Characterization of Atmospheric Fluidized Bed Combustion (AFBC) Residues and Their Use in Agriculture.

By
Jody K. Solem

Abstract

Increasing use of sulfur scrubbing technology in coal combustion has resulted in large amounts of high calcium, high sulfur solids. Power plants are faced with finding new ways of disposing of large amounts of these residues. Research over the last ten years has explored many applications of these solids in agriculture. The Department of Agriculture has recommended the use of AFBC residues as a liming agent on some croplands, pastures, or reclaimed surface mines.

Current research in the use of AFBC residues has explored its use in controlling soil erosion and weeds. Mineralogical and physical characterization of these residues and their response to water will help scientists understand the diversity of AFBC residues and their reactivity.

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Atmospheric Fluidized Bed Combustion is the process where a mixture of pulverized coal (or other solid fuels), crushed limestone, sand, and shale are suspended by jets of air. The churning mass of solids and gases act as a pseudo fluid. This type of combustion process is more efficient at producing energy for lower costs and removing sulfur and nitrous oxide from the exhaust gases.

- 150 FBC Plants in the U.S. producing 5 gigawatts electricity.

- Plants vary in size and operating conditions producing distinctly different combustion residues.

- Agricultural applications for these residues provide an alternative to disposal and include:

  * Source of Ca and S
  * Increase pH on acid soils and mine spoils
  Reduce surface erosion
  Control weeds

* Recommended use by the U.S. Department of Agriculture.

- Application rates follow liming rates and do not provide substantial utilization considering the amounts of residues produced annually.

- Besides chemical, physical, and mineralogical information on these diverse residues, researchers need more characterization including CEC, particle size distribution, soluble ions, and buffering capacity.

- Atmospheric Fluidized Bed Combustion (AFBC) processes include:

1. bubbling bed AFBC.
   ex. TVA's Shawnee 20 MWe pilot plant
   burning: high-sulfur Eastern U.S. bituminous coal
   residues: baghouse ash, char, spent bed ash

2. circulating bed AFBC.
   ex. Colorado-Ute Nucla demonstration plant
   burning: low-sulfur bituminous coal
   residues: baghouse ash, spent bed ash

- In a circulating AFBC, the spent bed ash contains a greater range of particle sizes because the ash is recycled into the furnace.

TVA 20 MW Pilot Plant

Shawnee

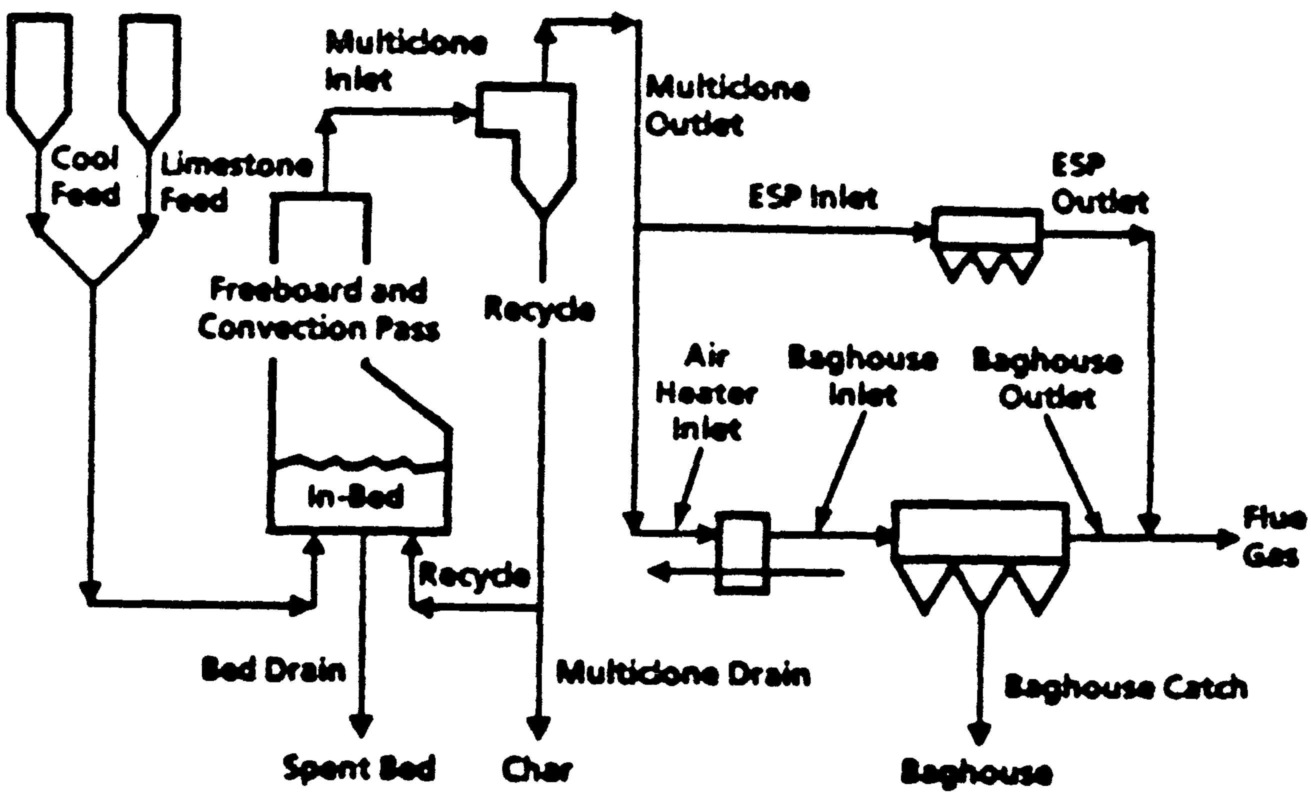
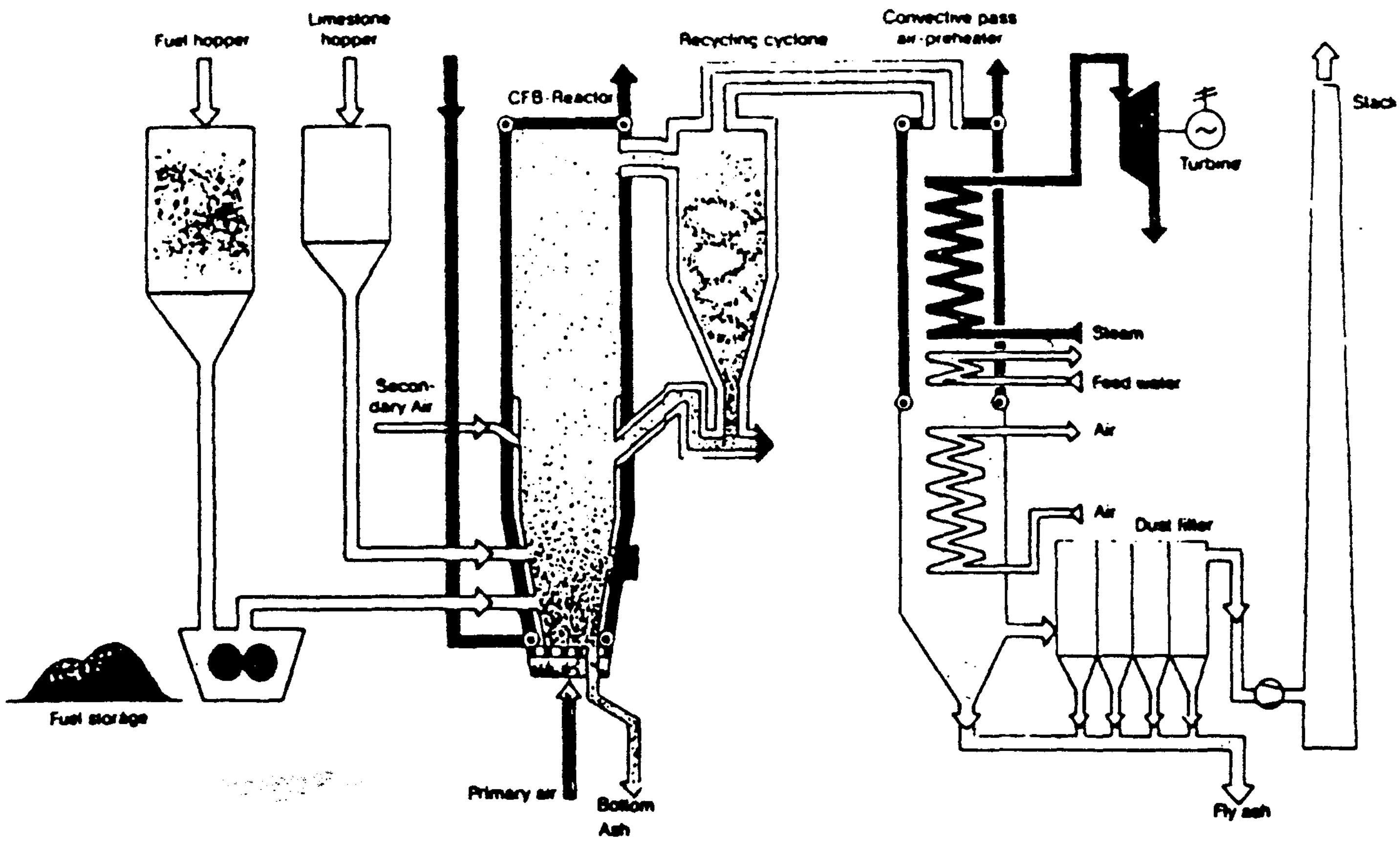


