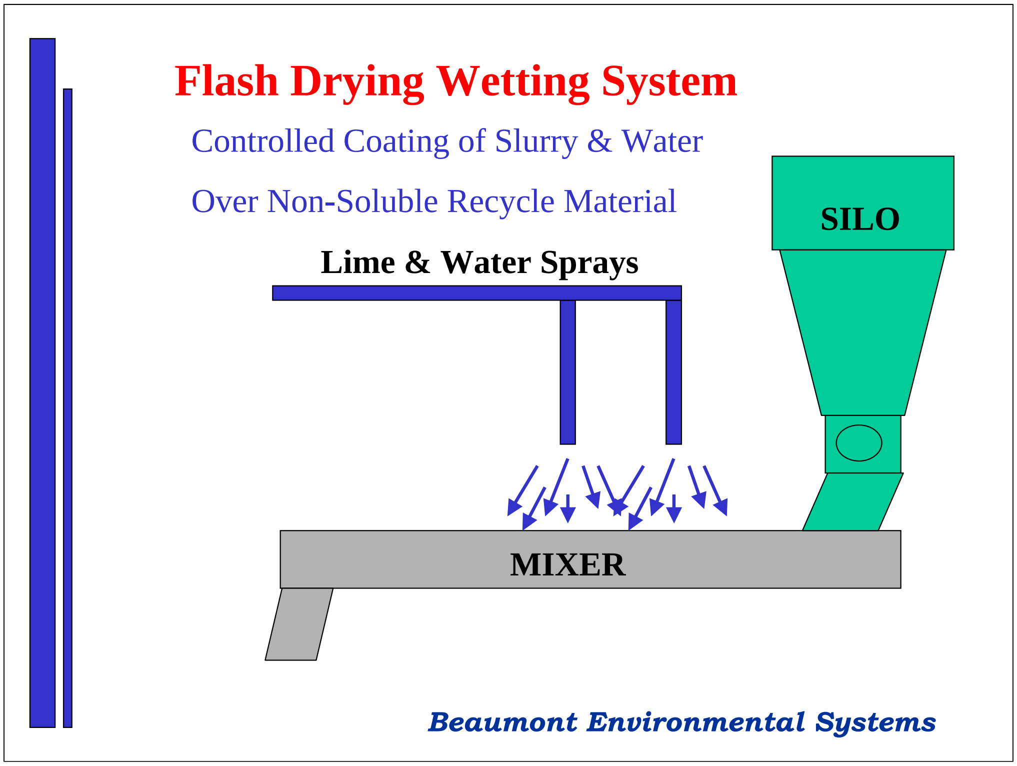
In the mixer where the liquids are being added, they coat, in a thin film, the dry recycled material that will be introduced into the reactor. It is this thin film that quickly flashes dries. The liquid content is controlled to less than 20% to assure that a thin film is produced.

It is advantageous to have fine recycle material, which provides a large surface area. For this reason we prefer to recycle off a fabric filter everything that is collected. Additionally de-agglomeration occurs in transport and passage through the mixer.

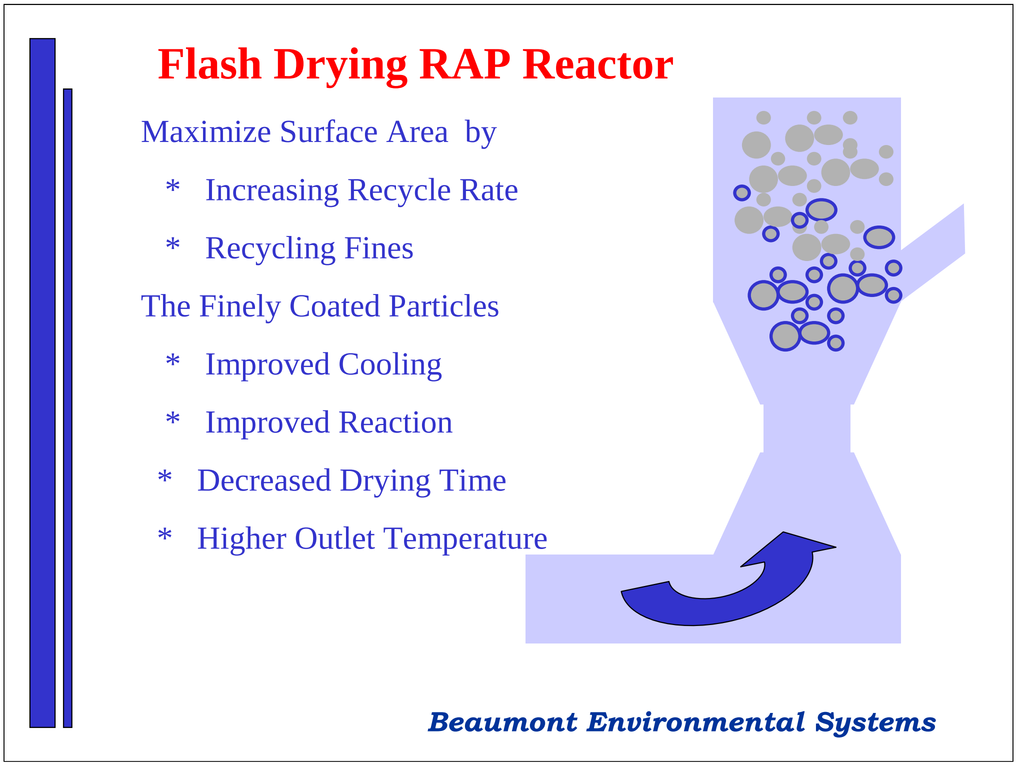
This flash drying process has improved the lime utilization, raised the removal efficiency's, and allows for high temperature discharge to the stack.



