Biochar: A Renewable Material for Removing Contaminants from Water

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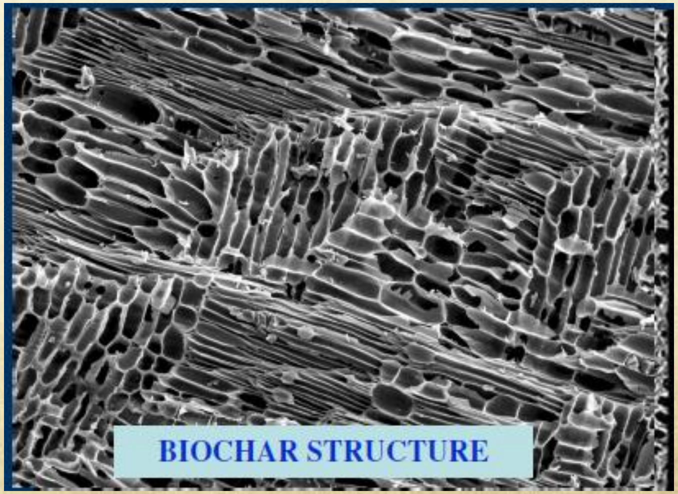
What is Biochar?

Carbon rich, high energy density solid product resulting from the thermal degradation of biomass. It consists of C, H, O, N, and ash

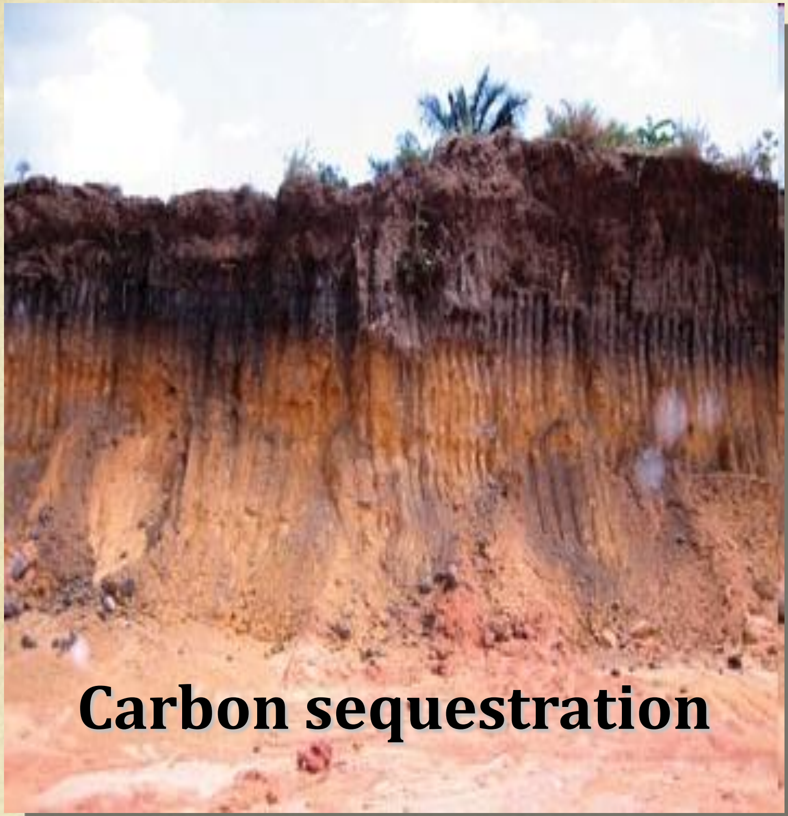
Essentially a charcoal

Unlike charcoal it is not used as primary fuel

- Highly porous and irregular surface
- Its potential as soil amendment was utilized by indigenous people of Amazon



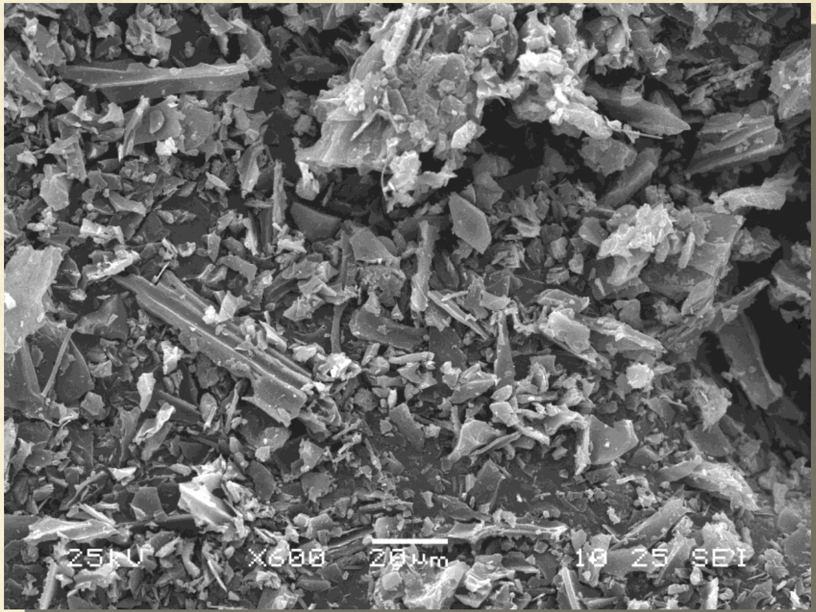
Soil Application



- ✓ Historically, biochar has been used in soil to enhance the plant growth.
- ✓ It helps in improving the water quality.
- ✓ The leaching of nutrients from soil, which is one of the cause of ground water pollution is retarded in the presence of biochar

Biochar as Sorbent for Water Treatment

- Porous structure, irregular surface, high surface to volume ratio, and presence of functional group
- Adsorbs both organic pollutants and heavy/trace metals



Biochar can be cost effective alternative to activated carbon

Feedstock for Biochar?

- ✓ Essentially, all forms of biomass can be converted to biochar.
- ✓ Lignocellulosics such as forest thinning, herbaceous grasses, crop residues, manure, and paper sludge are some of the potential feedstock.