Figure 1. Schematic Diagram of the 20MW AFBC Pilot Plant.

from Cooke, 1988

Circulating AFBC Colorado Ute



A model of a Fluidized-bed Combustion Power Station

from: Eklund, 1988

Table 2-3
Particle Size Characteristics of FBC Materials

bubbling bed / circulating bed

Screen (% retn'd)	μ	Char	TVA FA	TVA SBM	Chatham BH	Chatham BA	Colorado-Ute FA	Colorado-Ute BA
16#	1180	..	..	9.88	..	9.33	..	15.8
30#	600	0.02	..	40.86	..	16.8	..	11.83
50#	300	7.07	..	37.45	..	27.24	..	23.22
100#	150	17.15	..	7.11	1.26	35.17	..	34.37
200#	74	20.75	..	2.85	11.16	10.93	..	14.48
325#	45	13.28	1.50	0.64	16.21	0.27	0.5	..
Pan	< 45	41.73	98.50	1.2	71.37	0.25	99.5	..

Smaller size particles

Table 2-4
Chemical and Partial Phase Compositions (mass %) of FBC Materials

	Char	TVA FA	TVA SBM	Chatham BH	Chatham BA	Colorado-Ute FA	Colorado-Ute BA
Chemical Composition:							
SiO_2	8.75	22.65	7.43	27.98	26.50	47.00	47.90
Al_2O_3	2.72	10.65	2.30	8.56	8.25	23.50	20.00
Fe_2O_3	6.87	11.16	2.08	16.71	5.83	3.20	1.94
CaO	47.55	29.31	52.45	30.71	36.07	10.88	16.29
MgO	0.98	1.20	1.90	1.72	2.55	0.86	1.19
Na_2O	0.24	0.29	0.15	0.53	0.75	0.15	0.22
K_2O	0.33	1.08	0.41	0.66	1.63	0.91	1.43
TiO_2	0.13	0.54	0.08	0.47	0.38	0.94	0.51
P_2O_5	0.03	0.17	0.02	0.58	0.36	0.01	0.03
SO_3	20.10	15.81	30.72	10.59	17.88	4.82	8.99
Carbon	6.67	5.26	0.20	0.60	0.05	6.77	1.20
CO_2	3.83	3.14	0.22	0.32	0.27	n.a.	n.a.
H_2O	1.70	0.12	1.26	0.13	0.64	n.a.	n.a.
Total	99.90	101.38	99.22	99.56	101.16	99.04	99.70
Phase Composition:							
CaO (Lime)	23.3	13.9	26.7	22.4	21.2	7.5	10.0
$Ca(OH)_2$ (Portlandite)	7.0	0.5	5.2	0.5	2.6	..	..
$CaSO_4$ (Anhydrite)	34.2	26.9	52.2	18.0	30.4	8.2	15.3
$CaCO_3$ (Calcite)	8.7	7.1	0.5	0.7	0.6	..	..
Carbon	6.7	5.3	0.2	..	..	6.8	1.2
Other*	20.1	46.4	15.1	58.3	45.1	77.5	73.5

↑ Si, AL

* Assumed to be coal-associated minerals (e.g., silica, calcined clay)