In the process flow, shown, lime slurry and water is added along with recycle material from the fabric filter.



The recycle silo feeds the mixer. The liquids being added are mixed and a fine coal of the liquid is deposited on the recycle material. It then feeds by gravity to the reactor below.



The coated particles hit the hot gas and immediately flash dry, dropping the flue gas temperature and reacting with the acid gases.

The fast reaction eliminates the need for long treatment times. The material exiting the reactor will be less than 1% moisture.

SO2 Control

- 90 to 99% SO2 Removal
- High Outlet Temperature - 180 to 200 F
  - Less Potential corrosion
  - Reduces need for Reheat
  - Eliminates Special Chimney Liners
- High Utilization
- Requires Smaller Footprint
- Requires Less Power

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The Flash Dryer Process uses Lime Slurry which is sprayed across the recycle material in the mixer and introduced dry into the reactor where it rapidly dries and the SO2 is converted to sulfates and sulfites.

The Flash Dryer has been Demonstrated to Remove 90 to 99% of the SO2, much higher than Semi-Dry Scrubbers.

The Outlet Temperature can Range from 180 to 200 F providing Corrosion Protection for the Baghouse and Stack. These temperatures are much higher than the older Semi-Dry Outlet Temperatures. With high sulfur coal or low entry temperatures the outlet temperature may need to be lower to evaporate the liquid in the lime slurry.

The Utilization is also higher than Semi-Dry Designs, requiring 20% or greater savings in lime cost.

SO2 Control

Morning Start Up with the Recycle Lean
Cooling Water Being Added Slowly

	Date	ACFM	Efficiency	Stoich	Util%	Temp Out	PPM SO2 In	PPM SO2 Out	
		Start Up - No Water Added							
1	6/12/02	33,780	85.38	2.94	29.00	276	212	31	0.848 S Coal
		30 Minutes Later							
2	6/12/02	33,083	95.2	1.91	49.74	263	333	16	1.332 S Coal
		30 Minutes Later							
3	6/12/02	33,404	92.85	1.17	79.37	250	539	38	2.156 S Coal
		30 Minutes Later							
4	6/12/02	37,213	93.39	0.94	99.72	262	604	40	2.416 S Coal

First 3 are at 140% of Reactor Rating
Fourth reading at 160% of Reactor Rating

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This data is very important as start up occurs after running overnight without adding water or sorbent. The recycle is run which, with continuing SO2 reaction, uses up the lime in the recycle material reaching a lean condition.

As seen above, the slurry was initiated at a level to give us 90% removal at 600 ppm. The sorbent addition was adequate to improve the lean condition of the recycle while removing the SO2 present.

As the ppm level rose the unit was able to easily maintain 90% + control as the stoichiometric level decreased. All this occurred without adding water to improve efficiency.

The reactor ran at 40 to 60% above design rating, decreasing treatment time but easily maintaining a high efficiency.

With exit temperatures above 250 degrees Fahrenheit, the performance is extraordinary.

The requirement for reheat or adding of chimney liners is no longer required.

Comparison of Flash Drying and Spray Drying

1% + Sulfur Coal (250 ppm = 1.0 % S)

	Date	Efficiency	Stoich	Util	Temp Out	PPM SO2 In	PPM SO2 Out	Duration
	Cooling Water Added at the Mixer							
1	3/13/02	99.56	2.17	0.4596	336	225	1	1 Hour
	Switch Cooling Water to Sprays							
2	3/13/02	88.24	2.49	0.3548	385	187	22	1 Hour
	Switch Back to Water at the Mixer							
3	3/13/02	98.3	3.26	0.3015	405	176	3	1 Hour

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One of the later demonstrations we performed was to verify that flash drying was truly different than semi-dry scrubbing.

The idea was to add cooling water along with the slurry, at the mixer, where it coats the recycle material and is available for evaporation and cooling immediately on introduction to the hot flue gas.

The second step was then to introduce the water into the evaporative cooling sprays. This is where older style semi-dry designs added the water along with the slurry.

The results were an immediate fall off in efficiency.

Upon switching back to water introduction at the mixer the efficiency returned to the higher efficiency.

Comparison of Operating Points - Adding Cooling Water In Steps

2% + Sulfur Coal (1056 ppm = 3.0 % S)

	Date	Efficiency	Stoich	Util	ATS (F)	PPM SO2 In	PPM SO2 Out	H2O (lbs/hr)	Duration
1	6/12/02	86.74%	1.32	0.86	131	623	91	3,657	2 Hours
2	6/12/02	87.73%	1.32	0.86	108	662	80	4,599	60 Minutes
3	6/12/02	95.50%	1.28	0.97	105	688	31	4,783	30 Minutes

Water Added over Last 3 1/2 Hours in Steps

As the Gas Temperature Comes Down the Efficiency Goes Up

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This data was recorded as water was added and the temperature decreased.Typical of the flash dryer it moves slowly to a stable point unless the lime is increased to accelerate reaching the desired efficiency. In this case sorbent feed remained constant.