Forest Residue

Wood Mill Residue

Bark

Switchgrass

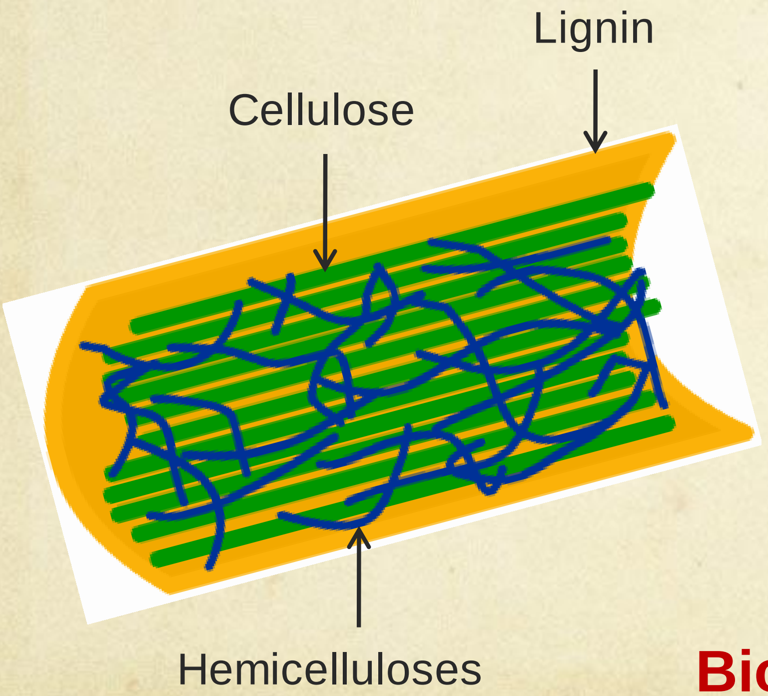
Corn Stover

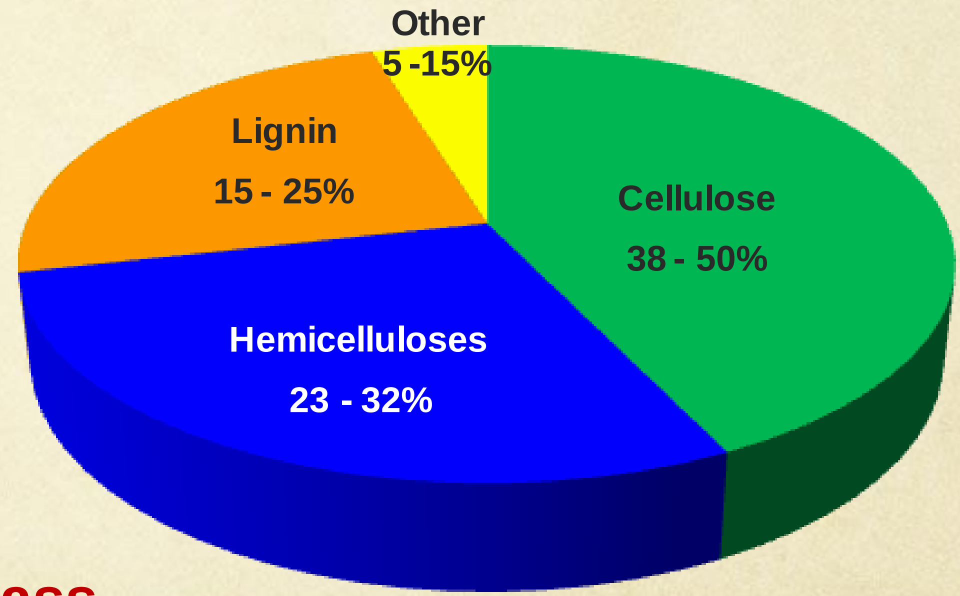
Bagasse

Wood chips

Lignocellulosic Biomass

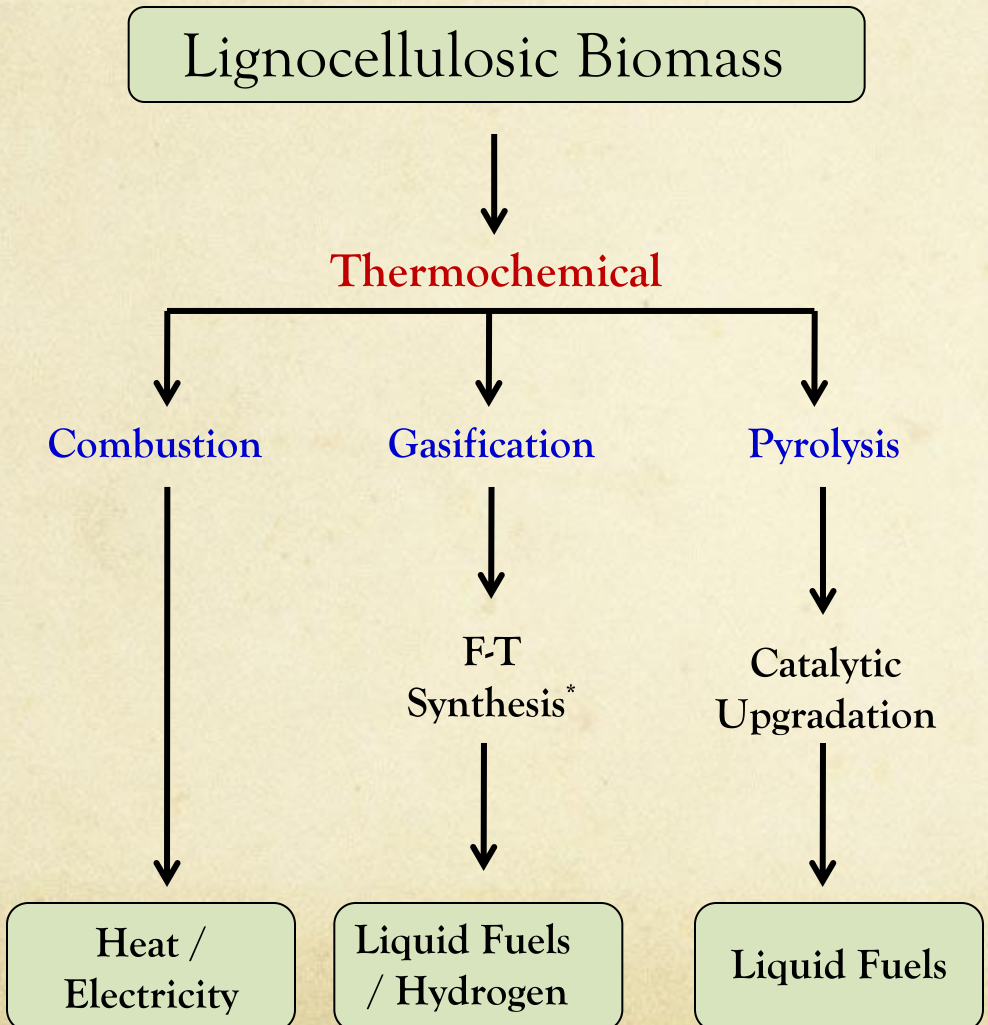
- Renewable organic material
- Non starch based fibrous part of plant material
- Major feedstock for achieving 36 BYG of biofuels by 2022 (EISA, 2007)





Biomass
$CH_{1.4}O_{0.7}$

Thermochemical Conversion of Biomass for Biofuels



A Byproduct from Future Biorefineries

Temperature ↑

Process	Temperature (°C)	Time	Biochar Yield (%)
Gasification	~ 750	~ 10-20 s	10
Pyrolysis			
Fast	400-700	~ 1 s	12
Moderate	400-700	~ 10-20 s	20
Slow	400-700	~ 5-30 min	35
Hydrothermal Carbonization	200-350	30-90 min	30-60

Biochar Yield ↓

Biochar
($CH_{1.2}O_{0.2}$)

