

# Local Biochar Adsorbent for Control of Herbicide in Surface Water: Laboratory Experiments and Field Experiences

Josh Kearns, Detlef Knappe, R Scott Summers

**Josh Kearns**, ABD [ PhD expected Dec. 2016 ]

Environmental Engineering, University of Colorado-Boulder

Visiting Researcher, North Carolina State University

Director of Science, Aqueous Solutions

joshua.kearns@colorado.edu | josh@aqolutions.org

(+1) 720.989.3959 | josh-kearns.info



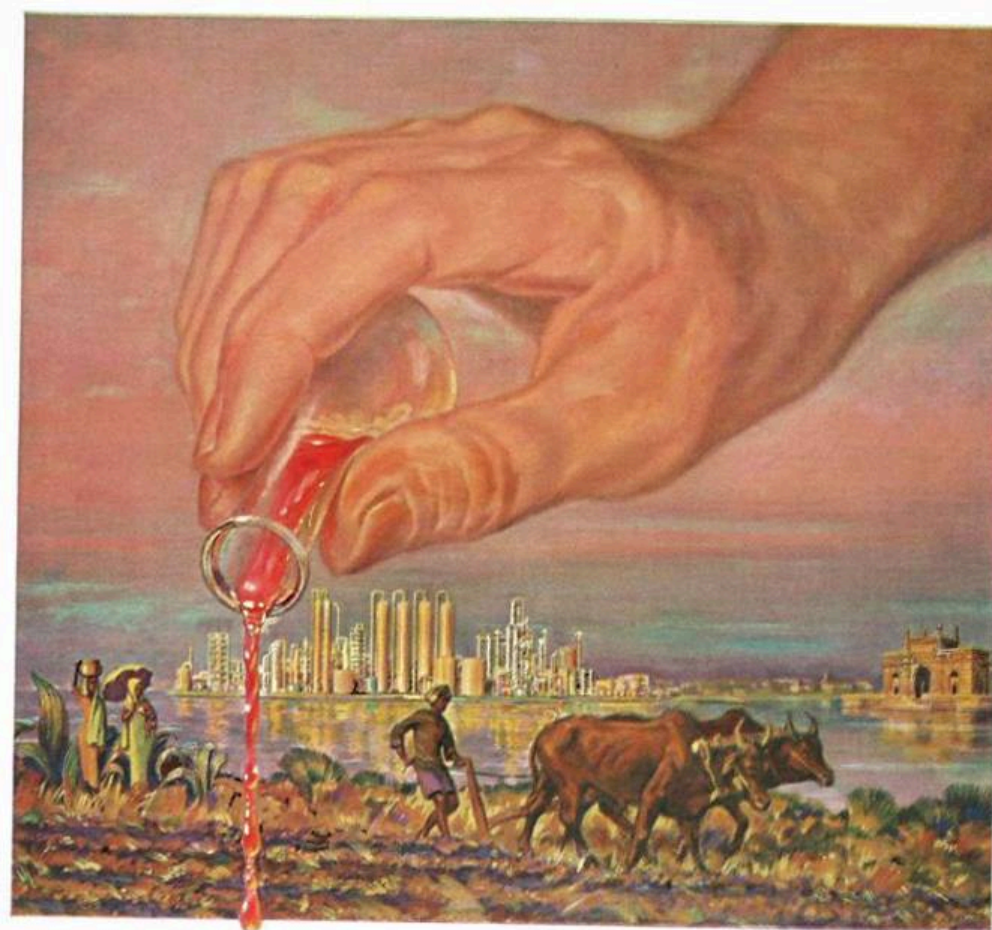
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Advancing the Science of Self-reliance

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## pesticides, herbicides...

- Estimates ranging from 2.4 – 5 million tonnes of pesticide active ingredients used annually, which “constitute a major impairment to water quality on a global scale.”
  - Weiss et al., 2016, Eawag.
  - Schwarzenbach et al., 2006, *Science* 313, 1072.
  - Stehle and Schulz, *PNAS*, 2015.
- “Pesticide pollution” appears twice in the Top Ten in *The World’s Worst Toxic Pollution Problems Report*.
  - Blacksmith Institute/Green Cross Switzerland, 2011
- “In developing countries, exceedances of regulatory levels for pesticides in surface waters significantly more frequent than in affluent countries. In contrast to trends in affluent countries, exposure risks are increasing in developing countries due to increased use and simultaneously weak or nonexistent regulation schemes.”
  - Stehle and Schulz, *PNAS*, 2015.
- Around 75% of the pesticides used in S/SE Asia are banned or heavily restricted in the West due to ecological and human health effects
  - Pesticide Action Network, 1997



### Science helps build a new India

Oxen working the fields . . . the eternal river Ganges . . . jeweled elephants on parade. Today these symbols of ancient India exist side by side with a new sight — modern industry. India has developed bold new plans to build its economy and bring the promise of a bright future to its more than 400,000,000 people. ▶ But India needs the technical knowledge of the western world. For example, working with Indian engineers and technicians, Union Carbide recently made available its vast scientific resources to help build a major chemicals and plastics plant near Bombay. ▶ Throughout the free world, Union Carbide has been actively engaged in building plants for the manufacture of chemicals, plastics, carbons, gases, and metals. The people of Union Carbide welcome the opportunity to use their knowledge and skills in partnership with the citizens of so many great countries.