Comparison of Operating Points - All 2.25 to 3% S Coal

3% + Sulfur Coal (1056 ppm = 3.0 % S)

	Date	Efficiency	Stoich	Util	ATS (F)	PPM SO2 In	PPM SO2 Out	Duration
1	5/15/02	91.49%	1.21	0.76	82	752	65	15 Minutes
2	5/15/02	83.13%	0.85	0.98	85	1065	200	15 Minutes

The Flow and Slurry feed remained constant

System is Starved for Lime at Higher SO2 Inlet

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Using 3% sulfur coal, we were able to track the efficiency change as the SO2 varied at the inlet. The controls were in manual mode and the water and sorbent feeds were constant.

The sorbent feed was set to give us >90% removal at a little over 2% Sulfur in the coal.

As the sulfur increased the removal went down until the system was using all the available lime (98% utilization). This is excellent utilization that was assisted by to using some of the lime in the recycle.

Finally over 200 F outlet temperature. Improves corrosion and eliminates the need for re-heat or special chimney liners.

Stoichiometric Ratio Vs. SO2 Removal Efficiency

Some Operating Results

SR	Efficiency	Utilization	
0.85	80.00%	94.12%	3% Sulfur & 200 F Outlet
1.00	87.00%	87.00%	3% Sulfur & 250 F Outlet
1.20	91.00%	75.83%	3% Sulfur & 200 F Outlet
1.60	96.00%	60.00%	3% Sulfur & 200 F Outlet
1.75	99.00%	56.57%	2.5% Sulfur & 200 F Outlet

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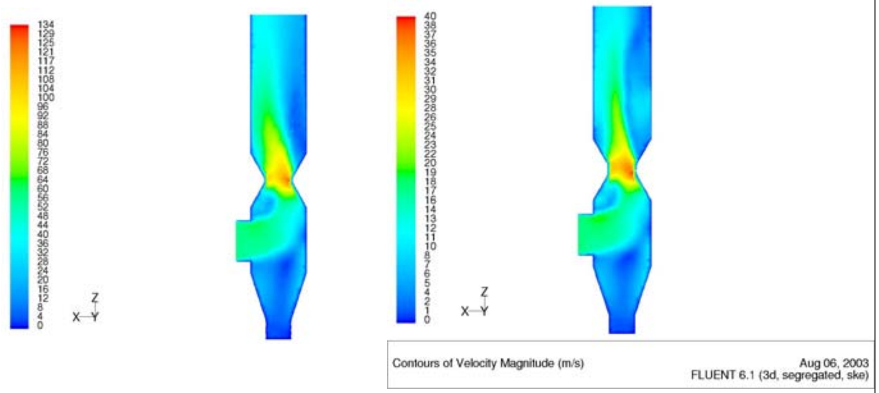
From the data we can select several operating points and generate a curve of Stoichiometric Ratio vs. Removal Efficiency.

This data could vary +- 20% due to the changes in the solid concentrations of the slurry. We assume 1.12 solids concentration but we measured the concentration from 1.01 to 1.13.

The data did not vary appreciably as we changed outlet temperature and SO2 concentration in ppm's.

Highly Scalable Design

22 ft. dia. **220 ft. dia.**



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Scaling up a round vessel with a venturi section is highly predictable. Typically 8 to 1 scale ups have been demonstrated in the refinery industry.

Adding
Mercury Control

- Adding the Second Stage
- Adding Conditioning Acids
- Adding Special Oxidized Sorbents