Oxygen is present in biochar

Producing Biochar by Slow Pyrolysis

Combustion

Abundant Oxygen

- CO_2
- H_2O
- soot
- ash
- HEAT

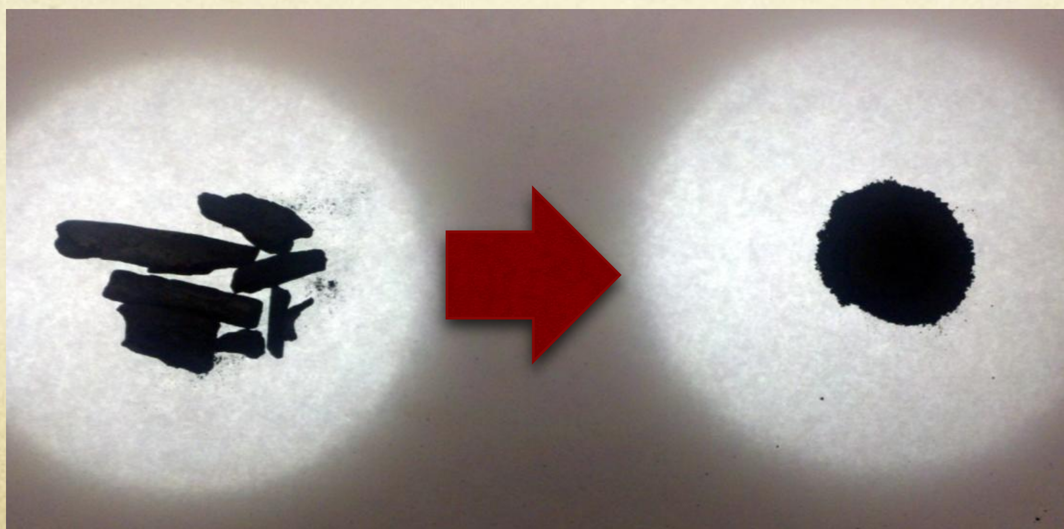
Pyrolysis

Little or no Oxygen

- little or no heat
- little or no CO_2
- H_2O
- small organics
- char

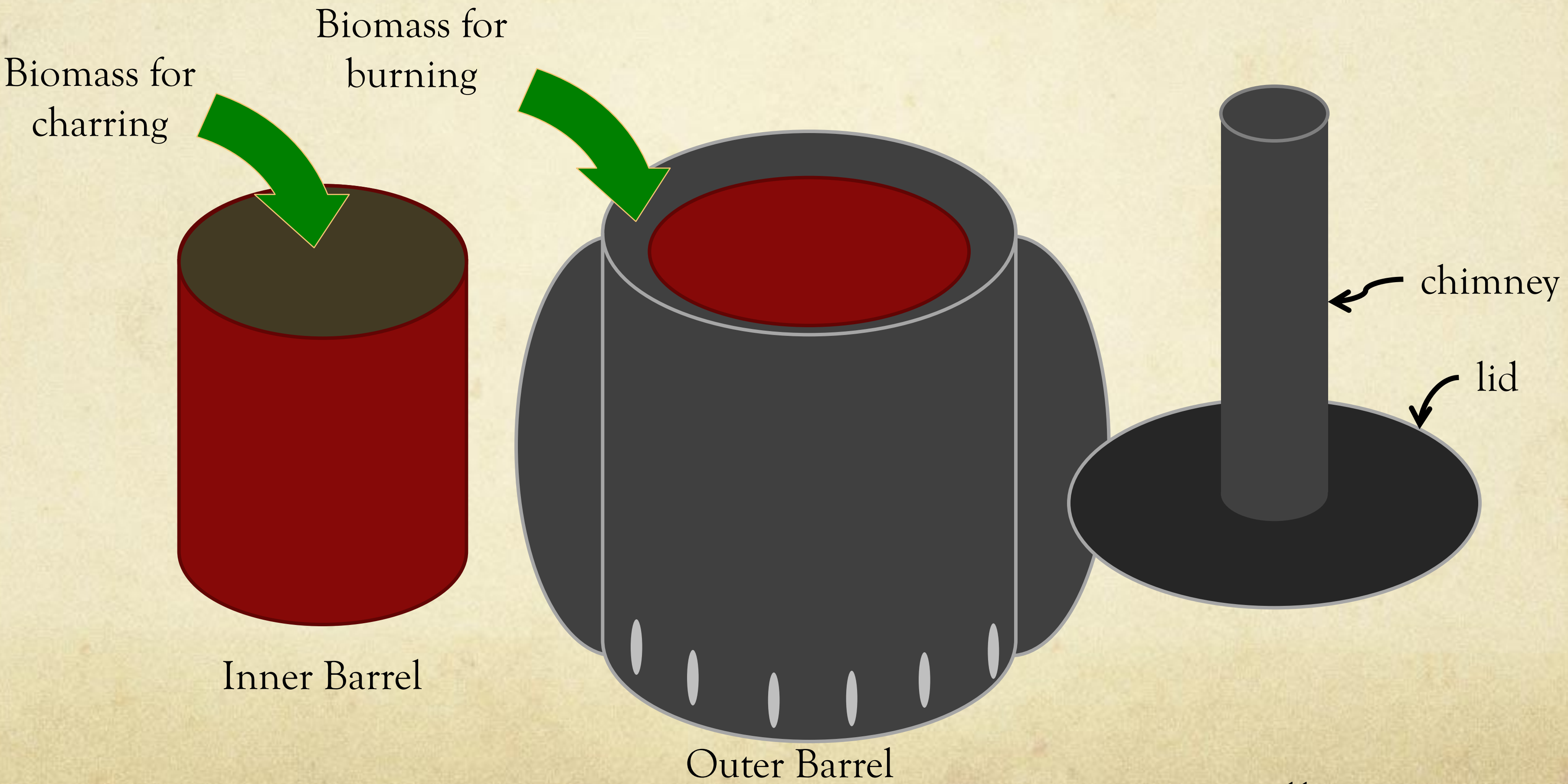
Use combustion to provide heat for pyrolysis

Biochar from Slow Pyrolysis



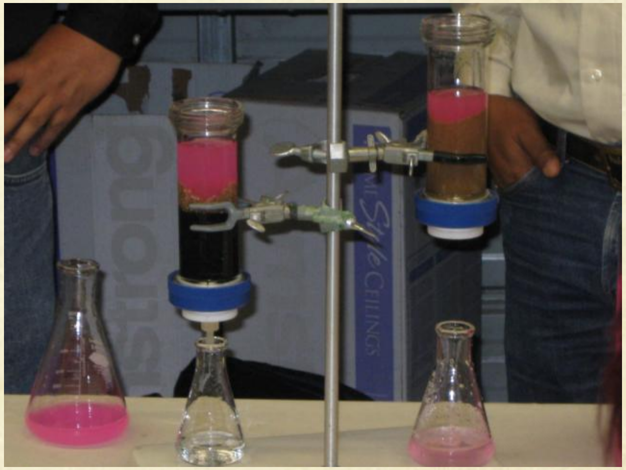
Two-Barrel Pyrolyzer

(Developed by NASA Langley Center)



Bluebird Gap Farm, Hampton Event, Nov. 19-20, 2010



City of Hampton, NASA Langley Research Center, and Old Dominion University

Demostration of biochar production via slow pyrolysis and its application in water purification

Using Biochar to Help Plants

Use of Biochar for Water Treatment

Experimental Study with Copper, Cadmium, and Lead Contaminants

Contaminants MCL and their Sources

Trace Metal Contaminants	MCL (mg/L)	Sources
Copper	1.3	Corrosion of household plumbing system, erosion of natural deposits
Cadmium	0.005	Corrosion of galvanized pipes, erosion of natural deposits, discharge from metal refineries, runoff from waste batteries and paints
Lead	0.0	Discharge from steel and pulp mills, erosion of natural deposits, corrosion from household plumbings, erosion of natural deposits

Materials

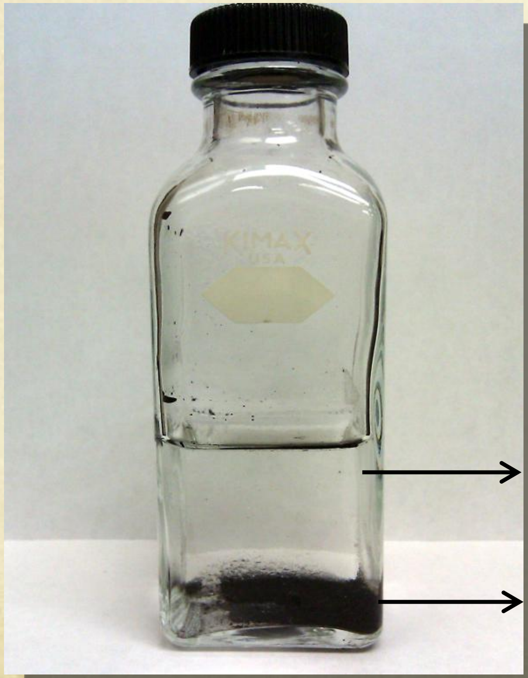
Single ion solution Cu, Cd, and Pb were prepared

Trace Metals	Concentration (mg/L)	Chemical
Copper	40	$CuSO_4.5H_2O$
Cadmium	40	$Cd(NO_3)_2.4H_2O$
Lead	40	$PbNO_3$

BATCH STUDY

Batch Experiments

- Three metal solutions were treated with 2 g/L, 1 g/L and 0.5 g/L of biochar
- Samples were collected at 30 mins, 1 hr, 2hr, 6 hr, 24hr, 48 hr, and 72 hr

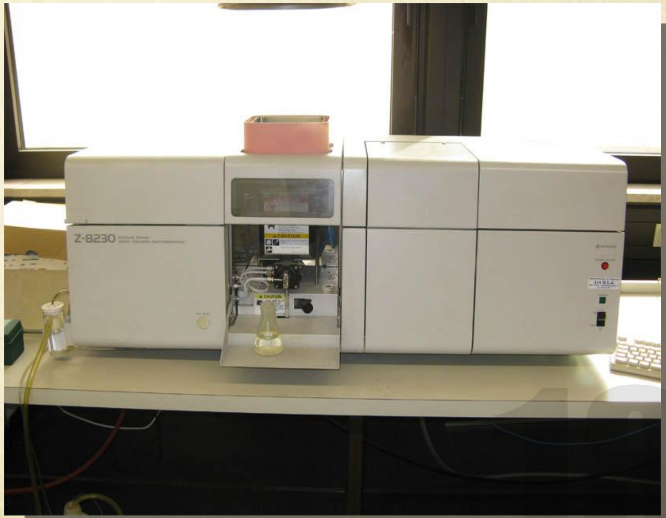


Metal solution

Biochar

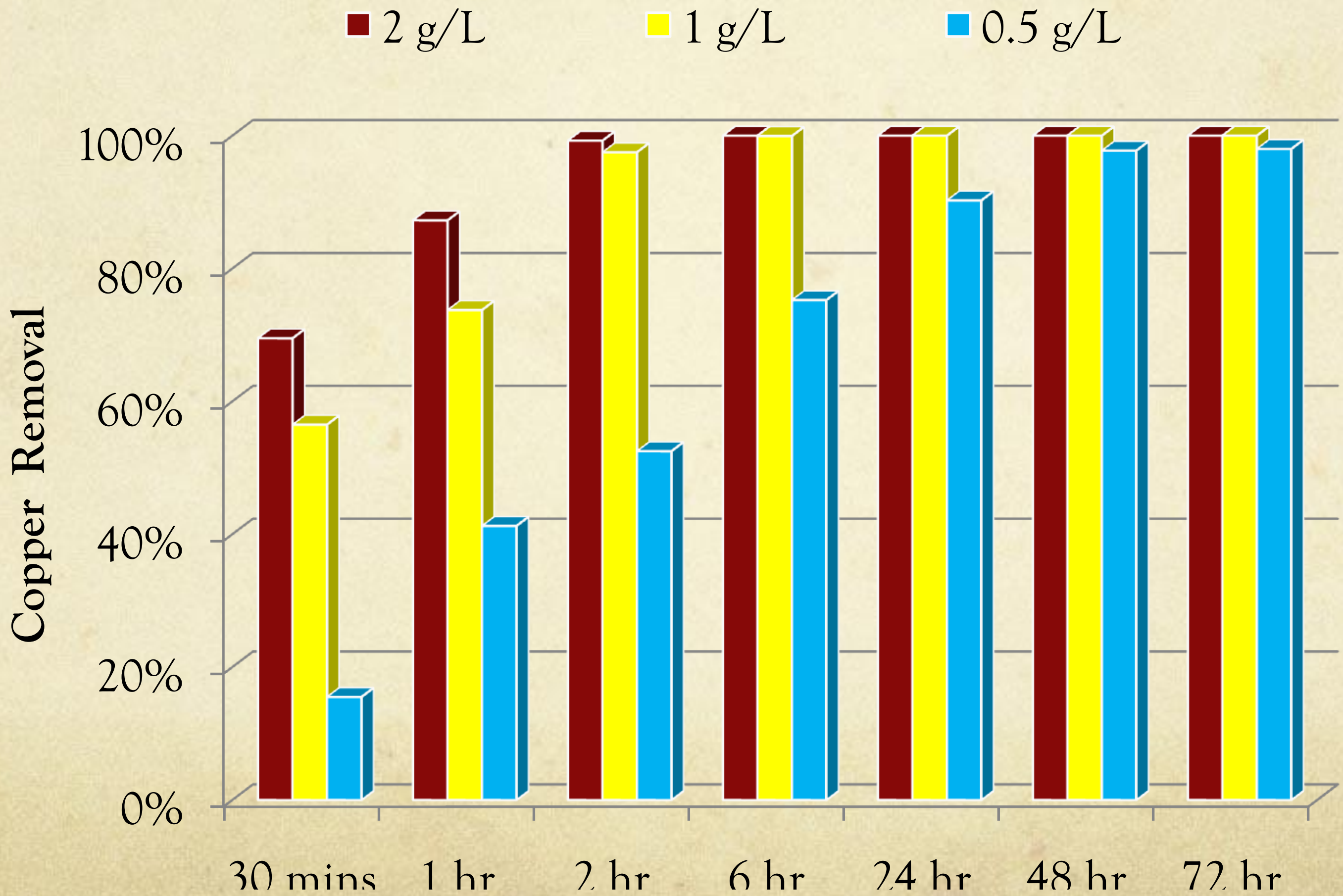
Analysis:

Atomic absorption spectrometer (AAS Hitachi Z-8230) to measure metal contaminants



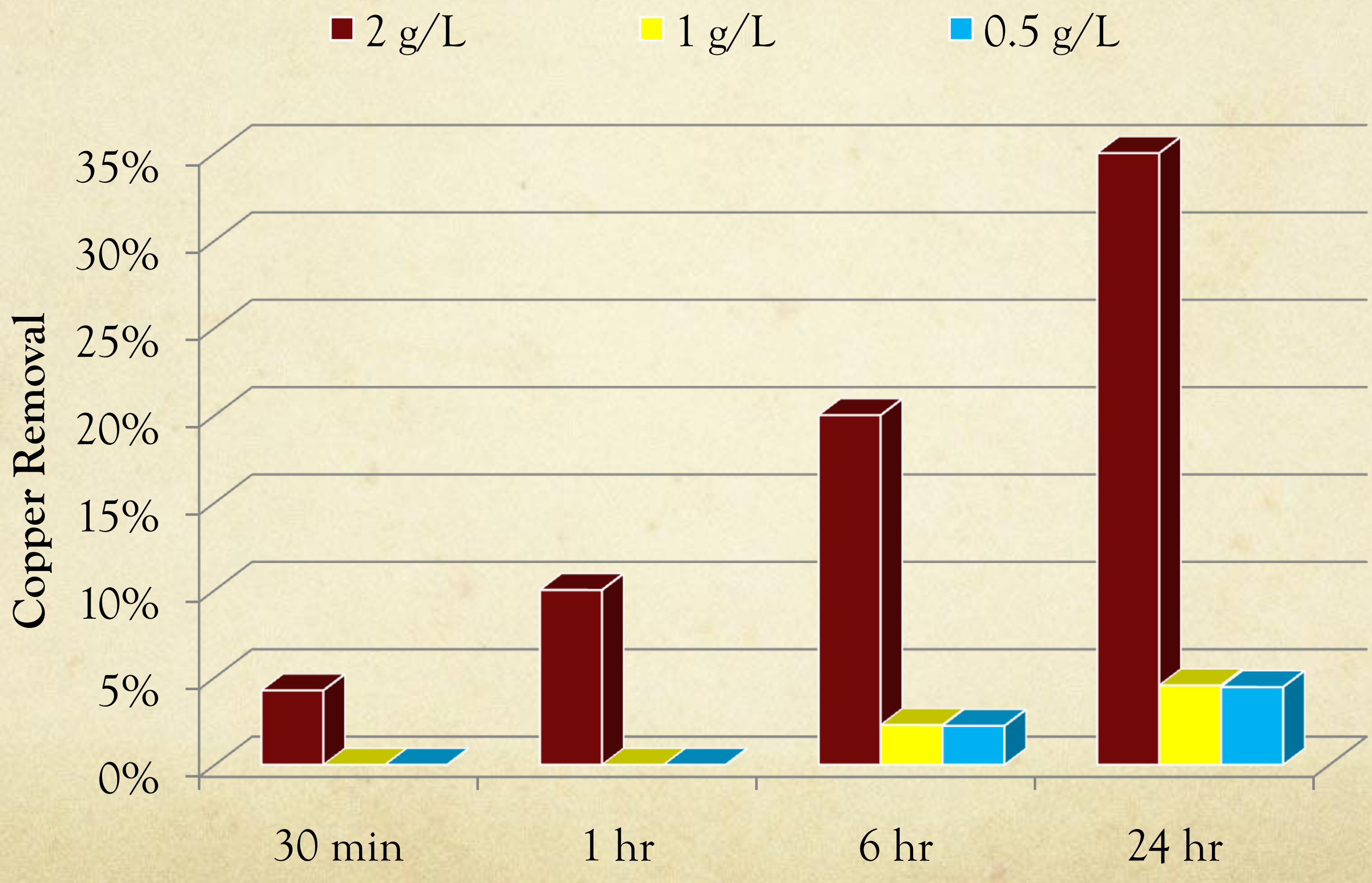
Copper Removal

Initial metal conc	pH
40 mg/L	7



PAC: Copper Removal

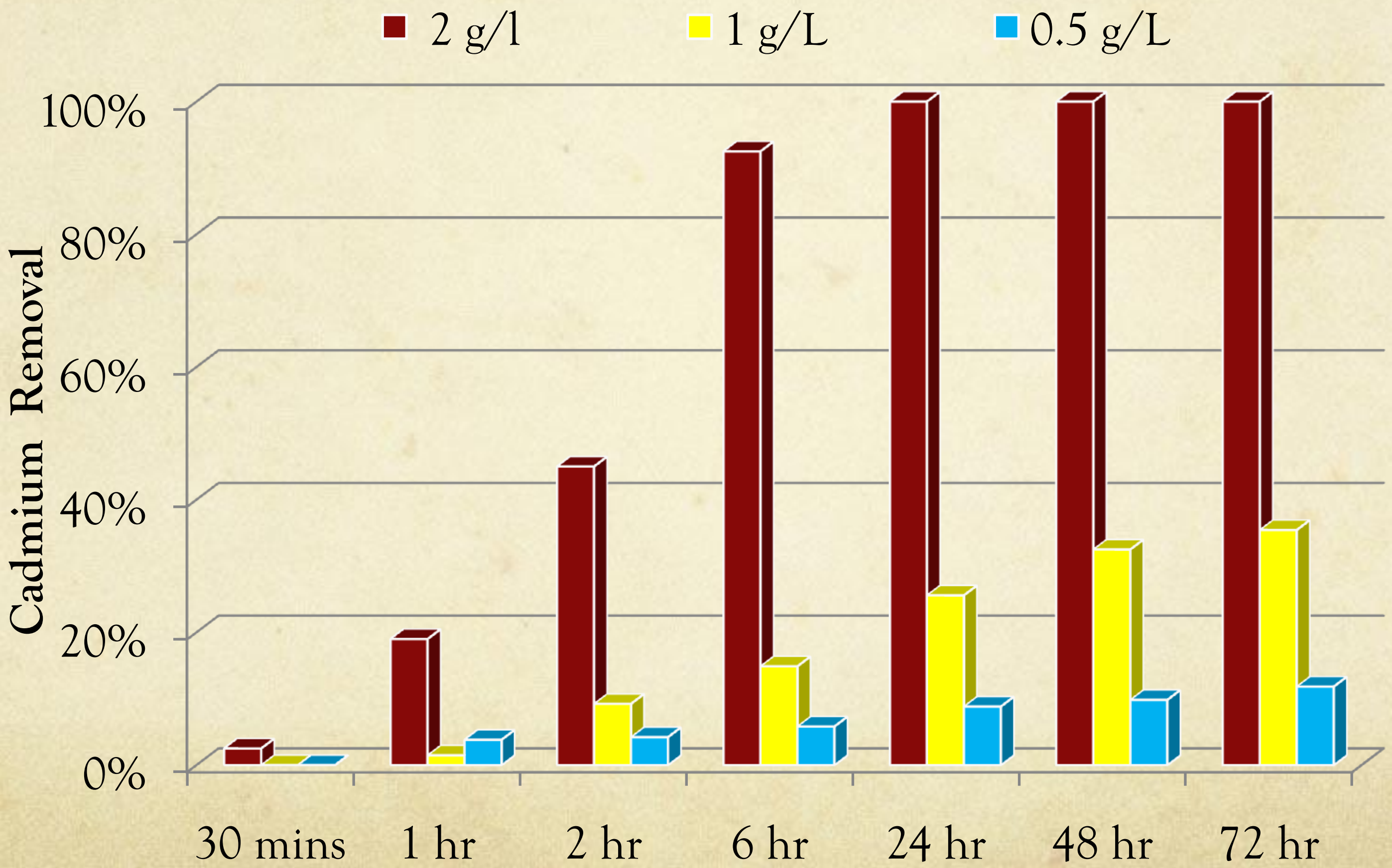
Initial metal conc	pH
40 mg/L	5



PAC: Powdered Activated Carbon

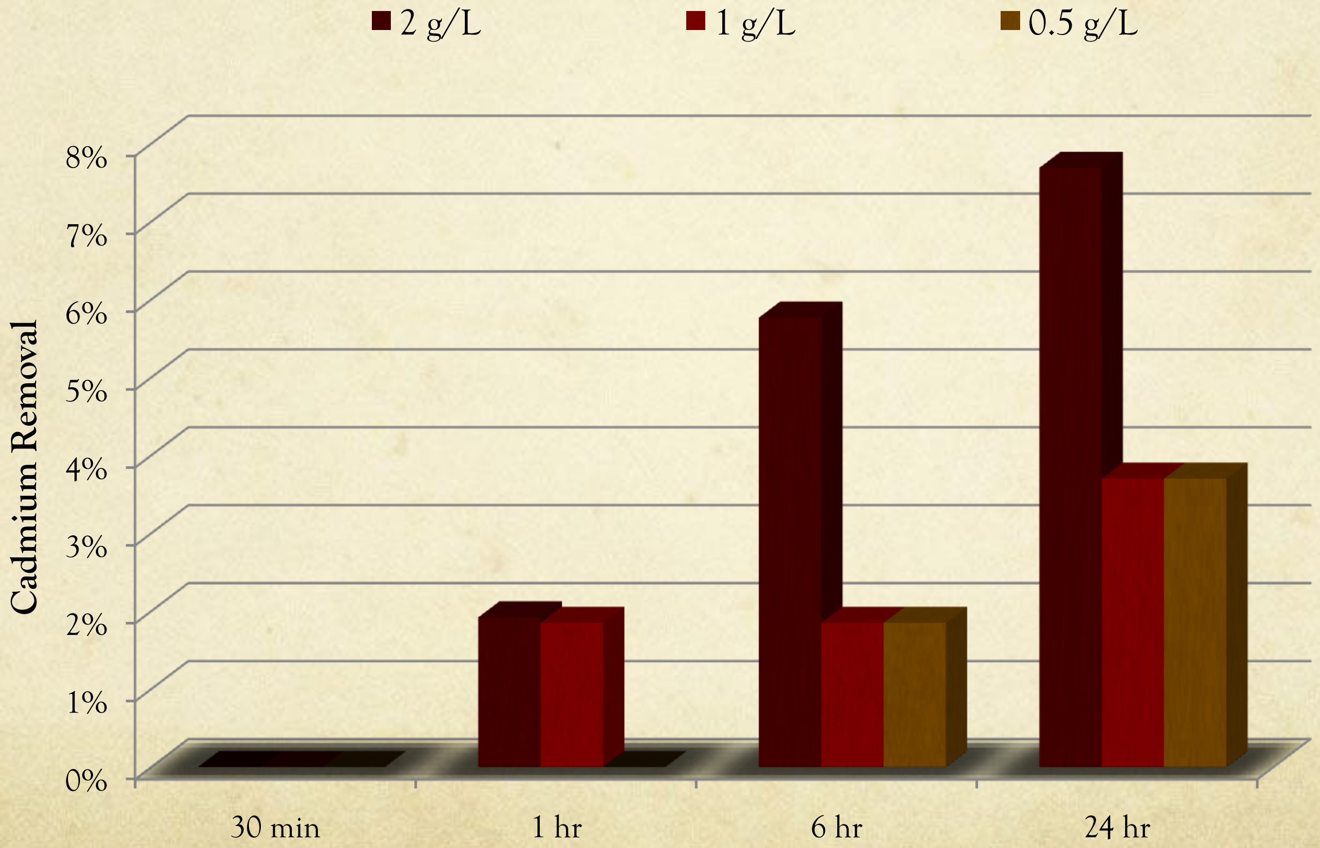
Cadmium Removal

Initial metal conc	pH
40 mg/L	7



PAC: Cadmium Removal

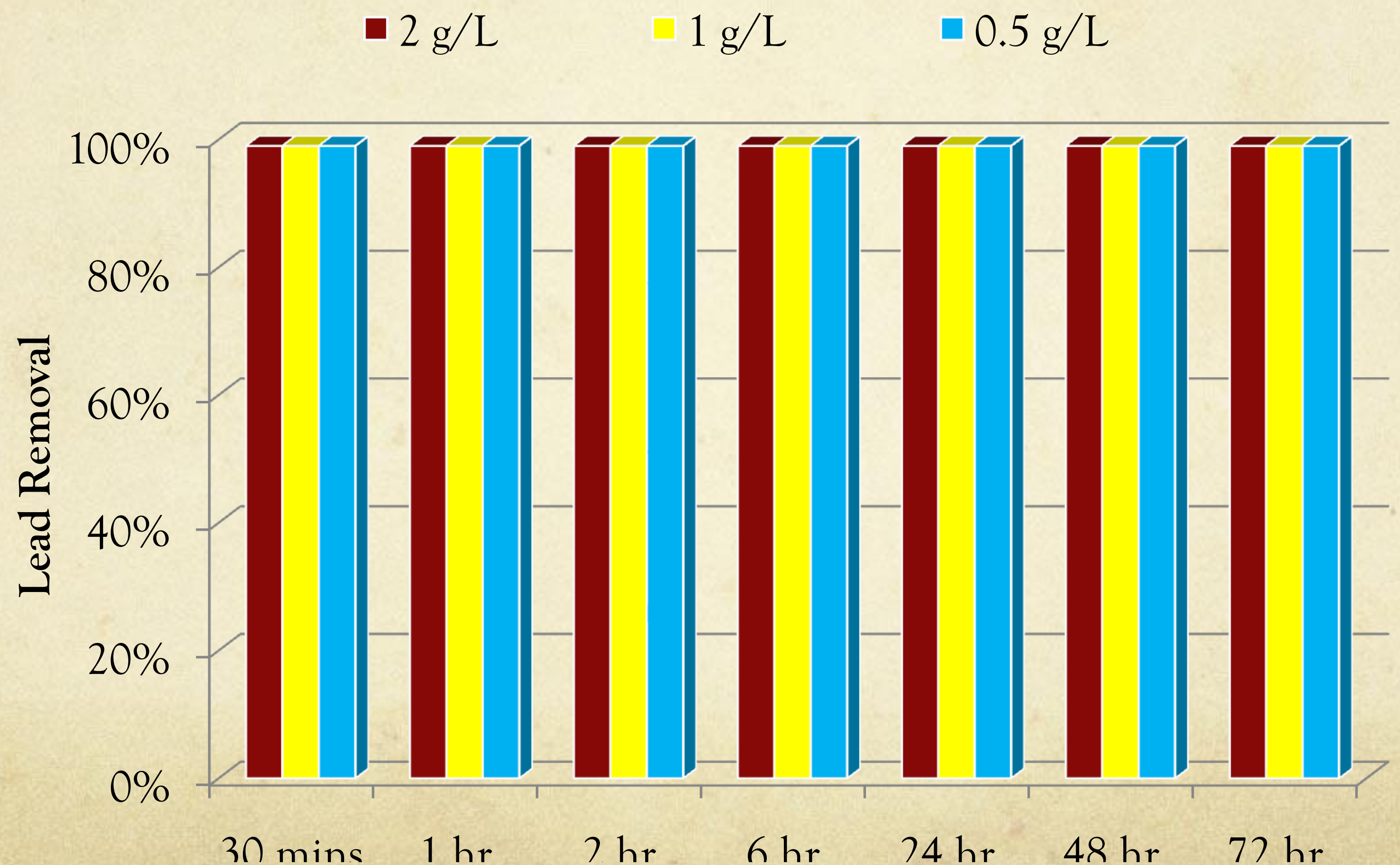
Initial metal conc	pH
40 mg/L	5



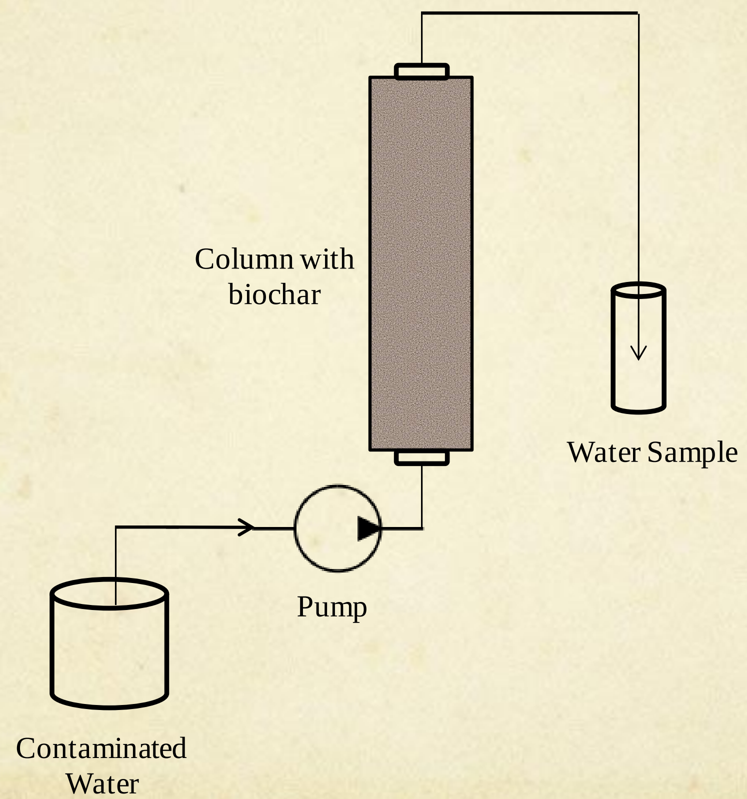
PAC: Powdered Activated Carbon