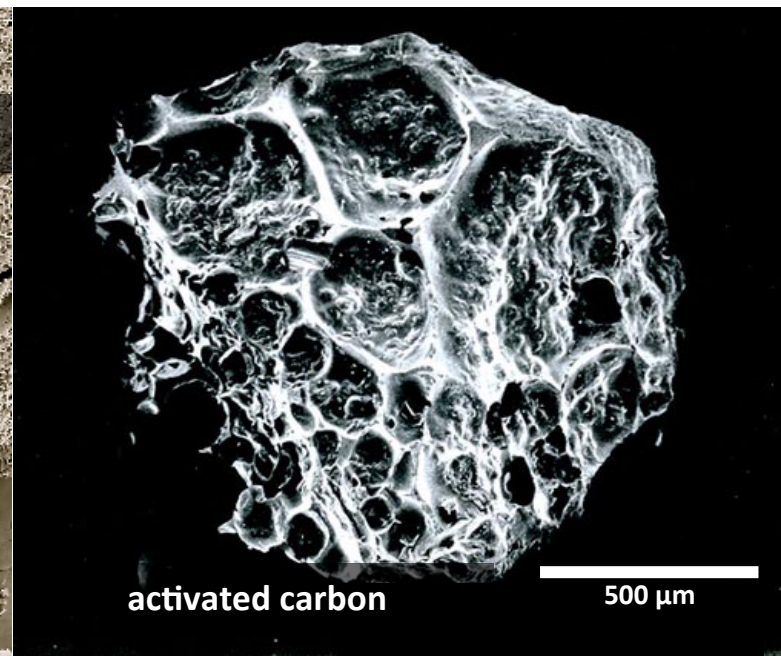
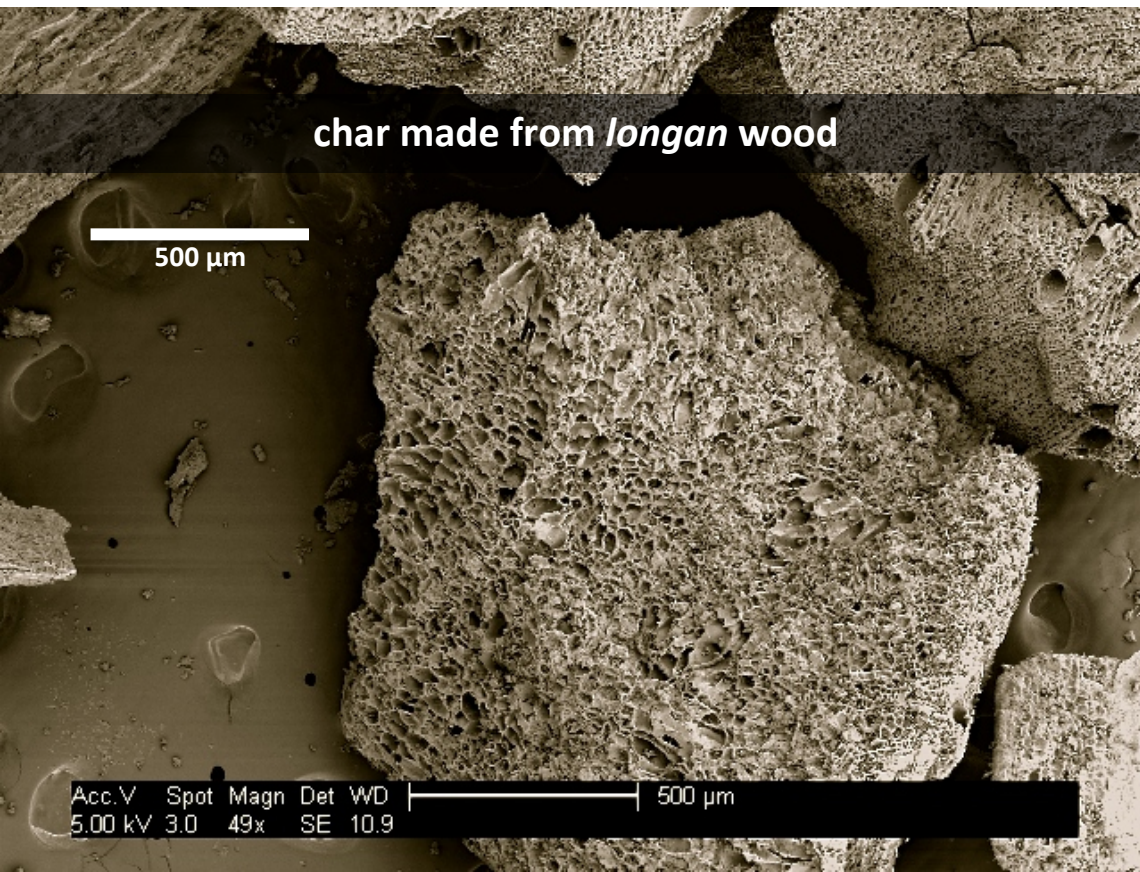
WRITE for booklet B-11 "The Exciting Universe of Union Carbide" which tells how research in the fields of carbons, chemicals, gases, metals, plastics and nuclear energy keeps bringing new wonders into your life.

1962 Union Carbide Ad in Scientific American New York 17, N.Y.

UNION  
CARBIDE

## General Hypothesis:

Locally produced chars could be effective adsorbents because they possess structure and properties similar to activated carbon.



## ancient / traditional methods of char production...



Fired for several days up to 1 week

Peak temperature 350-600 °C

Zonal differences up to ~ 300 °C during heating phase, ~ 150 °C peak



Fired for ~ 8 hrs

Peak temperature 550-750 °C

Zonal differences up to ~ 200 °C during heating phase, ~ 100 °C peak

**Based on traditional kiln charcoals produced from eucalyptus, pine, and longan woods, and bamboo:  
We developed a protocol for generating lab furnace chars from these feedstocks as effective proxies for  
traditional kiln/retort chars from a sorption perspective**

# household and village-scale adsorbent biochar generation...



gasifier cookstove



gasifier drum oven



*Constructed using surplus drums,  
scrap metal, and common hand  
tools – no electricity needed!*

natural draft (ND)  
625 ± 25 °C

forced draft (FD)  
875 ± 75 °C

pine pellets  
bamboo pieces  
cherry pits  
pecan shells (~750 °C)  
bagasse pellets  
jatropha pellets

pine pellets  
bamboo pieces  
cherry pits  
pecan shells  
rice husk (? °C)

natural draft (ND)  
750-800 °C

chopped bamboo  
corncobs

natural draft (ND)  
850-900 °C

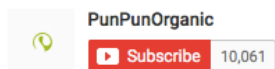
chopped eucalyptus

forced draft (FD)  
850-900 °C

hardwood pellets (HWP)



## พันความรู้ 01 : เผาถ่านไร้ควันกับพีโจน จันได (English Sub)



301,248 views

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Published on Sep 28, 2013

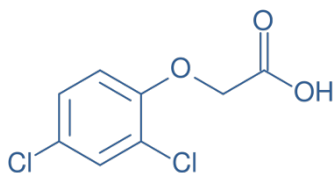
เมื่อก่อนเราเผาถ่านกัน ต้องสร้างเตาเผาถ่านวันวาย เเผาครั้งนึงใช้เวลานานแถมควันเยอะ  
วันนี้เรามีวิธีเผาถ่านแบบใหม่ ประหยัด ใช้เวลาน้อย ไร้ควัน แถมได้ถ่านคุณภาพสูงกว่าด้วย  
ลองดูกันนะ

(as of Oct-10-16)

# Sorption of select organic water contaminants by biochars...

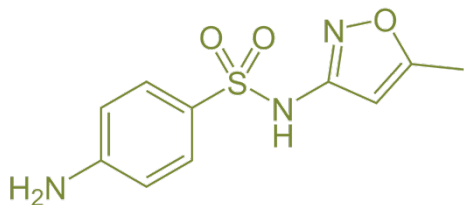
Probe compound selection criteria  
from a water treatment perspective:

- environmental relevance
  - heavily used, widely occurring, recalcitrant
- negative human health impact
- impair water aesthetics
- difficult to remove