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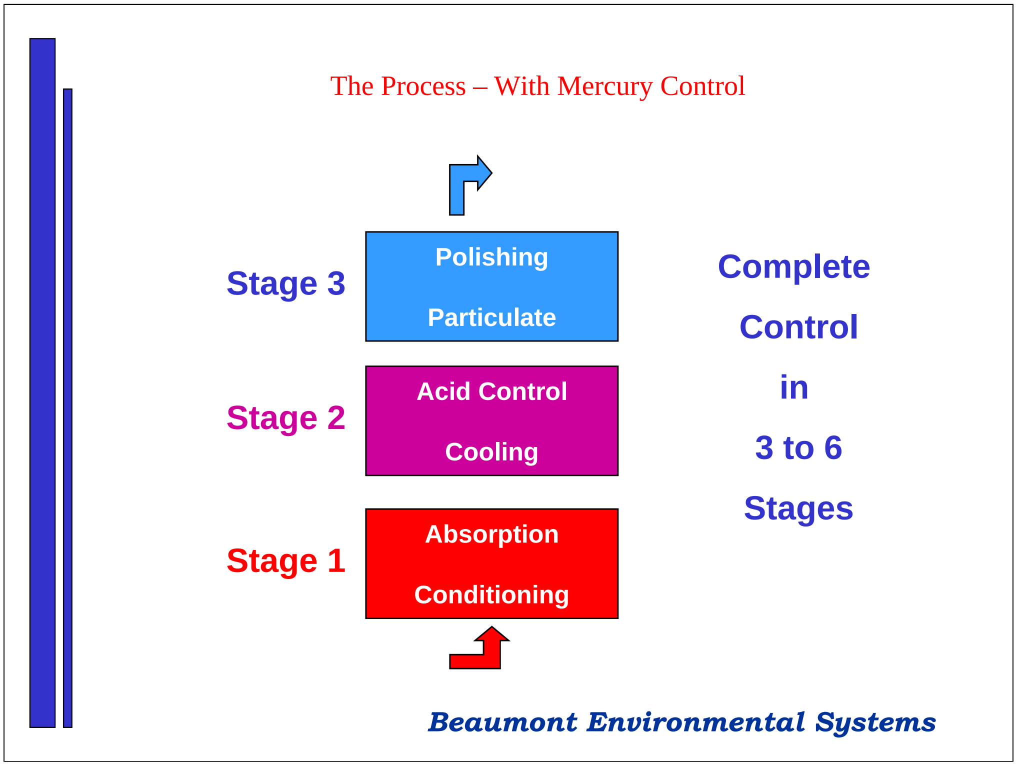
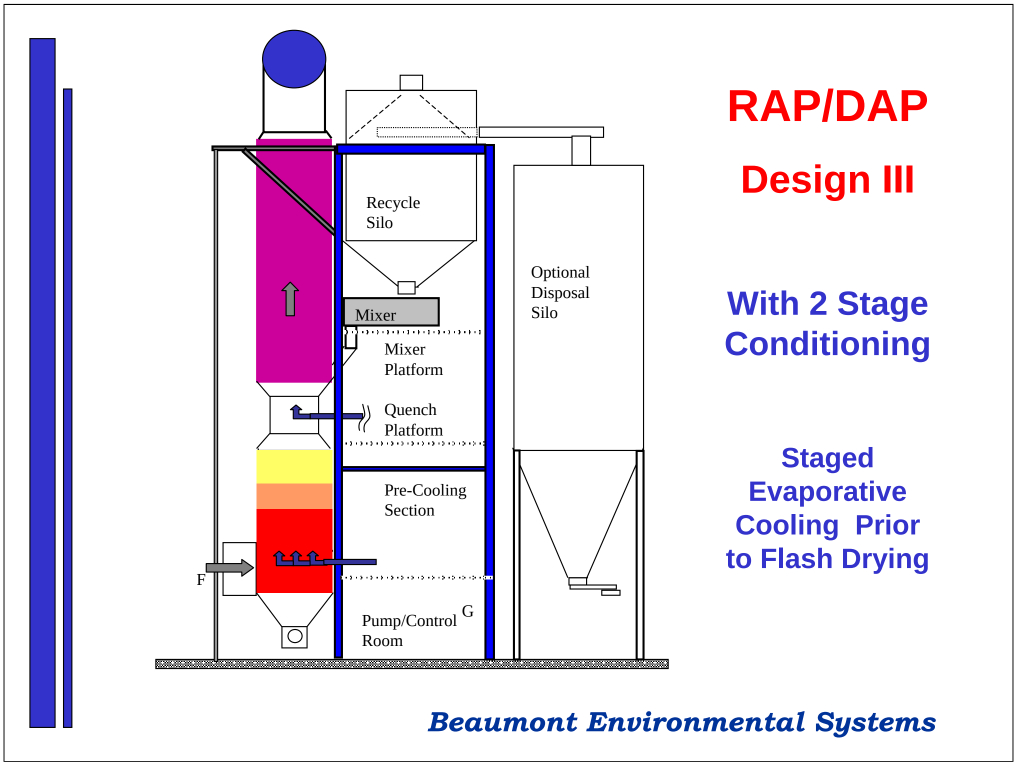
Using the RAP system as a starting point we can address mercury removal by adding a conditioning stage or adding a reactive sorbent at the final filter.



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

In stage two, where we normally provide SO2 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.



To enhance Mercury control with bituminous coals we can pre-condition the incoming flue gas and ash. We attempt to overcome the lack of acid (SO3) in the flue gas of lower-sulfur fuels for elemental mercury removal. Added acid can be absorbed on ash acts as a landing zone for elemental Mercury.

Mercury Control - Coal Boilers

(Patent Pending)

- **Stage One – Mercury Removal**
  - Provides Evaporative Cooling
  - Addition of Acid for Lower Rank Coals
  - Elemental Mercury Oxidation/Absorption
    - High reaction rate on ash surface
    - Enhanced by turbulent gas-solid contact which enhances
- **Stage Two – SOx Removal/Mercury Polishing**
  - Sorbent Addition
    - Oxidized Lime
    - Activated Carbon
  - Absorption/Reaction
- **Stage Three – Particulate**
  - Particulate Removal
  - Final Mercury Polishing

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The approach to Stage 1 and Stage 2 will vary depending on the coal, the ash and the flue gas composition.

Different staging and additives will be employed depending on the flue gas composition.

Summary of Mercury Control

- Add on Process to Flash Drying
- 90% Control for Bituminous Coals
- For Low Rank Coals Acid Addition
- Special oxidants /sorbents for >90% mercury Control

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The use of the flash drying approach gives us control methods for all types of coal.

The approach presented operates at a very low cost. Mercury is first minimized before adding special oxidants to polish for additional Mercury removal.