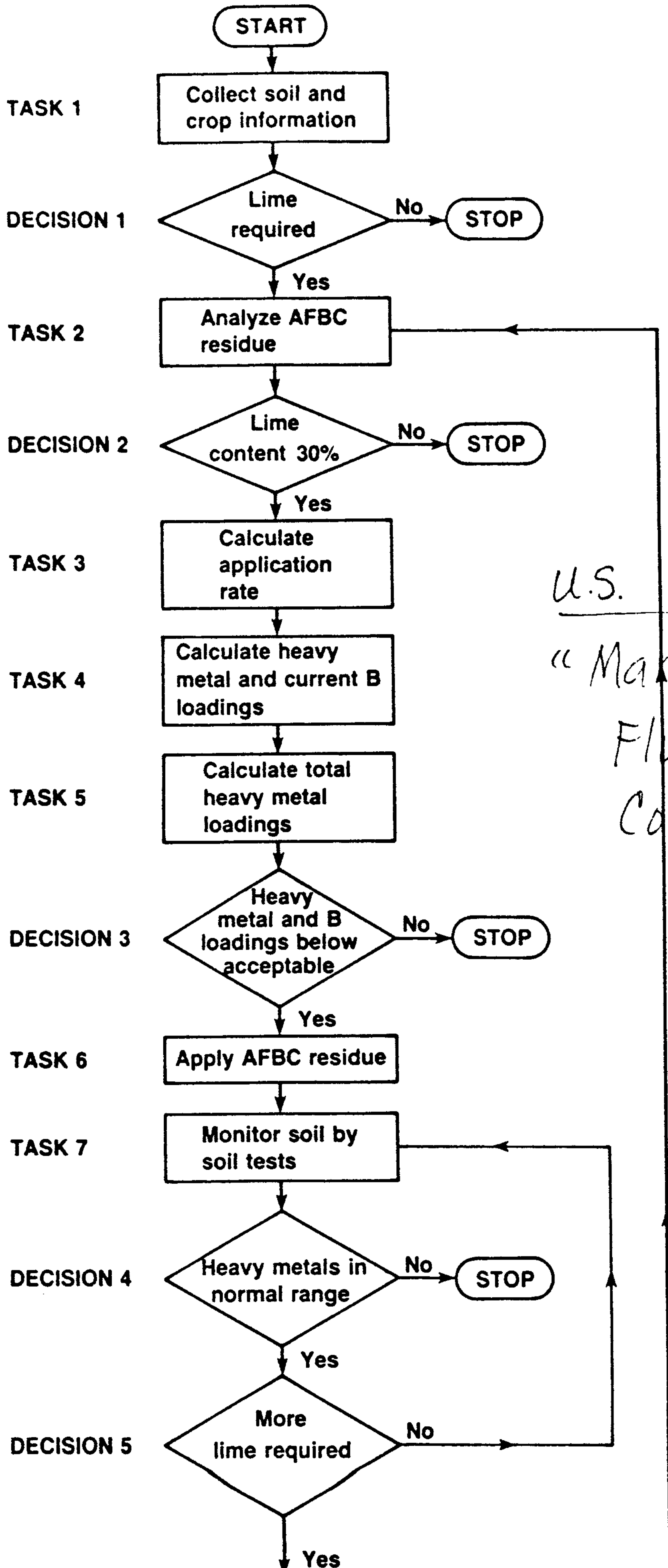
from: Berry 1991

Table 1
Variations in some chemical constituents of 9 samples of atmospheric fluidized bed combustion (AFBC) residue and soils

		AFBC residue[1]		Soils[2]	
Group	Component	Average	Range	Average	Usual range
		Percent of $CaCO_3$			
Lime	CaO and MgO	60	31-100		
		Micrograms per grams of dry material			
Essential plant nutrients	Ca	380,000	240,000-460,000		
	S	92,000	72,000-140,000	850	100-1,500
	Mg	7,100	5,000-12,000		
	K	2,500	500-8,000		
	P	430	380-500		400-3,000
	Fe	11,000	800-16,000	---	14,000-40,000
	Mn	485	210-685	850	200-3,000
	Mo	.19	.12-.28	2	.2-5
	B	110	95-170	10	2-100
	Cu	15	12-19	20	2-100
	Zn	55	29-105	50	10-300
Heavy metals	Ni	21	13-29	40	5-500
	Pb	3.2	1.5-7.5	10	2-200
	Cd	.5	---	.5	.01-.70
	Cr	15	9-23	200	5-1,000
Phytotoxic elements	Se	.29	.16-.58	---	.1-2
	Al	10,000	4,000-20,000	---	14,000-40,000

[1]From Stout, W.L., and others (25).
[2]From Baker, D.E., and L. Chesnin (2).

from: Stout, 1988



U.S. Dept. Agriculture:
"Manual for Applying Fluidized Bed Combustion Residue to Agricultural Lands."

from: Stout, 1988

Generalized Results of Agricultural Applications:

Liming of Mine Spoils and Acid Soils:

- No movement of heavy metals (B, Cd, Cr, Cu, Ni, Pb, Zn, Sr) through the mine spoil profile.
- Only Mn levels increased somewhat in the percolate from FBC treated columns.
- In the acid soil matrix Ca was the only element to move below 10 cm.
- Both Ca and SO_4 concentrations increased in the percolate.
- Ca, SO_4, and Mn concentrations were within safe drinking levels.
- No environmental problems were apparent from liming rate application of FBC residues on marginal soils and mine spoils.

Reduced Surface Sealing

- reduced surface sealing and soil erosion on slopes of 5% but not on slopes of 30%.
- Due to the flocculation of the clays.
- FBC residues was more effective at reducing surface sealing than phosphogypsum or flue gas desulfurization (FGD) residues. This was due to greater solubility of the minerals in the FBC.

Source of Ca and S

- FBC residues (1X to 3X lime requirement) maintained soil pH.
- Increased extractable Ca (and Mg in Dolomitic scrubber).
- In some cases increased leaf concentrations of Ca (conflicting results).
- In most cases there was no accumulation of heavy metals in the plant tissue.
- Reduced Pecan leaf N, Mn, Zn, and Al after 3 applications. Not recommended to use over long periods of time.
- Other than pecans there was no observed nutritional deficiencies.