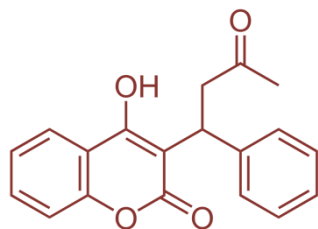


**2,4-D**

herbicide  
possible carcinogen,  
suspected endocrine  
disruptor  
USEPA MCL 70 µg/L  
WHO Guideline 30 µg/L  
pK<sub>a</sub> 2.7

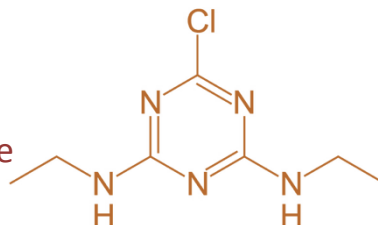


**sulfamethoxazole (SMX)**  
antibiotic (humans and livestock)  
pK<sub>a</sub> 5.6



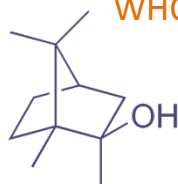
**warfarin (WFN)**

anticoagulant, rodenticide  
pK<sub>a</sub> 5.1



**simazine (SZN)**

herbicide, (neutral)  
USEPA MCL 4 µg/L  
WHO Guideline 2 µg/L



**2-methyl isoborneol (MIB)**

cyanobacteria metabolite  
not a health concern  
musty taste & odor at >10 ng/L

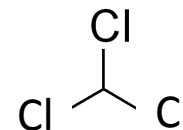
## trihalomethanes (THMs)

disinfection by-products (DBPs)

USEPA MCL 80 µg/L total THMs (TTHMs)

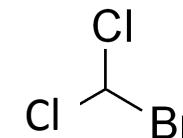
### chloroform

probable carcinogen



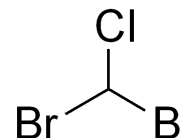
### BDCM

probable carcinogen



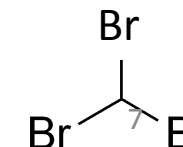
### CDBM

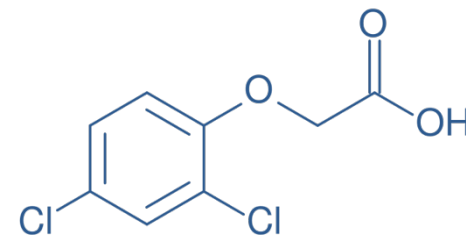
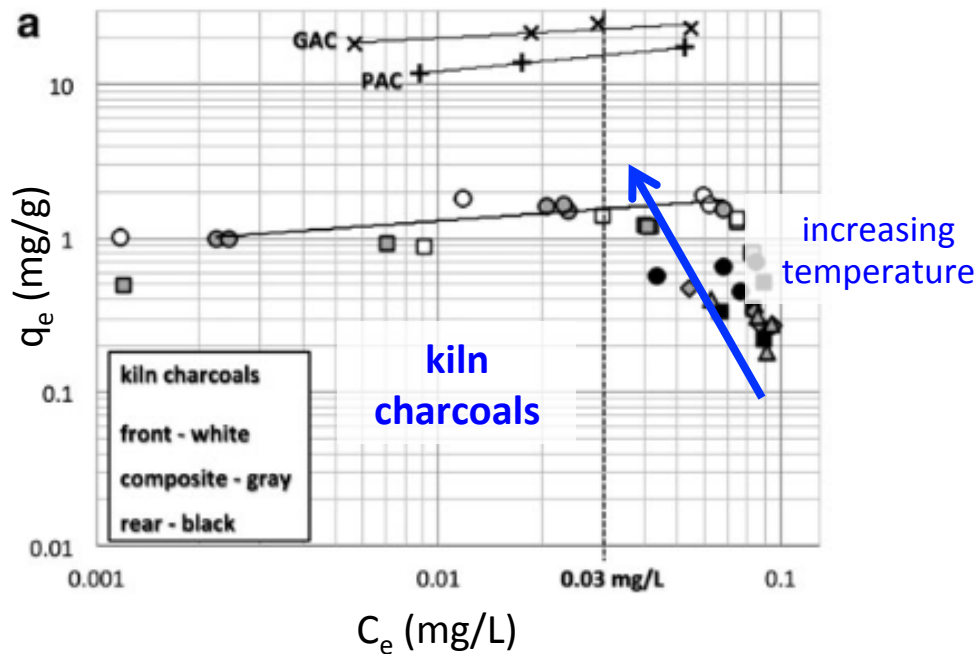
possible carcinogen



### bromoform

probable carcinogen





## BATCH TESTS

2,4-D herbicide  
surface water

100  $\mu\text{g/L}$   
pH 7, 4 mg/L TOC

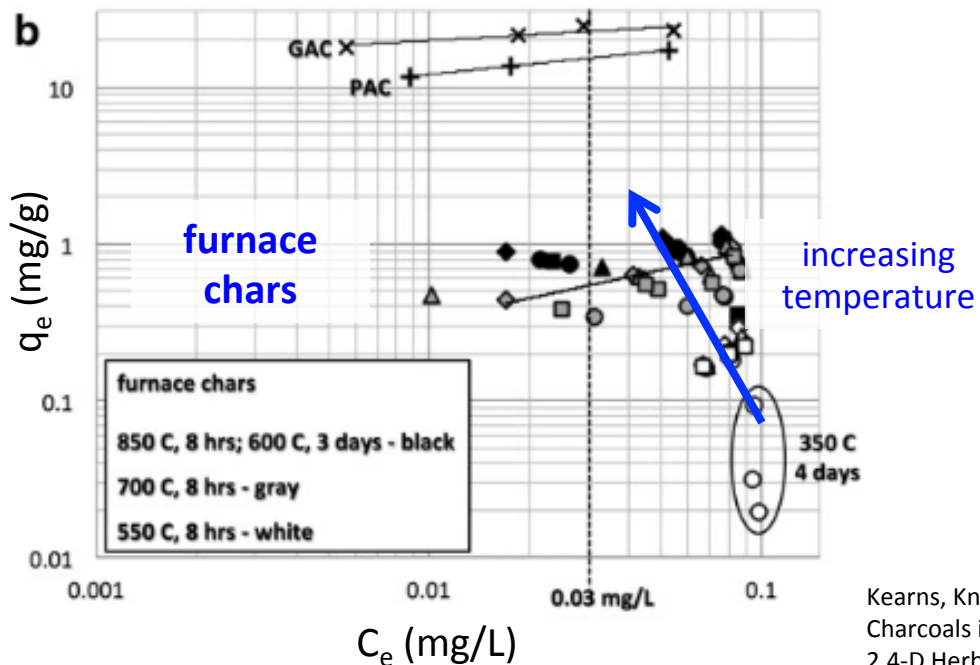
## KEY POINTS:

Did not observe a strong effect of feedstock for the materials studied (eucalyptus, *longan*, pine woods; bamboo)

2,4-D adsorption  $\uparrow$  as pyrolysis temperature or duration  $\uparrow$

Furnace good approximation for kiln

Low to modest adsorption capacity compared with commercial AC



## KEY POINTS

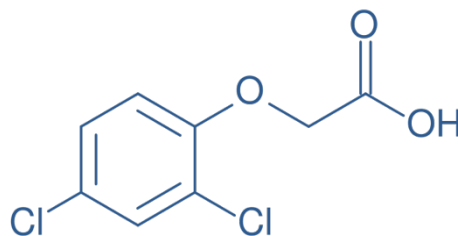
Did not observe a strong effect of feedstock for the materials studied

2,4-D adsorption  $\uparrow$  as pyrolysis temperature  $\uparrow$

Scalable: cookstove  $\rightarrow$  drum oven  $\rightarrow$  beyond?