Lead Removal

Initial metal conc	pH
40 mg/L	7



COLUMN STUDY

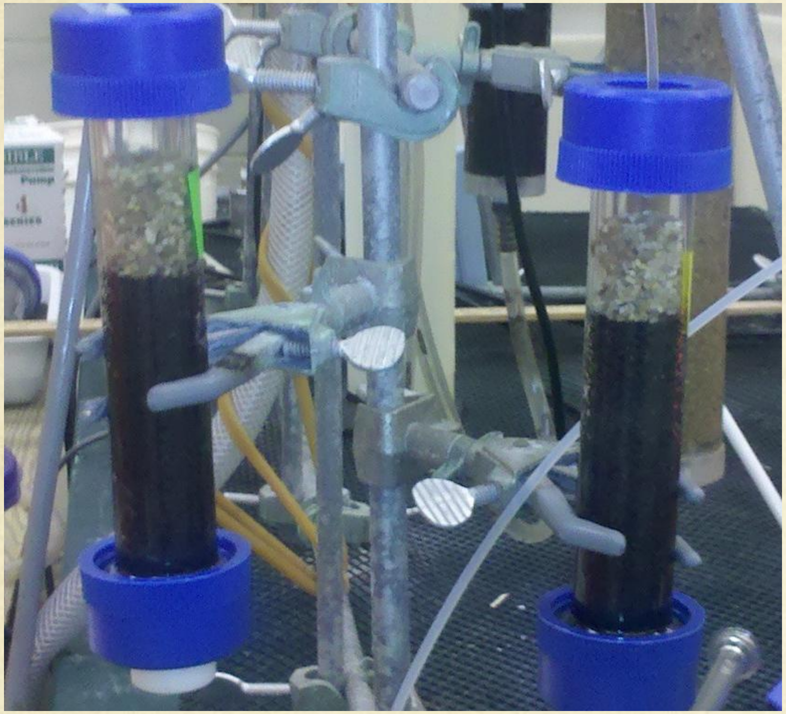


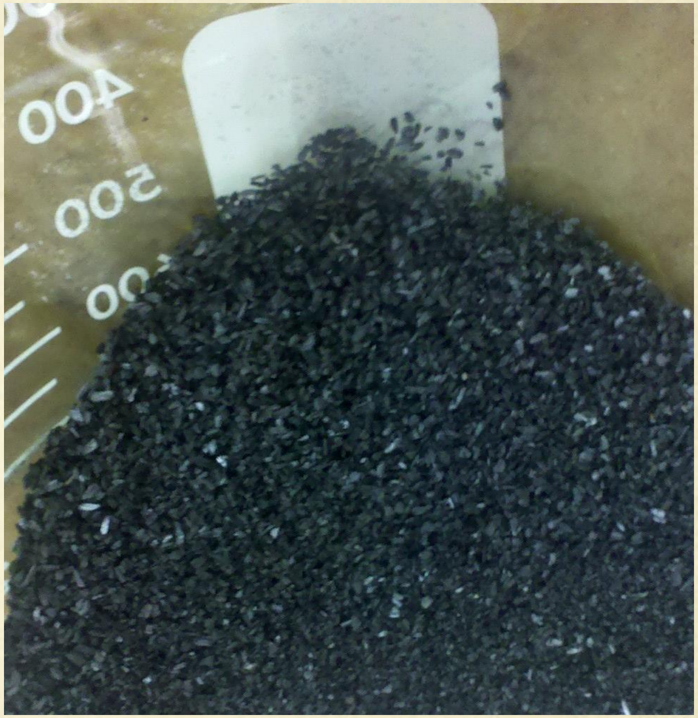
Schematic of column test apparatus

Copper and Lead removal

- Biochar particle size : 0.5 to 1.0 mm
- Measured porosity : 53%
- Volume used in column : 50 ml
- Flow rate for Cu: 2.5 ml/min
- Flow rate for Pb: 3.0 ml/min
- Measurements every 30 min, and 1h after 18 hours of experiment
- Samples analyzed using AAS Hitachi Z-8230

Copper and Lead removal: column study





- 2.5 cm diameter columns
- 50ml of filtering media used