Particulate Control

The back half of the multi-pollutant control system

- Pulse type Filter is recommended
  - Electro-Pulse for Fine Particulate Collection
- Designed for High Inlet Grain Loadings
- Shorter Bags, Wider Spacing
- Enhanced Cleaning Controls

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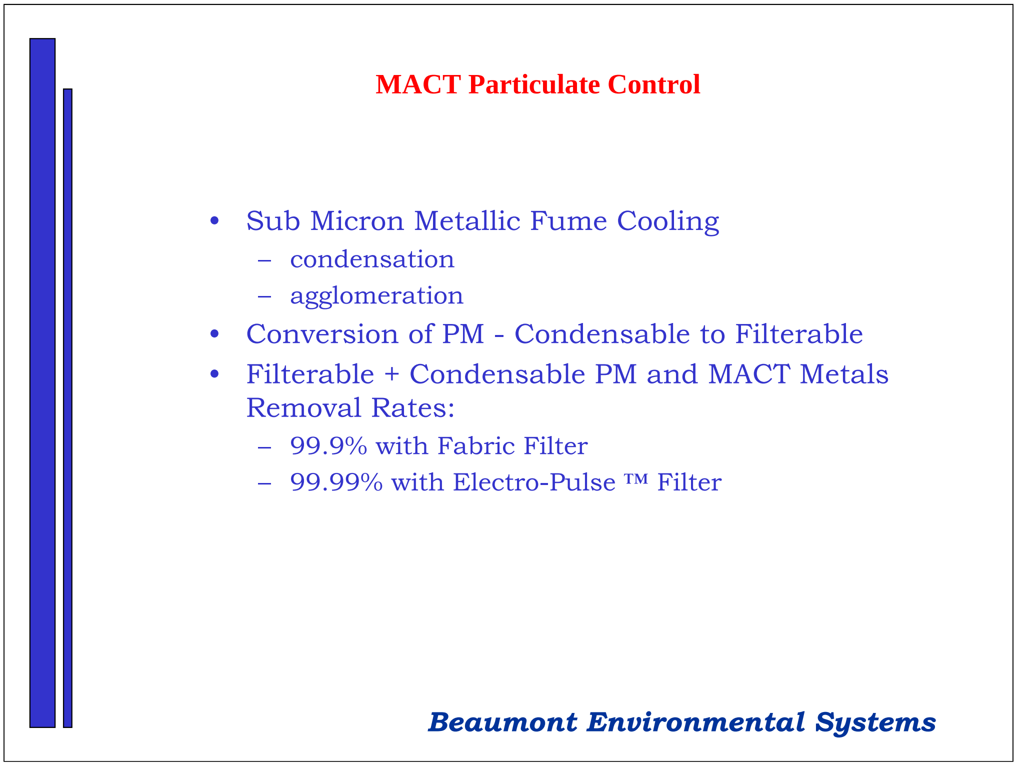
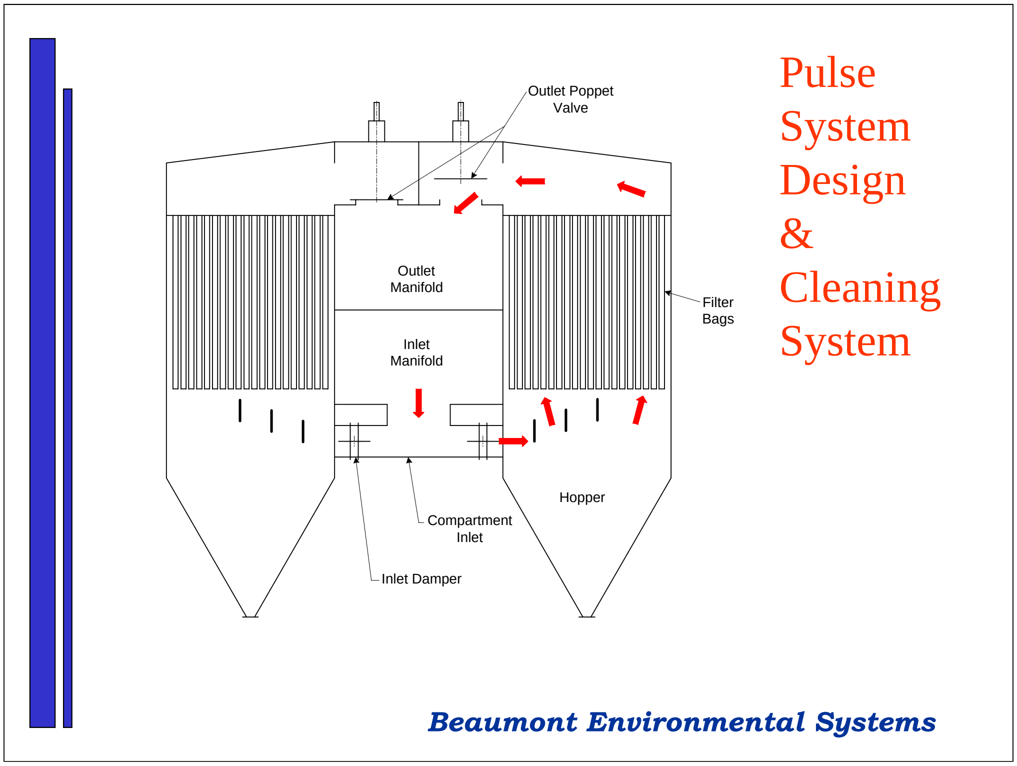
Classically, Reverse Gas Fabric Filters have been used in the Utility Industry.