High temperature + high draft chars performed nearly as well as commercial ACs

[ manuscript in preparation... ]



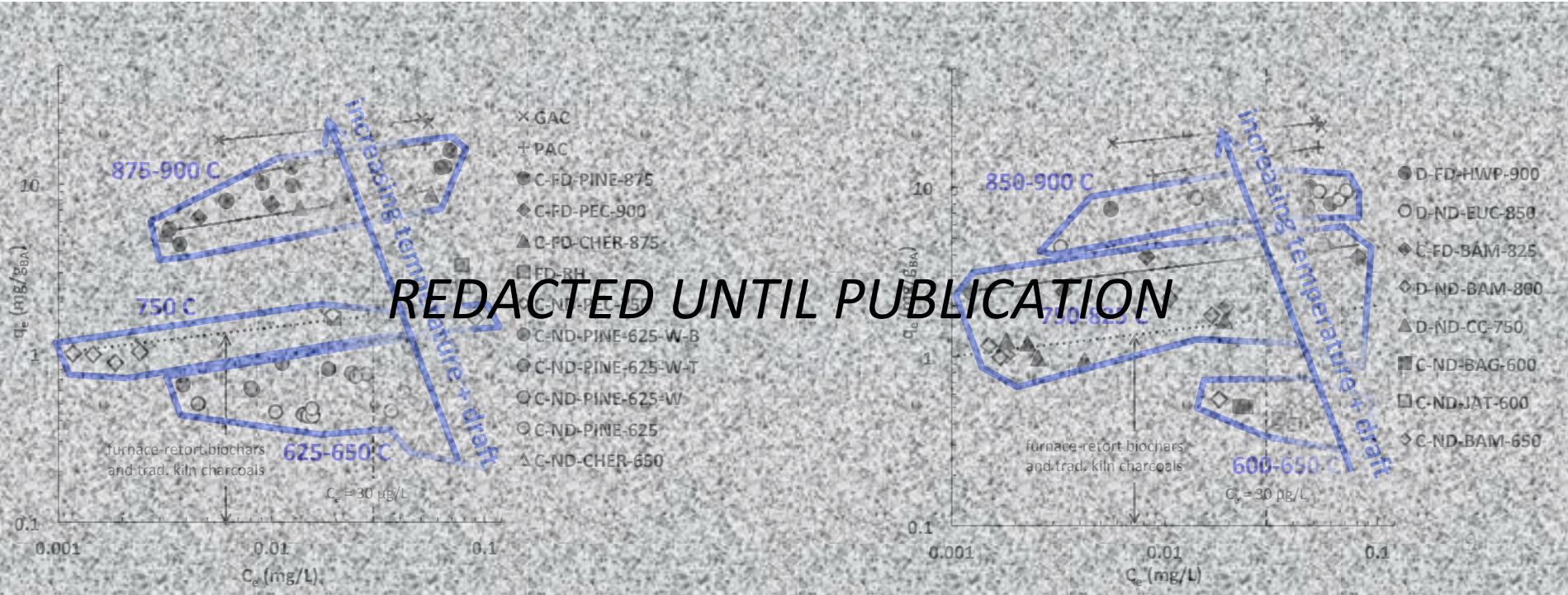
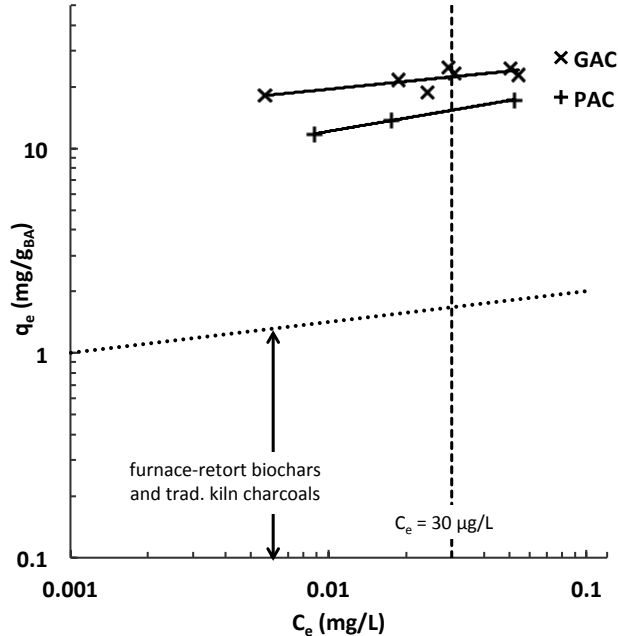
## BATCH TESTS