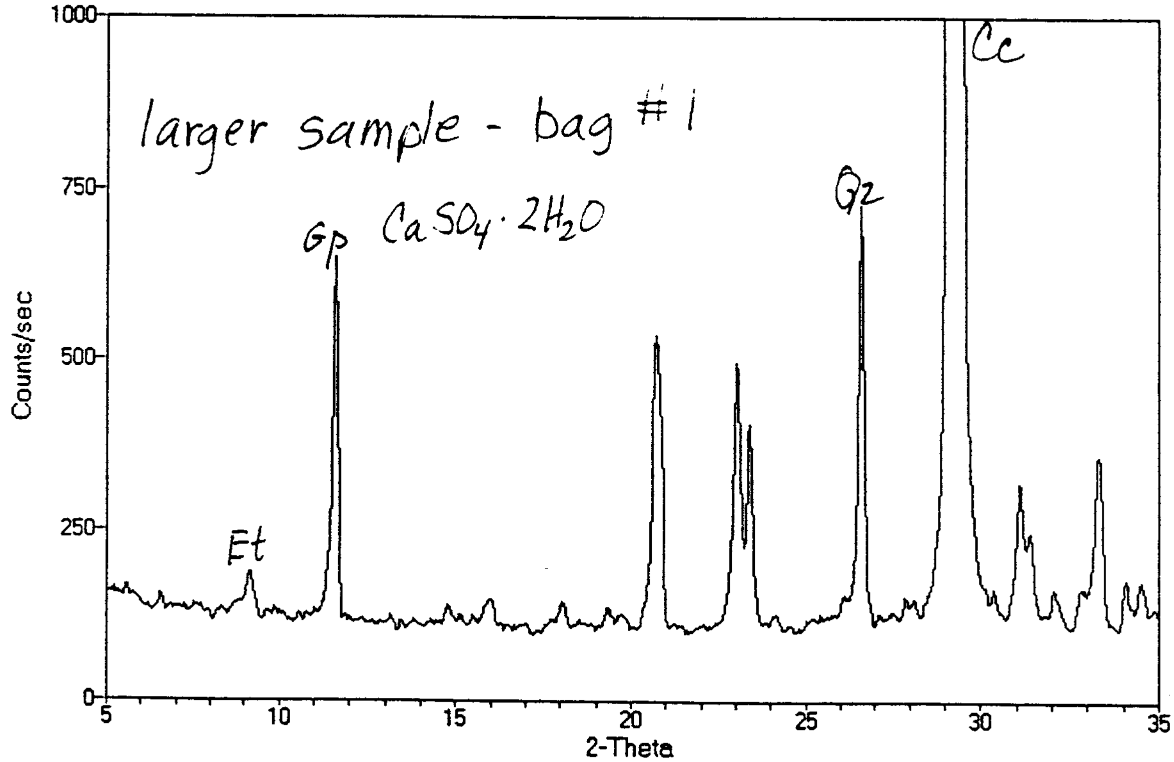
Disposal levels in control of weeds

- Lime substitute application is 2-6 mg/ha. Disposal rate applied was 9.2 Kg/m^2 and 36 Kg/m^2 (50 tons/acre).
- Apple yields increased for most cultivars.
- Leaf tissue Ca concentrations increased dramatically (dependent on rootstocks).
- Peel and Flesh Ca concentrations remained about the same.
- Mg concentrations in plant tissue did not decrease, and was higher at low application rate.

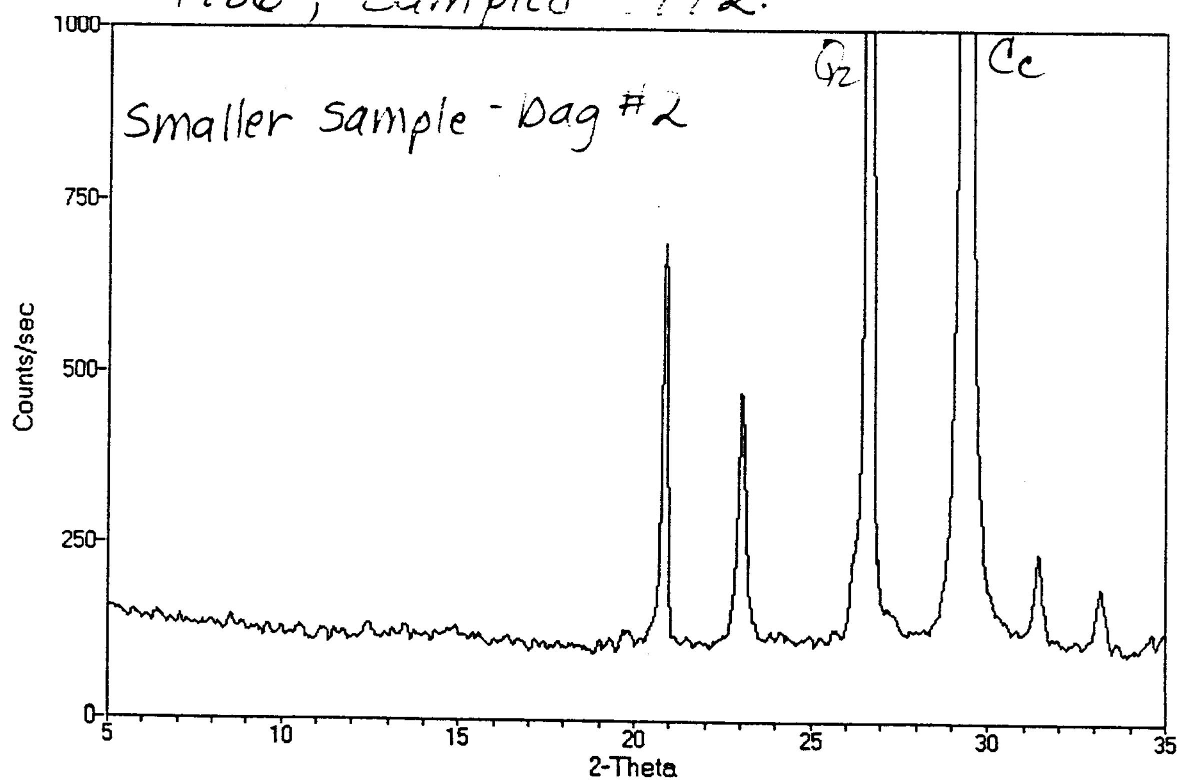
Materials from Pope, Evans, & Young Pilot Steam generator