For Multi-Pollutant control we will employ high recycle rates and are best served by a Pulse Cleaning type Filter.

Although long bag (up to 8 Meters) can be employed using medium pressure cleaning,, the application is better suited to shorter bags (5 to 6 meters) using high pressure cleaning.



The final filter controls condensable fume. The cooling prior to the final filter becomes quite important.

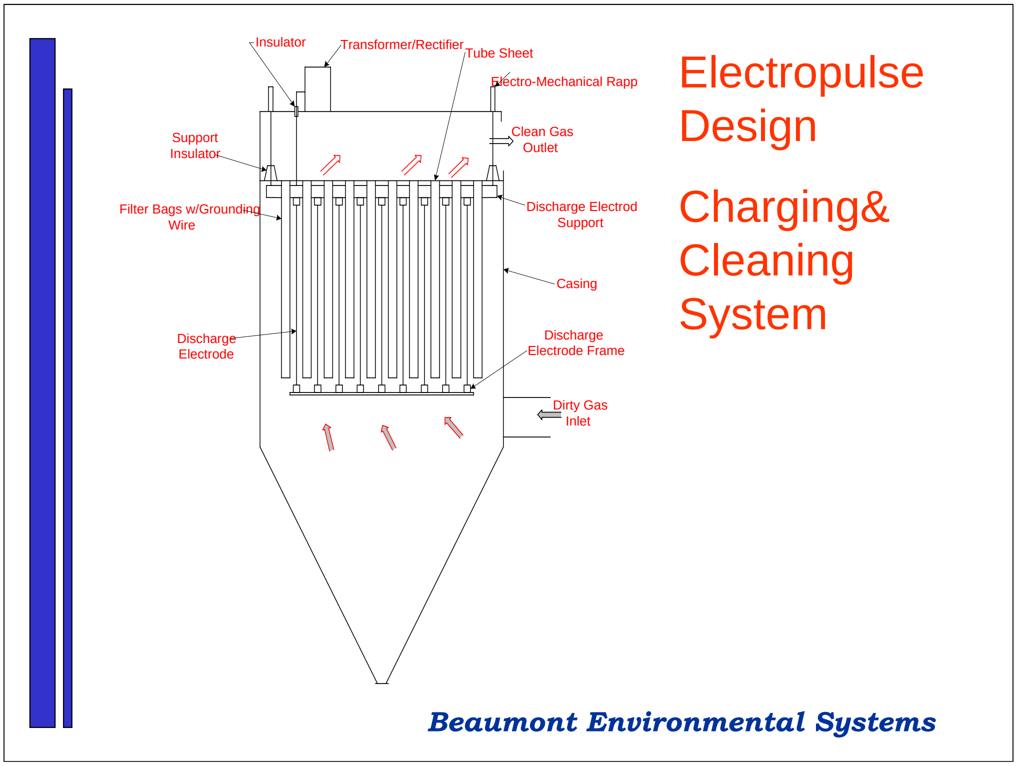


We prefer bottom bag entry for better coating of the bags.

The bag spacing is increased to lower the upward velocity. It assist in on-line cleaning

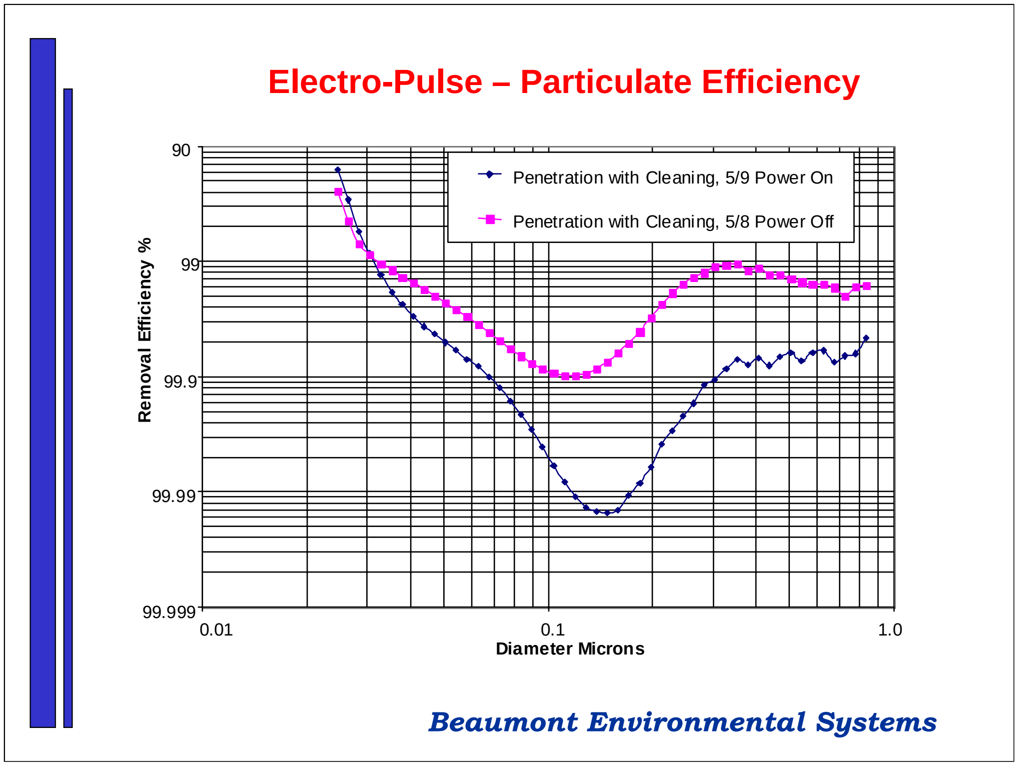
The Cleaning System should be designed for both on-line and off-line cleaning.