- 0.5 – 1.0 mm biochar particles

Copper removal

Time (hours)	C (mg/l)	Time (hours)	C (mg/l)
1	0.0	12	21.7
1.5	0.0	12.5	19.4
2	3.7	14	22.6
2.5	6.6	15	29.1
3	9.8	16	24.8
3.5	13.9	17	22.1
4	12.3	18	14.2
4.5	13.6	19	12.0
5	11.7	20	8.6
5.5	14.6	21	8.1
6	17.4	22	8.9
6.5	17.4	23	8.3
7	13.2	24	6.2
7.5	13.4	25	7.4
8	14.2	26	9.0
8.5	15.1	27	9.4
9	18.4	28	9.9
9.5	20.9	29	7.6
10	22.1	30	10.5
10.5	20.5	31	10.3
11	21.0		

C/Co = ratio of contaminant removed

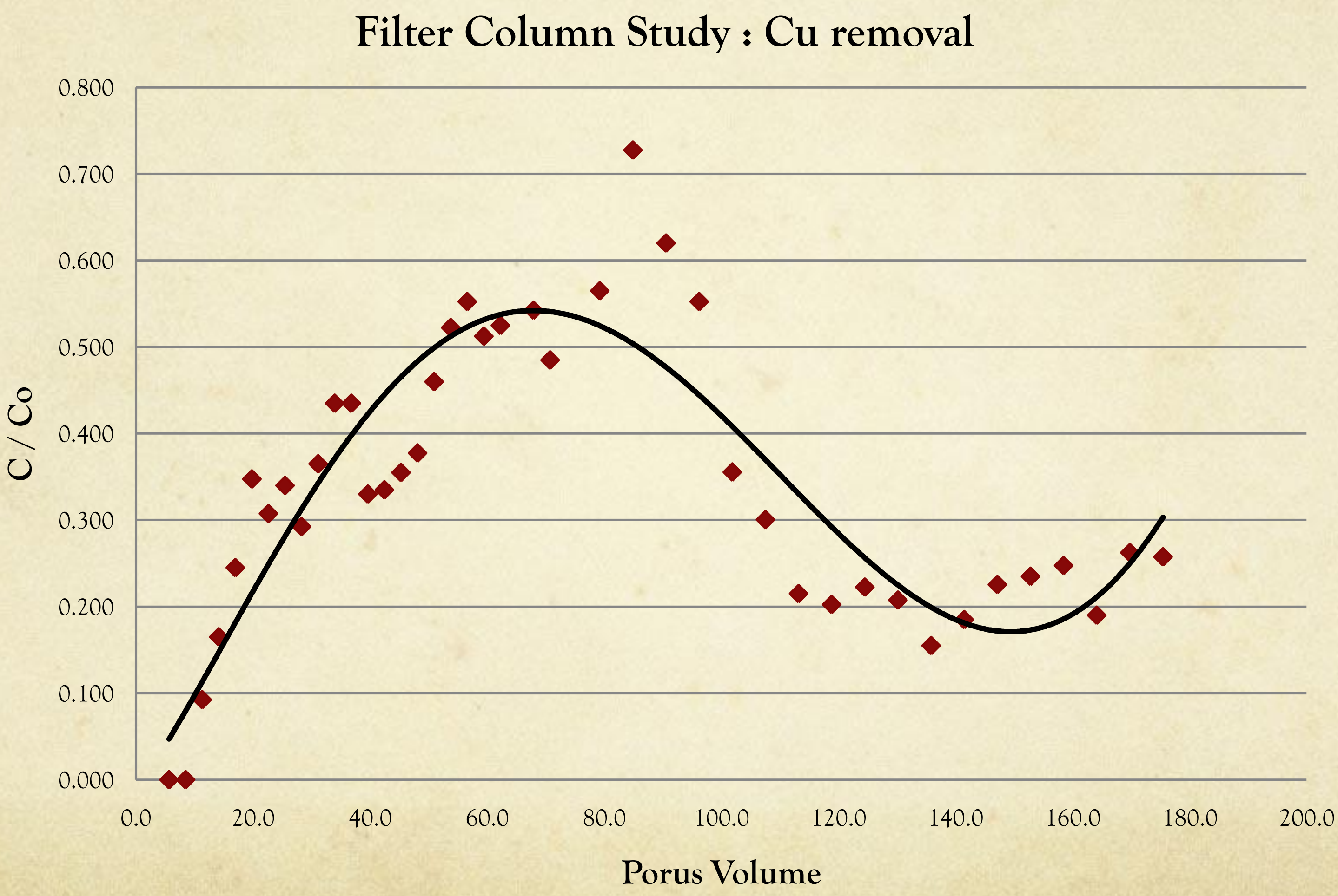
C = Concentration measured after filter
Co = Initial concentration (40mg/l)