Eastern bituminous coal

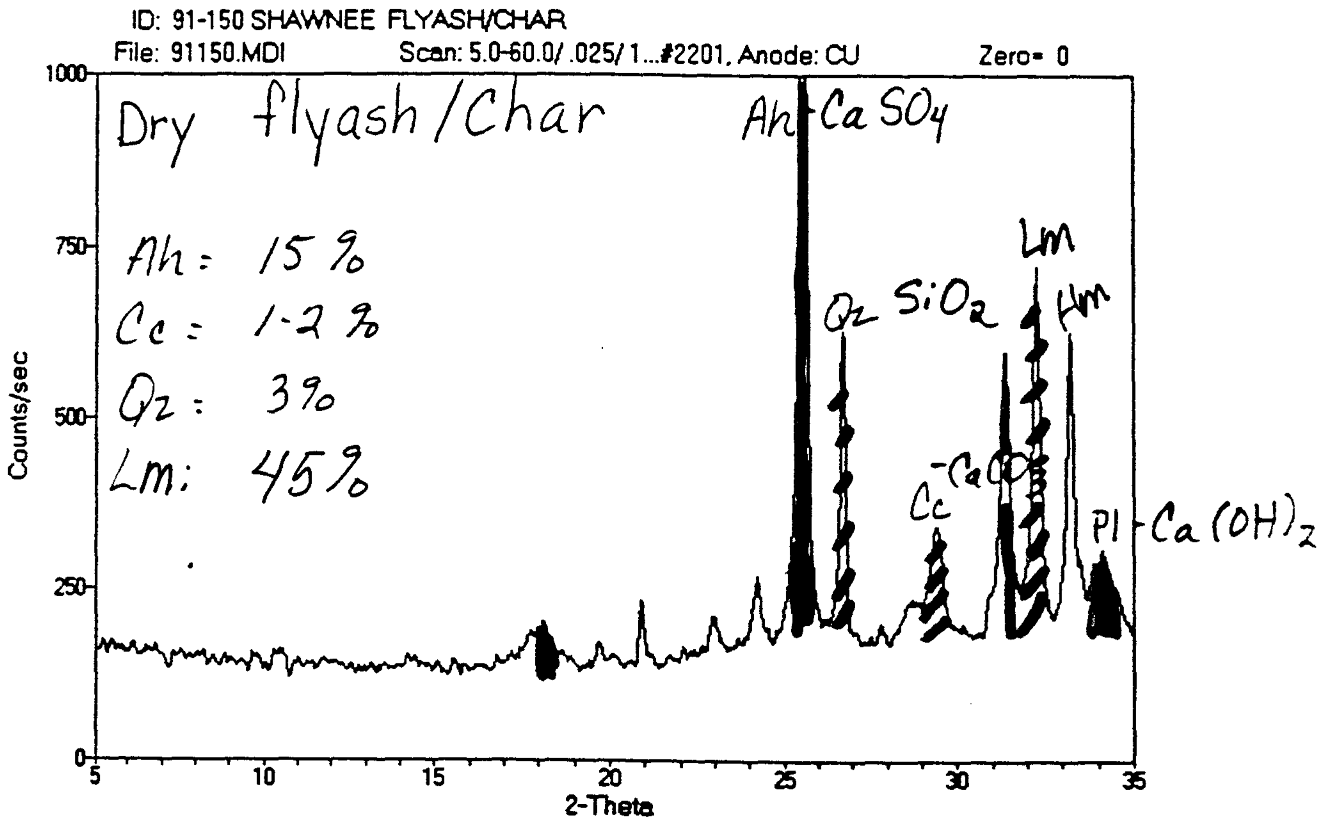
limestone bed

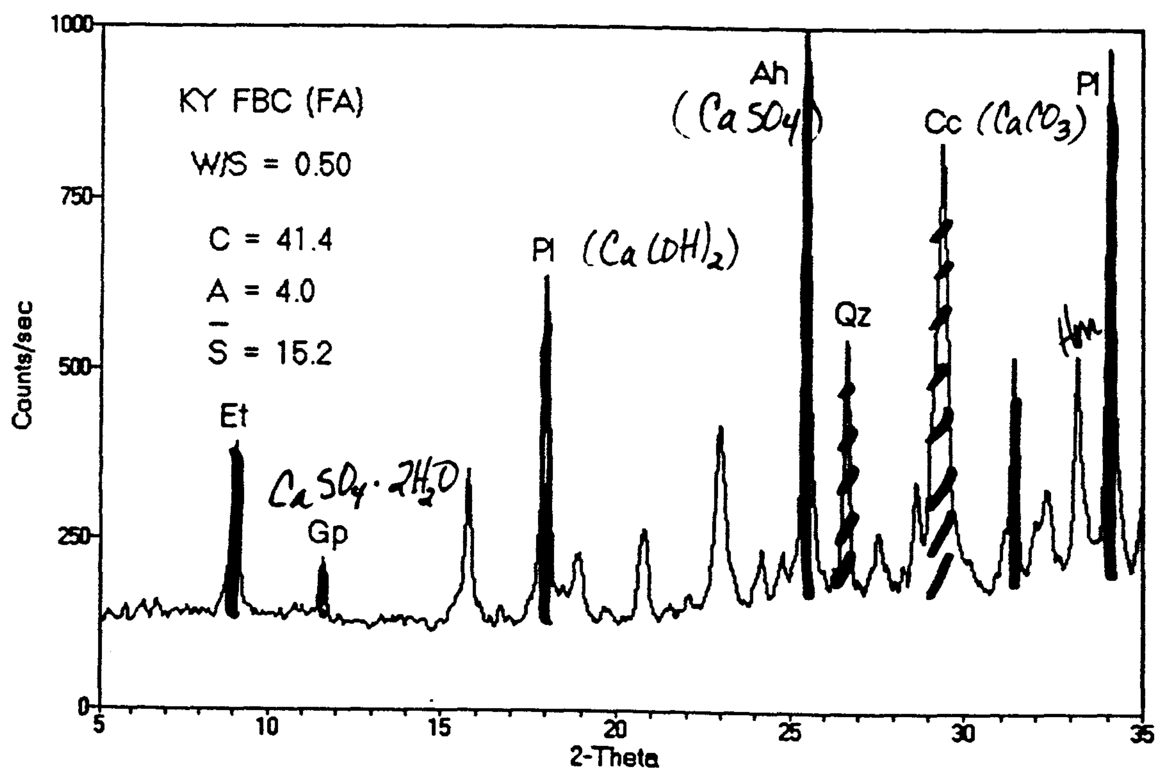


50 tons/acre Surface applied 1980, plowed under 1986, sampled 1992.