More smaller compartments is preferred to maintain a filtering cake, isolating leaks and maintaining lower air-to-cloth ratios.



We can take advantage of the wider spacing inherent in the Electro-Pulse to provide lower can velocities and better sorbent operation..

On 0.1 micron particles the removal efficiency increases by a factor of one or 90% reduction when using the charging system inside the Pulse Filter.



This graph shows the efficiency for a pulse collector with and without electrostatic charging. The loss during cleaning is not included but, with proper design, it can be minimized. The efficiency of the baghouse for 0.1 to 0.3 micron sized particles will be greater than 99% and 99.9% for the Electro-Pulse. The emissions are essentially what vapor passes through the PM collector and condenses in a wet FGD scrubber (if provided), less any collected by the FGD.

This curve on page one is based on the paper, "Estimating Sulfuric Acid Aerosol Emissions from Coal-Fired Power Plants" by Hardeman and Stacy from Southern Companies and Dismukes from SRI," presented at "Formation, Distribution, Impact, and Fate of Sulfur Trioxide in Utility Flue Gas Streams"

March 30-31, 1998 in Pittsburgh, PA (sponsored by FETC-DOE).

Typical Particulate Outlet – Standard Pulse

For 200 MWe Boiler the outlet can be easily calculated

Particulate at Exit - Maximum			Particulate at Exit - Minimum		
300	Temp (F)		**300**	Temp (F)	
200	MWe		**200**	MWe	
2000	mmBTU/hr		**2000**	mmBTU/hr	
3500	ACFM/Mwe @450		**3500**	ACFM/Mwe @450	
0.01	grains/acf		**0.005**	grains/acf	
584,615	at 300		584,615	at 300 acfm	
407,692	at 70 (SCFM)		407,692	at 70 (scfm)	
50.1099	lbs/hr Part		25.0549	lbs/hr Part	
0.0251	lbs/mmBTU		**0.0125**	lbs/mmBTU	
0.0156	grains/dscf		0.0078	grains/dscf	

Fabric Filter Maintains a Constant Outlet Usually between 0.01 and 0.05 grains/acf

(Efficiency varies by the Inlet Load)

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The outlet from a fabric filter will fall between the two circled values.

The outlet depends on the fabric filter design and cleaning system. The outlet of a fabric filter is constant assuming the size distribution of the flue gas is also consistent.

Summary of Fine PM Control

- $PM_{2.5}$ Dominated by Condensable PM
  - Controlled by staged cooling, absorption and condensation
- $PM_{2.5}$ Particulates - Majority of MACT Metals
- $PM_{2.5}$ Controlled to 99.9% with staged cooling and fabric filter
- $PM_{2.5}$ Controlled to 99.99% with staged cooling and control with Electro-Pulse™

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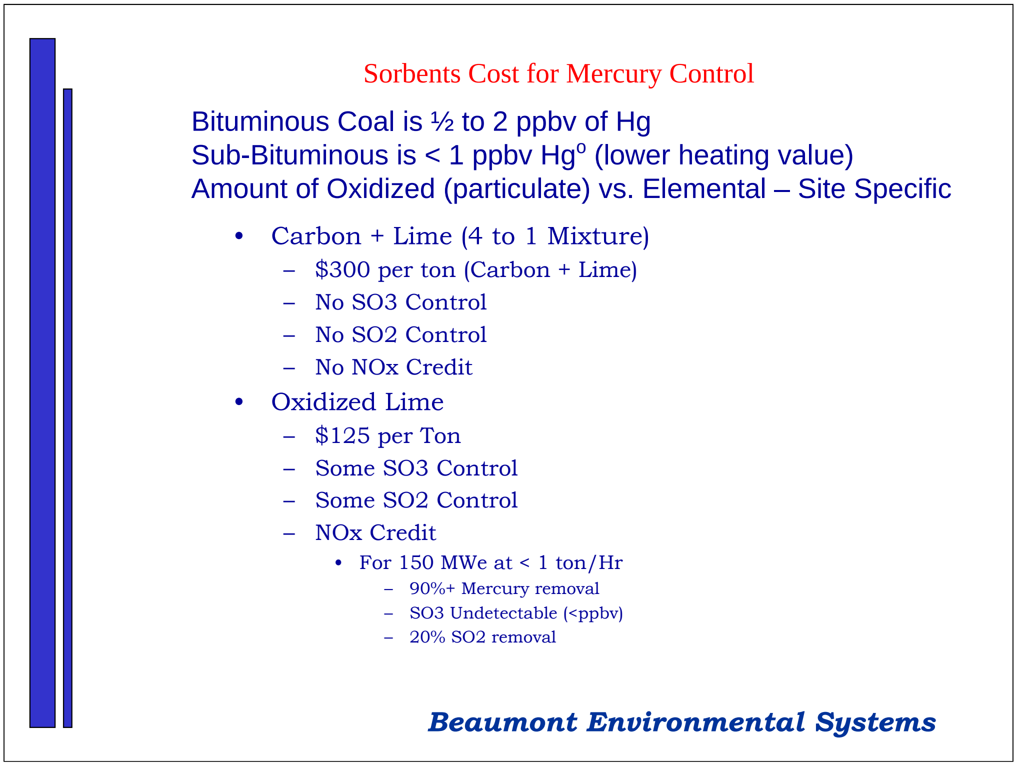
Cooling, condensing and filtering for high level particulate control will occur in a properly designed Multi-Pollutant control system..