Porus Volume = amount of water that went through the filter porus volume

- Filter volume = 50ml
- Porosity = 0.53
- Porus space = 26.5ml
- Flow rate = 2.5 ml/min
- pH = 4

Porus volume = (Flow rate * Time) / Porus space

Copper removal



Lead removal

Time (hours)	C (mg/l)
1	0
1.5	0
2	0
2.5	0
3	0
3.5	0
4	0
4.5	0
5	0
5.5	0
6	0
6.5	0
7	0
7.5	0
8.0	0
8.5	0
9.0	0

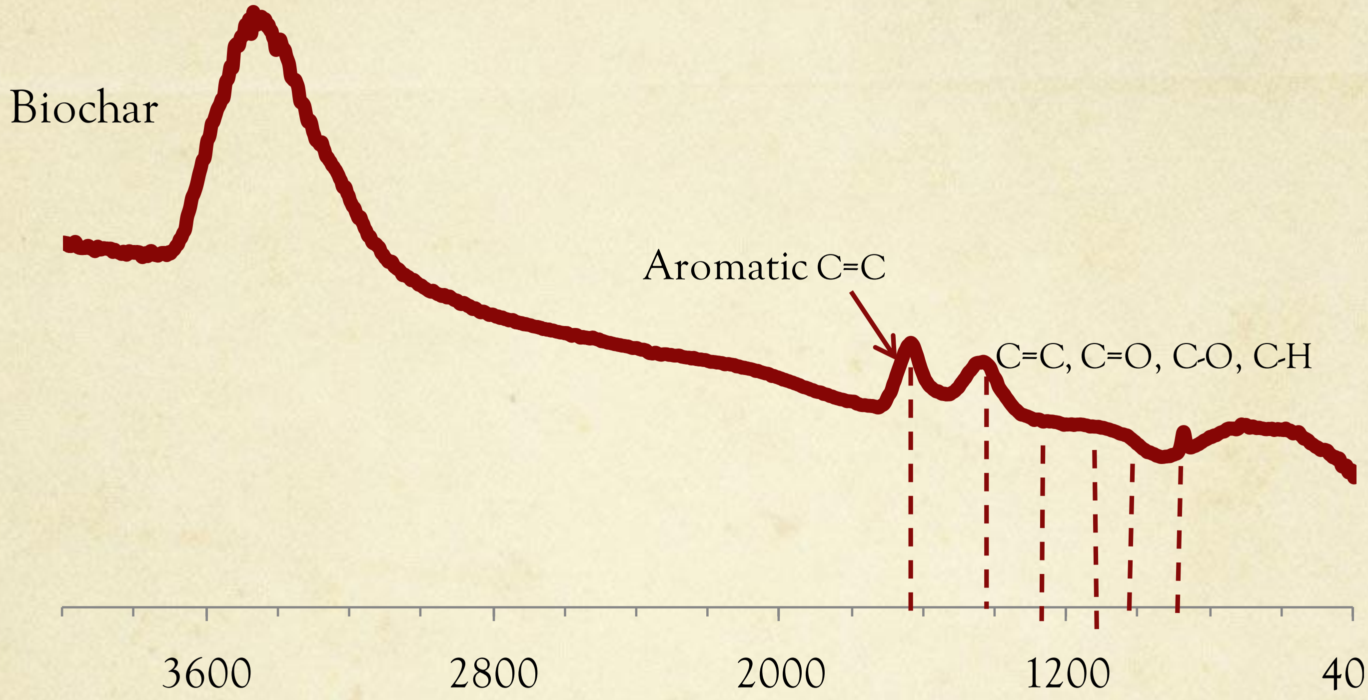
After 9 hours of sampling no lead was detected after filtration.

Experiment is still running

C= 0 even after 48 h

Why biochar worked so well?

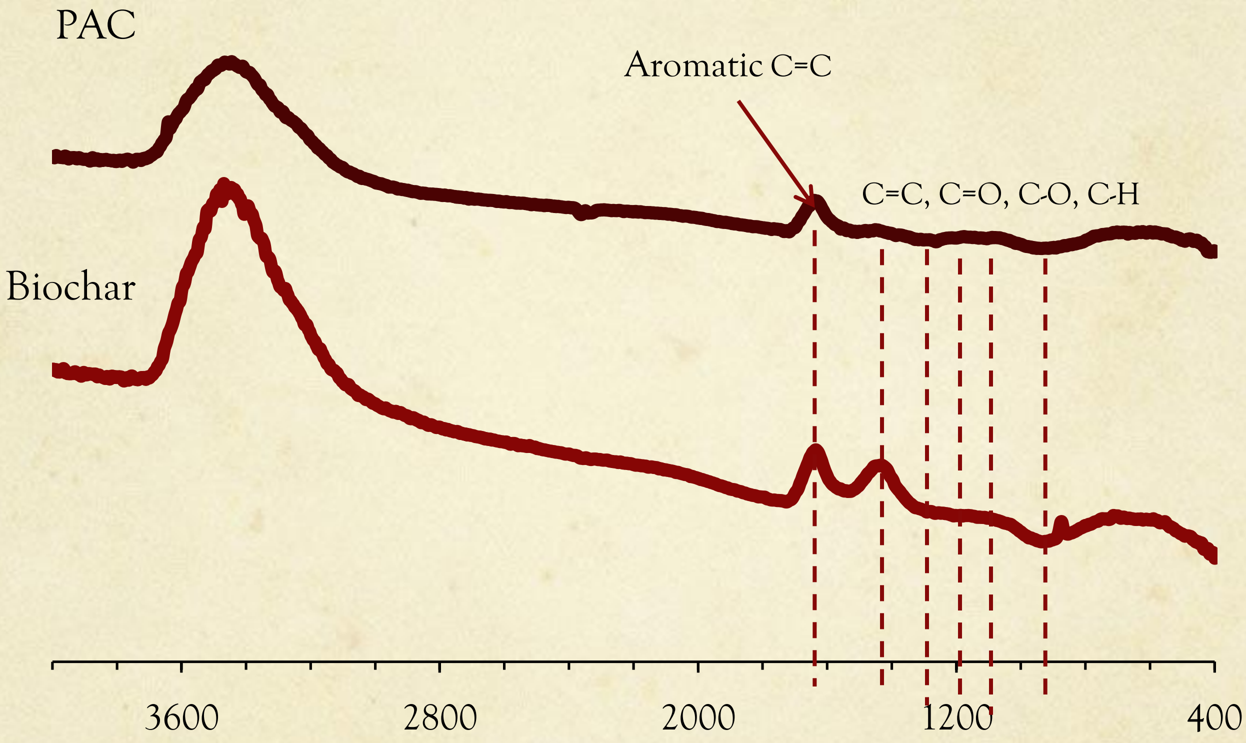
FTIR



- Presence of oxygen containing functional groups such as carboxyl (-COOH), lactone (C=O) and hydroxyl groups