2,4-D herbicide

100  $\mu\text{g/L}$

surface water

pH 7, 4 mg/L TOC

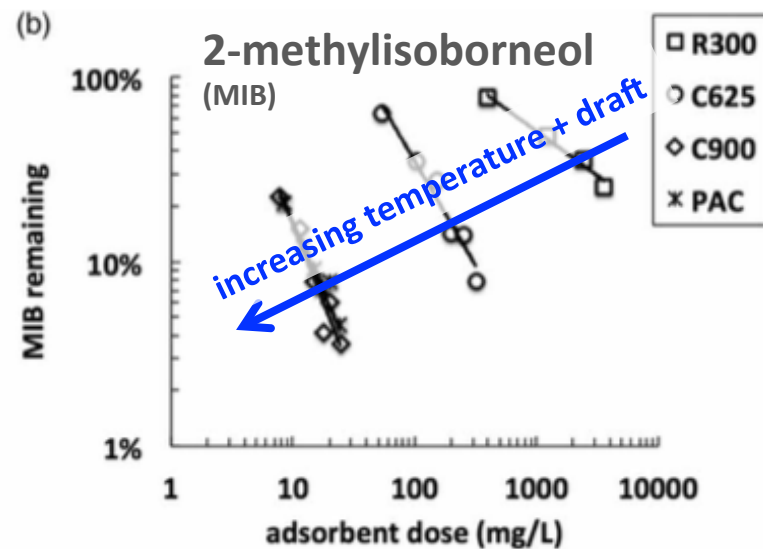
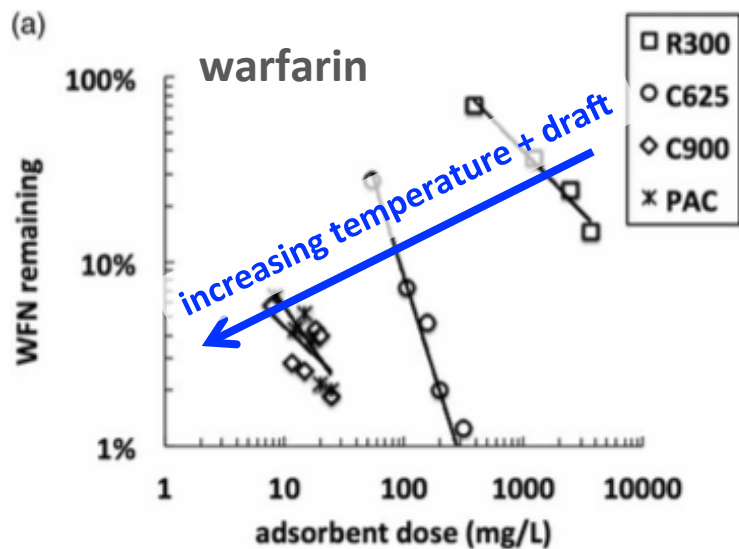
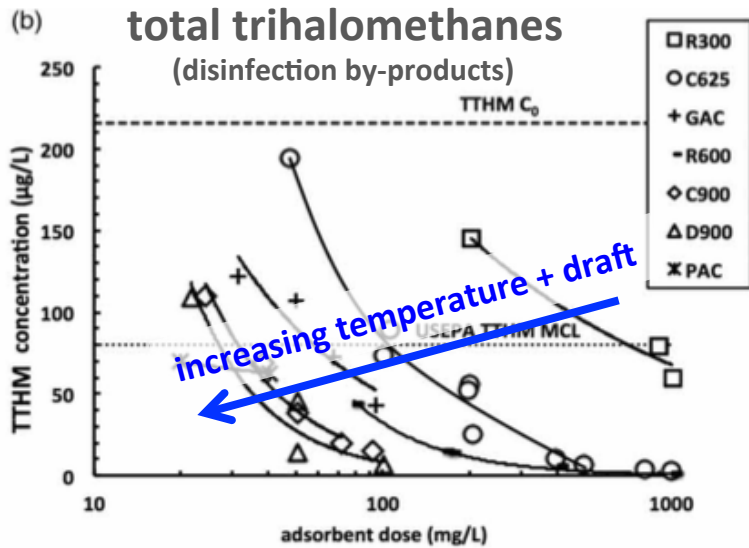
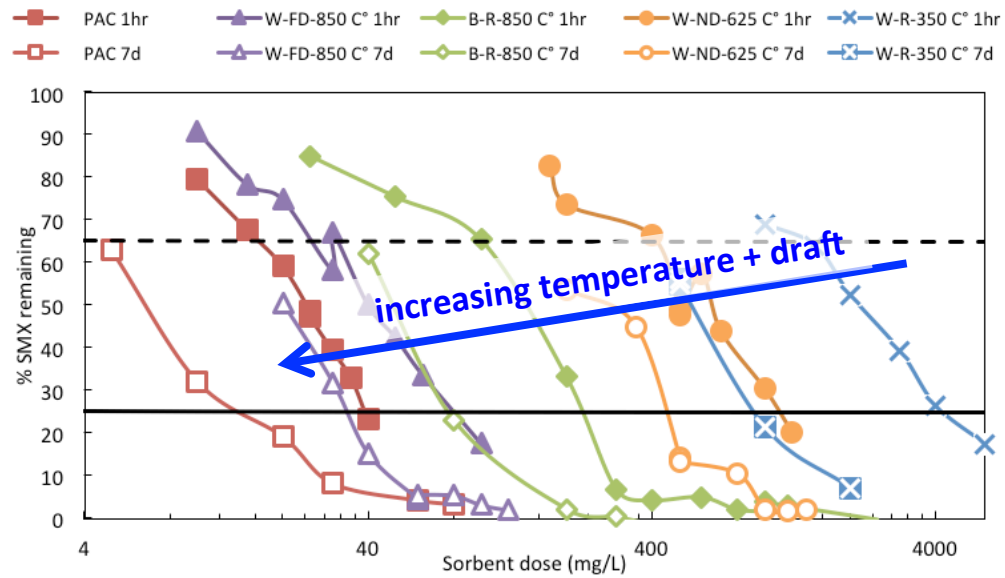


Shimabuku, Kearns, Martinez, Mahoney, Moreno-Vasquez, Summers. 2016. Biochar sorbents for sulfamethoxazole removal from surface water, stormwater, and wastewater effluent. *Water Research*, Vol. 96, pp. 236-245.

Thompson, Shimabuku, Kearns, Knappe, Summers, Cook. 2016. Environmental Comparison of Biochar and Activated Carbon for Tertiary Wastewater Treatment. *ES&T*, Oct. 2016.

Thompson, Shimabuku, Kearns, Knappe, Summers, Cook. 2016. Environmental Comparison of Biochar and Activated Carbon for Tertiary Wastewater Treatment. *ES&T*, Oct. 2016.

## sulfamethoxazole (surface water, storm water, wastewater)

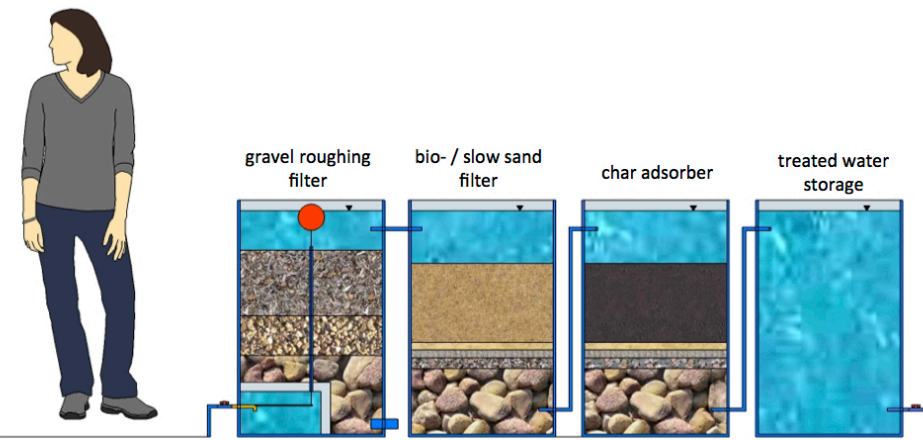


Kearns, Shimabuku, Mahoney, Knappe, Summers, 2015. Meeting multiple water quality objectives through treatment using locally generated char: improving organoleptic properties and removing synthetic organic contaminants and disinfection by-products. *J WASH DEV*. Vol. 5 Is. 3. pp. 359 -372.