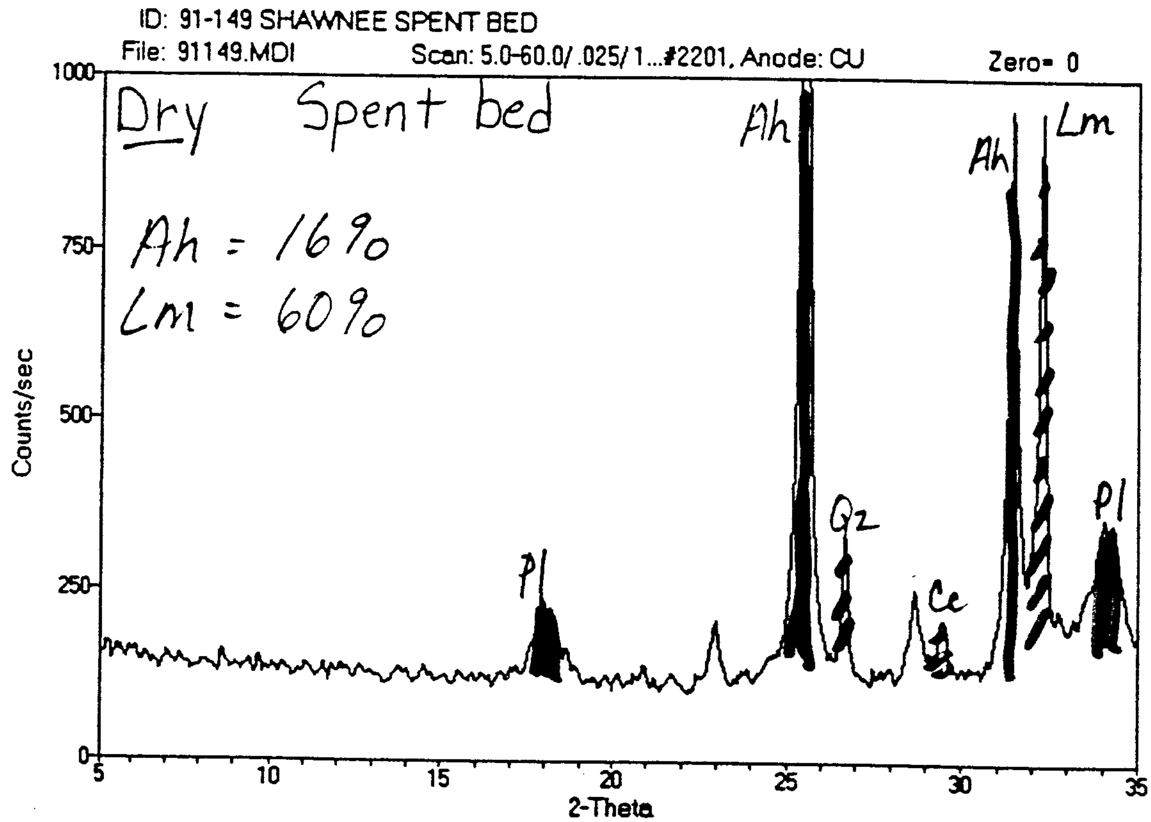
TVA: bubbling bed AFBC

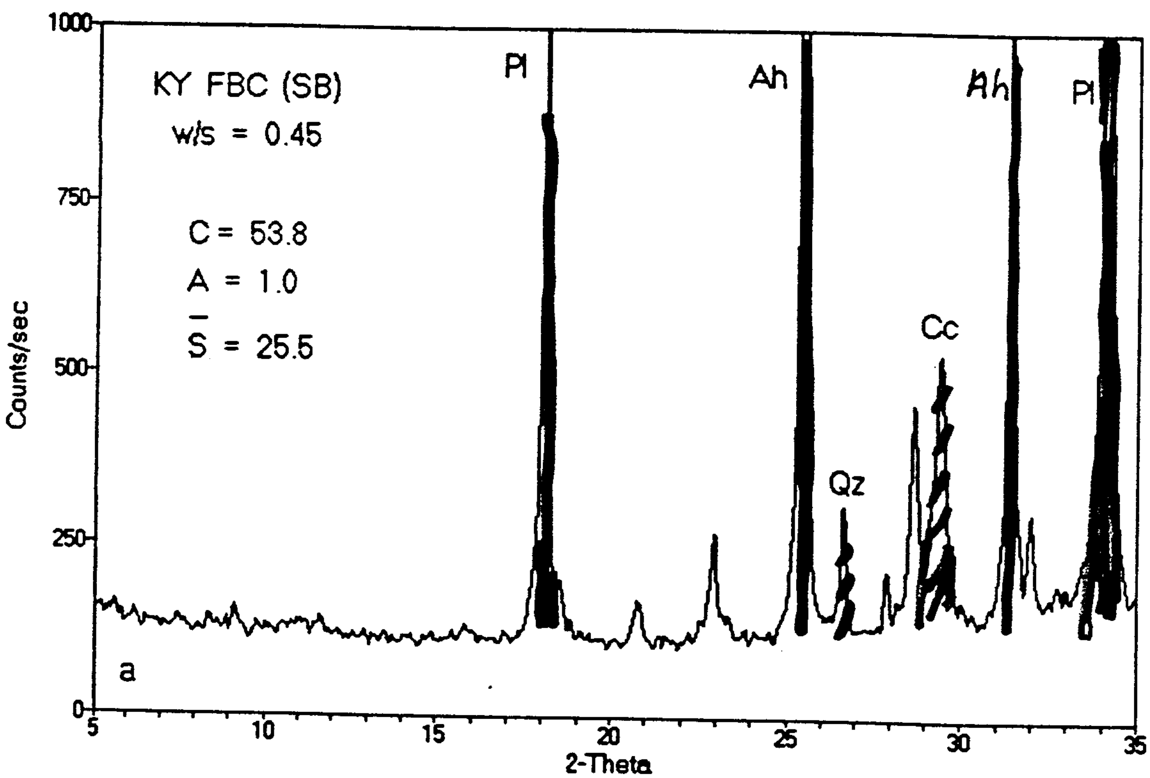




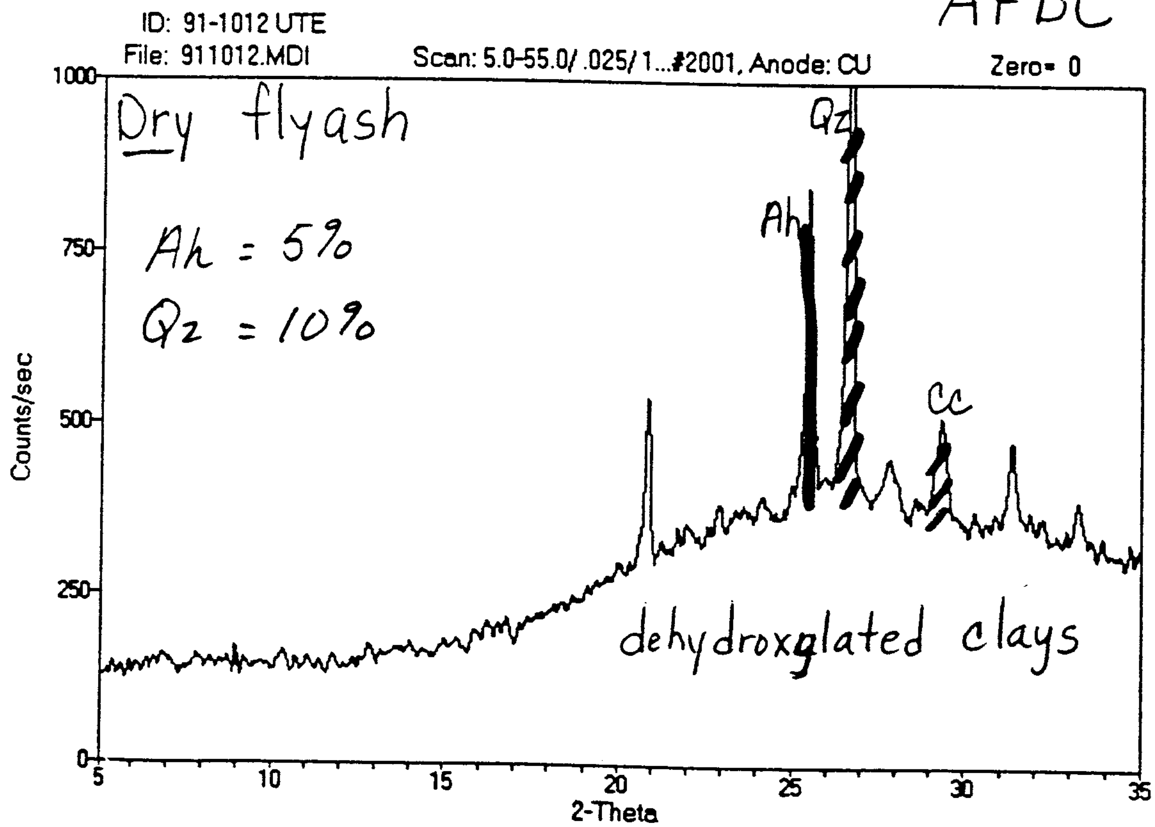
<u>Et</u> - $Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$