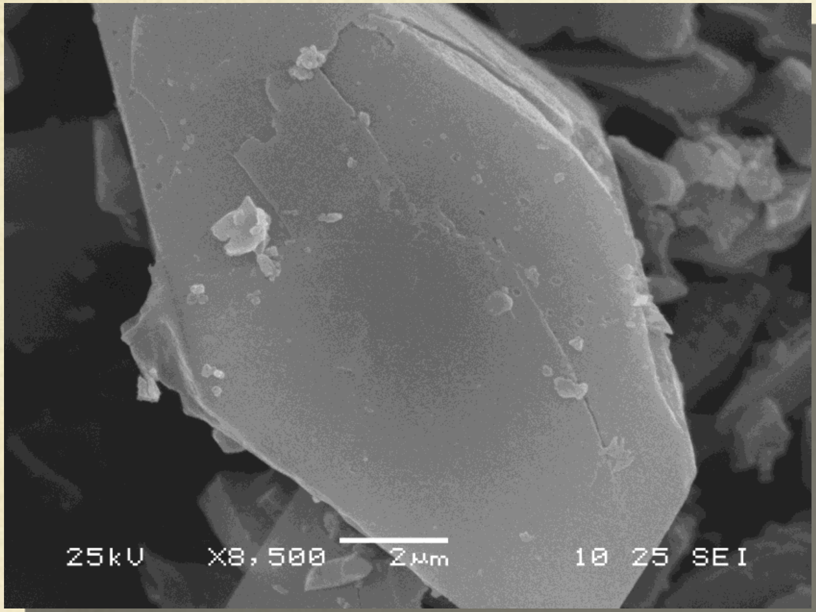
Including Powdered Activated Carbon

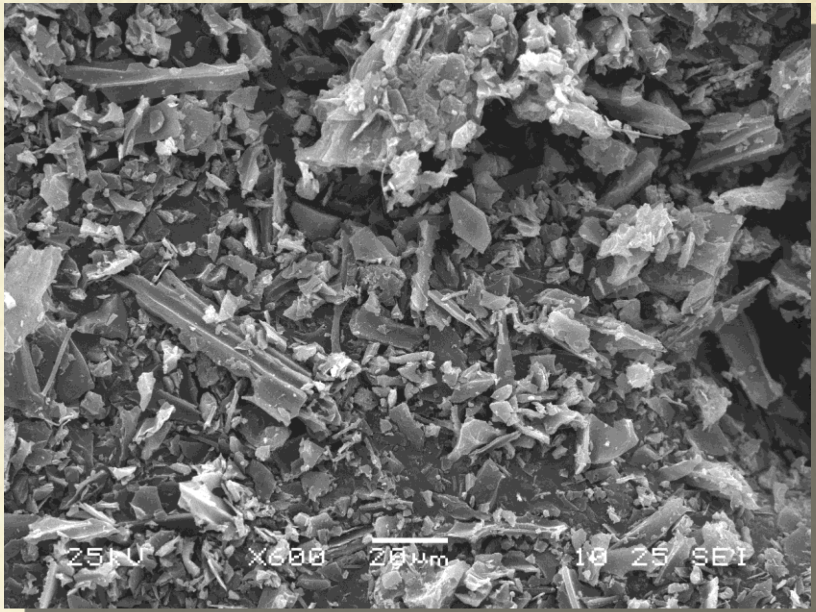
(Calgon WPH)



- Lack of oxygen containing functional groups in PAC

Biochar surface





	Biochar	PAC (Calgon WPH)
BET surface area	**70 m²/g**	726 m²/g

- Irregular surface with high BET surface area (not seen high temperature as in PAC)

Biochar Sorbent Properties

- ✓ The presence of oxygen rich organic compounds on the biochar surfaces adds substantial cation exchange capacity.
- ✓ Reported to adsorbs dissolved organic compounds from the soil solution and make them less bioavailable.
- ✓ High molecular weight polycyclic aromatic hydrocarbons (PAH) have been reported to be sorbed strongly to biochar surfaces.
- ✓ Biochar produced at higher temperature have benefits of high pH, cation exchange capacity, and surface area.

http://www.biochar-international.org/biochar

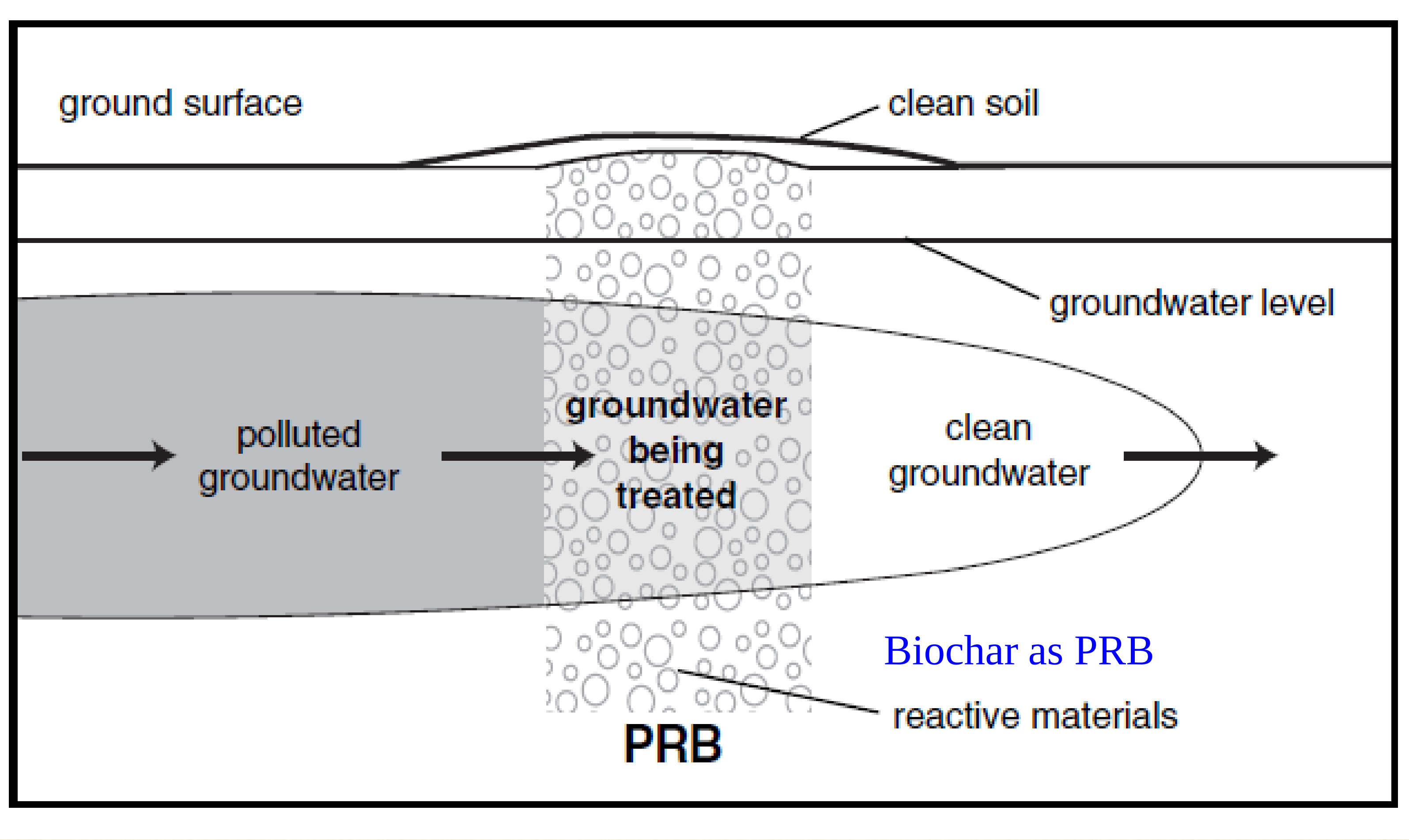
Biochar potential applications

Filter water

- Ground water
- Stormwater applications (BMPs)
- Industrial wastewater

Possible Treatment Applications Using Biochar as Sorbent

Biochar as a permeable reactive barrier (PRB) in groundwater treatment



Schematic of groundwater treatment using PRB system.

(Source: *www.**epa**.gov/tio/download/**citizens**/cit**prb**.pdf*)

Stormwater Applications

Intercepting storm water flow through the biochar bed

Types of BMPs and proposed biochar application:

i. **Infiltration Trenches / Basins:**

Proposal: Biochar bed are proposed to be laid over the stones. This may reduce the groundwater contamination by working as a filtration medium.

ii. **Detention Basins / Ponds :**

Proposal: Lay down a bed of biochar covered with sand / gravel to stop contaminants going to the ground water.

Similar applications of biochar are proposed in (iii) Retention Basins / Ponds (iv) Grassed Swales, and (v) Filter Strips and Buffers types of BMPs around Hampton

Covering the edges of the lawn and garden using biochar, sand and gravel mix

Ref: http://www.hrstorm.org/BMP.shtml

Conclusion

- Small scale community based slow pyrolyzer may be a cost-effective option to produce biochar from mixed biomass residue
- Biochar derived from mixed biomass residue can be used as sorbent for water contamination removal and cleaning up waterways
- Trace metal contaminants such as copper, cadmium and lead were almost completely removed by the bichar
- Lead was most amenable to treat with biochar

  Even at 0.5 g/L in 30 mins >99% removal was observed

- To understand the amenability of biochar to treat metal several analysis are being performed

Acknowledgement

- Daren Robinson at Hampton's Community Development Department
- Master Gardeners associated with community biochar project at Hampton
- Office of Research at ODU