# R&D with villagers in SE Asia → designs for biochar water treatment systems

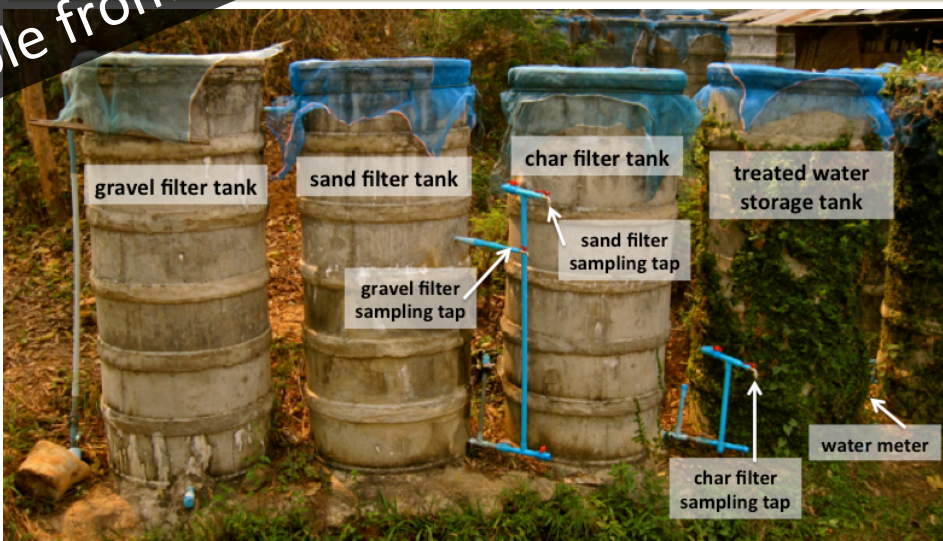
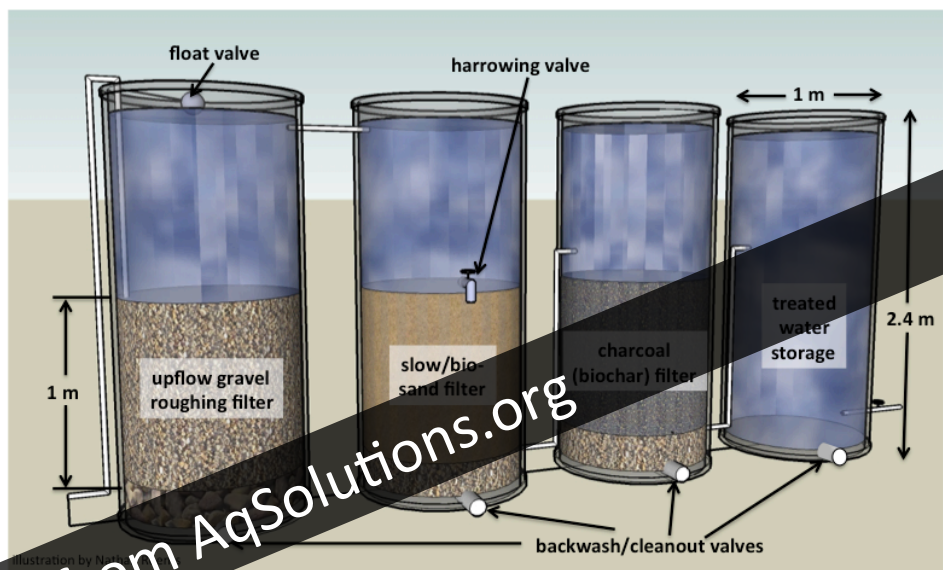
## portable treatment system

throughput	300 L/day
biochar bed life	1 year
approx. cost for 10 years' service	\$750
	\$250 capital <sub>(materials + labor)</sub>
	\$500 O/M <sub>(materials + labor)</sub>



## concrete tank system

throughput	2,000 L/day
biochar bed life	2 years
approx. cost for 10 years' service	\$1500
	\$500 capital <sub>(materials + labor)</sub>
	\$1000 O/M <sub>(materials + labor)</sub>



Pore diffusion modulus (Ed)	$Ed = \frac{4LD_gD_L\varepsilon}{d_p^2v_f\tau}$	Intraparticle mass transfer
Stanton number (St)	$St = \frac{2k_fL(1-\varepsilon)}{d_p v_f}$	Ratio of film mass transfer to advection
Peclet number (Pe)	$Pe = \frac{v_f L}{D_L \left[ 0.67 + 0.5 \left( \frac{d_p v_f}{\varepsilon D_L} \right)^{1.2} \right]}$	Ratio of advection to axial dispersion
Pore solute distribution parameter (Dg)	$Dg = \frac{\varepsilon_p(1-\varepsilon)}{\varepsilon}$	Local equilibrium
Reynolds number (Re)	$Re = \frac{\rho_w v_f d_p}{\varepsilon \mu_w}$	Ratio of inertial to viscous forces
Schmidt number (Sc)	$Sc = \frac{\mu_w}{\rho_w D_L}$	Hydrodynamic layer mass transfer ratio
Biot number (Bi)	$Bi = \frac{k_f d_p \tau}{2D_L \varepsilon_p}$	Ratio of internal to external mass transfer

## Pore and Surface Diffusion Model

RSSCT design equation

$$\frac{EBCT_{SC}}{EBCT_{LC}} = \left[ \frac{d_{p,SC}}{d_{p,LC}} \right]^{2-X} = SF^{X-2}$$

SF = scaling factor  
X = diffusivity factor  
[X = 0 for CD]

large column (LC)