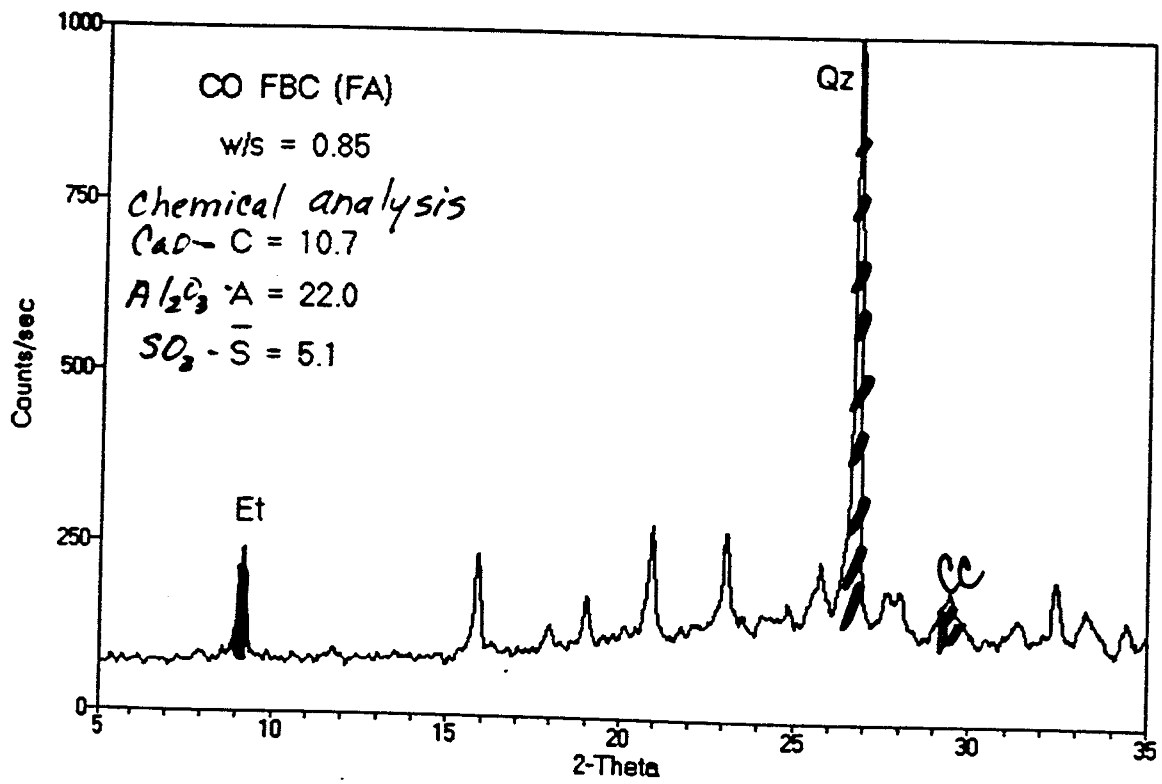
TVA : bubbling bed AFBC



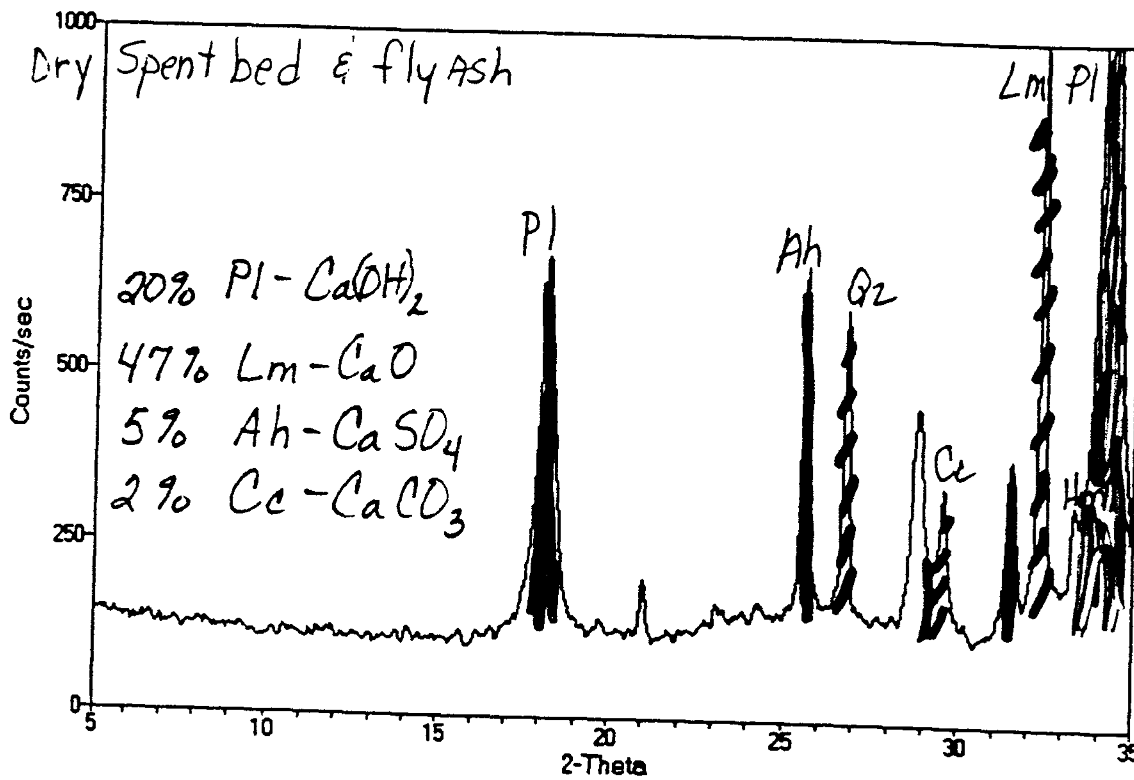


Colorado Ute: circulating bed AFBC

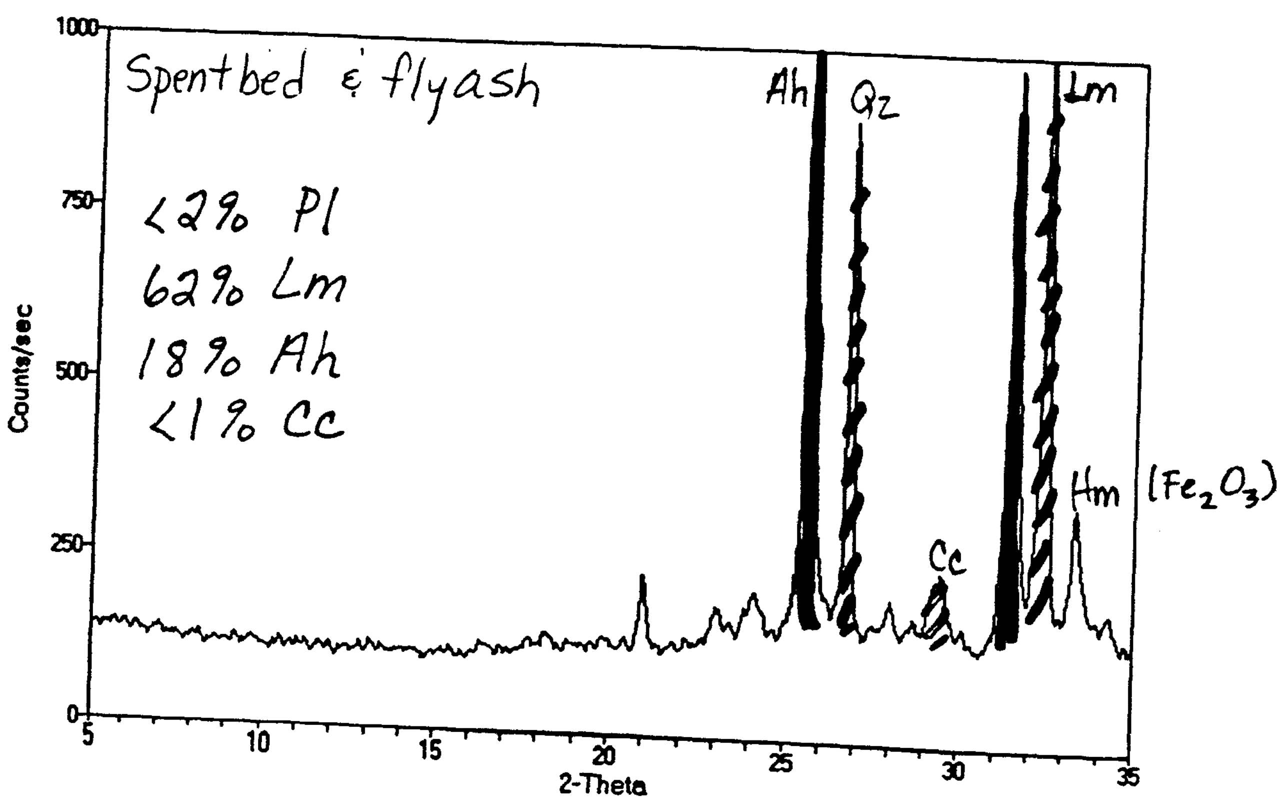




Georgetown University bubbling bed AFBC



Yorktown, PA Papermill circulating AFBC



Conclusions and Discussion

The U.S. Department of Agriculture has recommended AFBC residues for use as a liming agent on certain soils with proper guidelines. The major concern at this time is heavy metal loading on the soils. This is more of a problem for municipal sewage sludge and the flash from older coal combustion technologies, which are higher in heavy metal concentrations.

Disposal level applications of AFBC residues could dramatically alter the texture of soils and possibly the CEC.

Mixed research results in plant and soil elemental concentrations is probably due to variations in physical, chemical and mineralogical characteristics of FBC residues.

More work needs to be done characterizing the physical, chemical, and mineralogical properties of AFBC residues to better understand their diversity.

Additional characterization of such properties as CEC, particle size distribution, soluble ions, and buffering capacity of these residues would be highly recommended to better asses the impact of these residues on agricultural lands.

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