This chart compares the oxidized lime based sorbent with carbon. For comparing costs the carbon is assumed to be added with 4 parts to 1 of pebble lime. This equalizes the amount of sorbent added.

The delivery system can be used with any sorbent and can be upgraded making it a good selection for either new or retrofit applications.

Byproduct Material

- Material is Dry allowing Transport and Use
- Material Does Not Leach - Easy Disposal
- Material Can be Utilized for Fill
- Material can be integrated into byproduct building materials if no waste disposal is available

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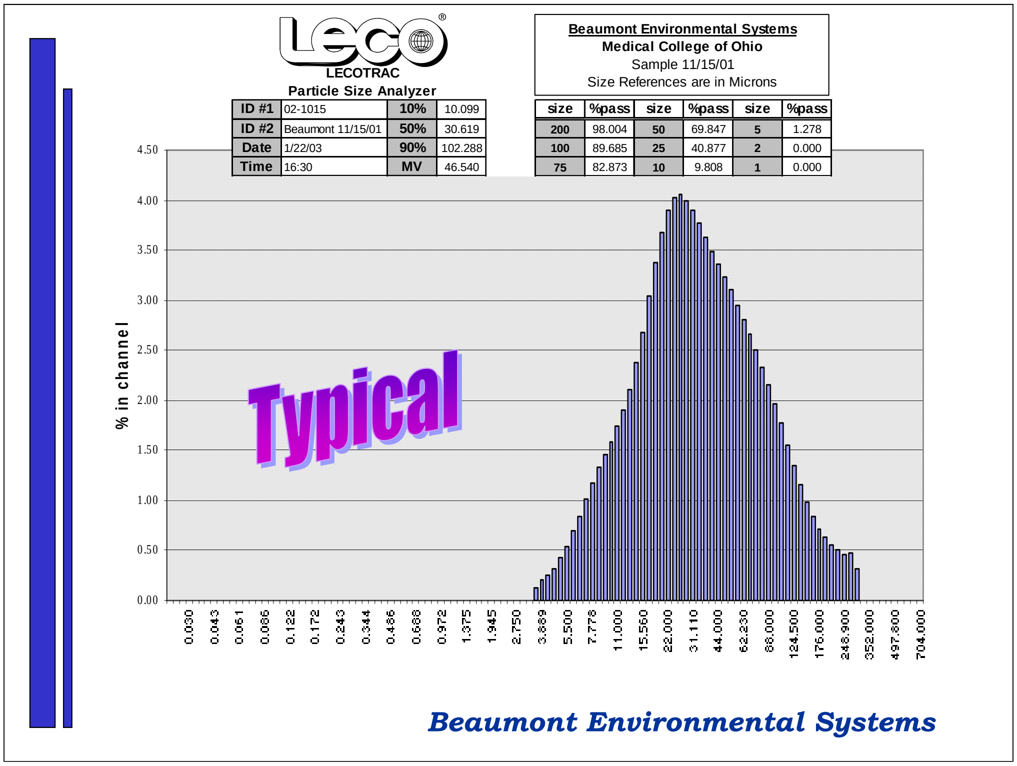
Testing of the by-product verified that it does not leach. The latest test at Medical College of Ohio demonstrated that water drained through the by-product was almost water quality.



This chart is typical particle size analysis performed on the MCO site.

Capital & Costs

- Typical 80 to 150 MWe (and up as modules) Turnkey
  - $35 / KW For Flash Drying System $40 / KW For Pulse Type Fabric Filter
  - $300 / Ton SO2 for <1% Sulfur Coal
  - $150 / Ton SO2 for <3% Sulfur Coal
- Below 80 MWe Capital Costs Will Rise
- Above 150 MWe Capital Costs Fall

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The above costs will vary with available space, customer specifications and plant operating costs for utilities and manpower.

References

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- Singer & Ghorishi, Sedman"Simultaneous Control of Hg^o,SO2,and NOx", presented at MEGA Symposium, Chicago, IL, August 21-23, 2001
- Singer & Ghorishi, Sedman"Lime based Multi-Pollutant Sorbents", presented at MEGA Symposium, Atlanta,GA, 1999

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The above papers are the most recent that have been presented covering aspects of the multi-pollutant control system.

The third paper traces history of semi-dry scrubbing that has led to the development of flash drying san covers some advantages of flash drying.

The first paper covers the operating results at the Medical College of Ohio and furnishes more detail on that project.