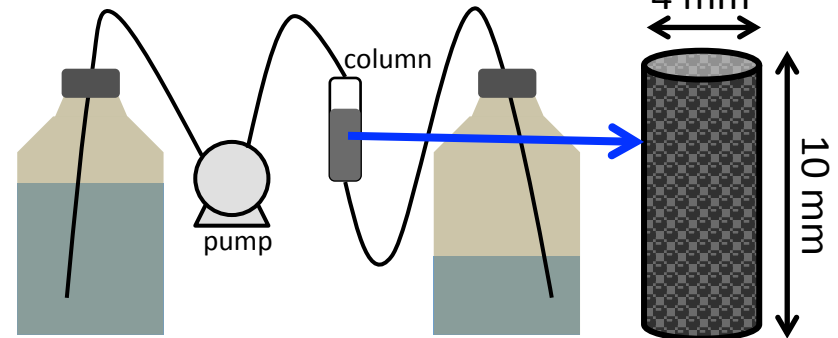
$$Q_{LC} = 300 \text{ L/day}$$

$$EBCT_{LC} = 8.2 \text{ hrs}$$

$$V_{bed LC} = 103 \text{ L}$$

$$d_{p LC} = 2.49 \text{ mm (5x1 mm)}$$

fixed-bed flow-through column tests



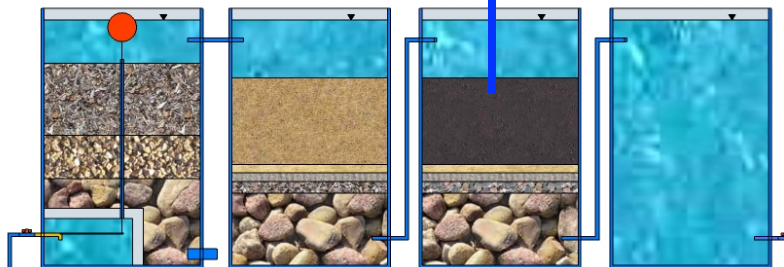
small column (SC)

$$Q_{SC} = 1.428 \text{ mL/min}$$

$$d_{p LC} = 0.108 \text{ mm}$$

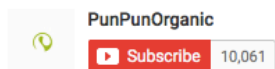
$$V_{bed SC} = 0.126 \text{ mL}$$

$$1 \text{ year}_{LC} \approx 1.5 \text{ hours}_{SC}$$





## พันควมรู้ 04 : คนเอาถ่าน.. มากรองน้ำ โดยพี่โจน จันได (English Sub)



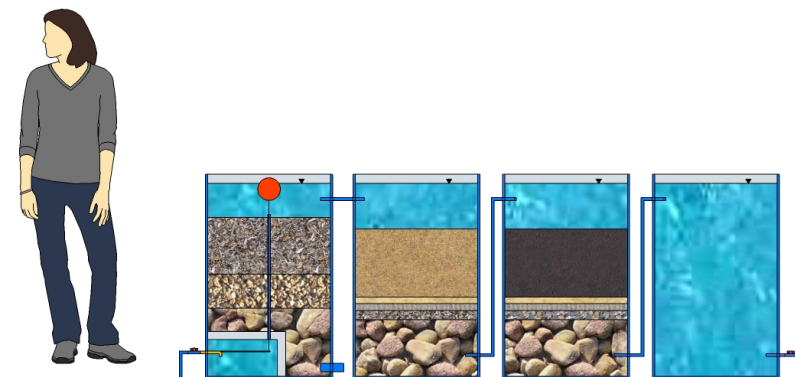
235,167 views

(as of Oct-10-16)

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Published on Jan 15, 2015

ทุกวันนี้ไม่ว่าจะซื้อหาอะไรก็จำเป็นต้องใช้เงินไปเสียหมด ไม่เว้นแม้แต่ น้ำบริสุทธิ์ที่เราจำเป็นต้องดื่มทุกวัน จะดีแค่ไหน ถ้าเราสามารถกรองน้ำดื่มได้เองทั้งครอบครัว ด้วยเครื่องกรองที่ผลิตจากวัสดุที่หาได้แถวบ้าน วิธีการทำง่ายแสนง่าย ที่สำคัญคือปลอดภัยได้มาตรฐานเหมือนเครื่องกรองที่ขายอยู่ทั่วไปเลยนะ



## Aq portable system

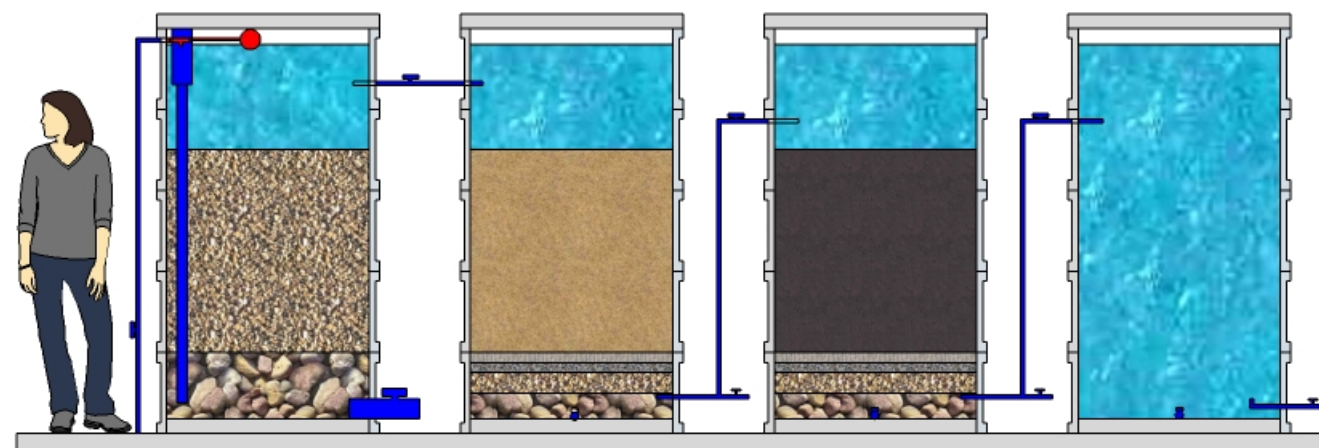
500 L/day

\$200 initial capital and labor costs

\$450 maintenance materials and labor for 10 years

\$100 capital & maintenance drum oven

**Total \$750**



*ROUGH COST  
ESTIMATES BASED ON  
PRICES IN THAILAND*

## Aq concrete tank system

2,000 L/day

\$500 initial capital and labor costs

\$900 maintenance materials and labor for 10 years

\$100 capital & maintenance drum oven


**Total \$1,500**

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Departments ▾ Fire & Kindle ▾ Recommended for Josh Today's Deals Gift Cards He

Sports & Outdoors Athletic & Outdoor Clothing Exercise & Fitness Outdoor Gear Hunting & Fishing Cycling C

Customers who viewed **Lifestraw Personal Water Filter...** also viewed



Sawyer Products Mini Water Filtration System  
Buy new: \$13.02 - \$116.99  
★★★★★ (854)



Emergency Mylar Thermal Blanket  
Buy new: \$6.99  
44 Used & new from \$5.99  
★★★★★ (1,640)

Sports & Outdoors › Outdoor Gear › Camping & Hiking › Hydration › Water Purifiers



Roll over image to zoom in

## LifeStraw Personal Water Filter

by LifeStraw

★★★★★ ▾ 1,880 customer reviews | 211 answered questions

List Price: \$25.00

Price: **\$19.95 & FREE Shipping** on orders over \$35

You Save: **\$5.05 (20%)**

**In Stock.**

Ships from and sold by Amazon.com. Gift-wrap available.

**Want it tomorrow, Nov. 19?** Order within **11 hrs 4 mins** and choose **One-Day Shipping** at checkout. [Details](#)

- Award-winning LifeStraw has been used by millions around the globe since 2005
- Removes minimum 99.9999% of waterborne bacteria (>LOG 6 reduction) and surpasses EPA standards for water filters
- Removes minimum 99.9% of waterborne protozoan parasites (>LOG 3 reduction) and filters to an amazing 0.2 microns
- Filters up to 1000 liters of contaminated water WITHOUT iodine, chlorine, or other chemicals
- Comes in a sealed bag, perfect for storing for emergencies

79 new from **\$19.35** 1 used from **\$17.83**



### Holiday Deals in Outdoor Gear

Beat the rush this holiday and score great deals on gifts for the outdoor lovers in your life. [Shop deals in Outdoor Gear.](#)

**\$20 retail, wholesale ???  
replacement after 700 L**

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Departments ▾ Fire & Kindle ▾ Recommended for Josh Today's Deals Gift Cards

Sports & Outdoors Athletic & Outdoor Clothing Exercise & Fitness Outdoor Gear Hunting & Fishing Cycling

Customers who viewed **LifeStraw Family 1.0 Water Pur...** also view



Lifestraw Personal Water Filter  
Buy new: \$19.35 - \$99.99  
★★★★★ (1,880)



Sawyer Product  
Buy new: \$13.00  
★★★★★ (1,880)



Sports & Outdoors > Outdoor Gear > Camping & Hiking > Hydration > Water Purifiers



## LifeStraw Family 1.0 Water Purifier

by LifeStraw

★★★★★ ▾ 134 customer reviews | 38 answered questions

List Price: \$89.95

Price: **\$74.95** & **FREE Shipping**

You Save: **\$15.00 (17%)**

**In Stock.**

Ships from and sold by Amazon.com. Gift-wrap available.

Want it tomorrow, Nov. 19? Order within **11 hrs 3 mins** and choose **One-Day Shipping** at checkout. [Details](#)

- Award-winning LifeStraw Family is used by over 13,200,000 people worldwide
- Surpasses EPA standards for water purifiers: removes 99.99% viruses, 99.9999% bacteria and 99.9% protozoan cysts to 0.02 microns
- Purifies 18,000 liters/4755 gallons WITHOUT iodine, chlorine, or other chemicals; Clean drinking water for a family of four for 3 years
- Gravity filter - pour water in the top and clean water comes out the bottom; Comes in a sealed bag, perfect for storing for emergencies
- Flow rate of 9 -12 liters per hour

12 new from **\$74.95** 3 used from **\$65.21**

**\$75 retail, \$30 "insider" wholesale replacement after 18,000 L**



### Holiday Deals in Outdoor Gear

Beat the rush this holiday and score great deals on gifts for the outdoor lovers in your life. [Shop deals in Outdoor Gear](#)



## The Safe Water System

### Safe Water System

Disease and SWS Impact

Household Water Treatment

Chlorination

► **Flocculant/Disinfectant Powder**

Solar Disinfection

Ceramic Filtration

Slow Sand Filtration

Safe Water Storage

Behavior Change Communications

Starting a SWS Project

CDC at Work: The Safe Water System

Publications and Research

Resources

[Safe Water System](#) > [Household Water Treatment](#)



## Flocculant/Disinfectant Powder

### Flocculant/Disinfectant Powder [2 pages]



A P&G™ sachet  
(Procter & Gamble)

The Procter & Gamble Company developed P&G Purifier of Water™ in consultation with the Centers for Disease Control and Prevention (CDC). P&G™ sachets are now centrally produced in Pakistan, and sold to non-governmental organizations (NGOs) worldwide at a cost of 3.5 US cents per sachet. The P&G™ product is a small sachet containing powdered ferric sulfate (a flocculant) and calcium hypochlorite (a disinfectant). P&G™ was designed to reverse-engineer a water treatment plant, incorporating the multiple barrier processes of removal of particles and disinfection. To treat water with P&G™, users open the sachet, add the contents to an open bucket containing 10 liters of water, stir for 5 minutes, let the solids settle to the bottom of the bucket, strain the water through a cotton cloth into a second container, and wait 20 minutes for the hypochlorite to inactivate the microorganisms.

*P&G sachets are now centrally produced in Pakistan and sold to NGOs worldwide for 3.5 US cents per sachet.*

*Each sachet treats 10 L of water.*

### On this Page

- [Effectiveness and Impact](#)
- [Benefits, Drawbacks, and Appropriateness](#)
- [Implementation Examples](#)
- [Economics and Scalability](#)
- [References](#)
- [Additional Resources](#)

### Related Links

[CDC Healthy Water](#)

[CDC Global Water, Sanitation, and Hygiene \(WASH\)](#)

[WHO Household Water Treatment and Safe Storage](#)

[WHO Water Sanitation and Health](#)

## Lab Effectiveness, Field Effectiveness, and Health Impact

The flocculant/disinfectant powder P&G™ has been proven to remove the vast majority of bacteria, viruses, and protozoa, even in highly turbid waters. P&G™ has also been documented to reduce diarrheal disease from 90% to less than 16% incidence in five randomized, controlled [health intervention studies](#). P&G™ also removes heavy metals—such as arsenic—and chemical contaminants—such as pesticides—from water. Studies showing the efficacy of P&G™ have been conducted for highly turbid water in the laboratory, in developing countries, in rural and urban areas, refugee camps, and include all age groups.



## ceramic pot filter

\$5 - \$25

20 L/day

replacement 1-2 years

Source: UNICEF/UN Water & Sanitation Program, 2007

*Use of Ceramic Water Filters in Cambodia*

[unicef.org/eapro/WSP\\_UNICEF\\_FN\\_CWP\\_Final.pdf](http://unicef.org/eapro/WSP_UNICEF_FN_CWP_Final.pdf)

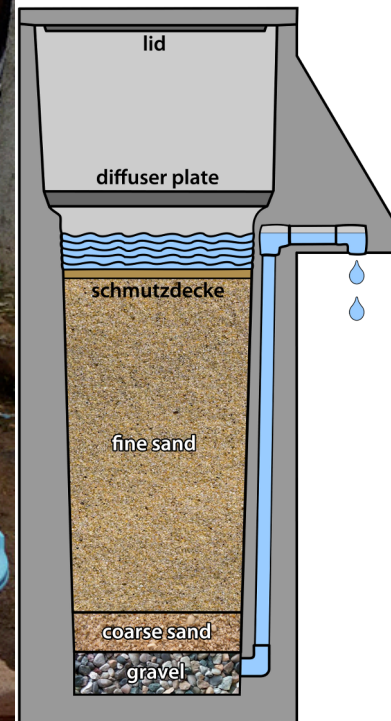
## “biosand” filters

\$15 - \$100

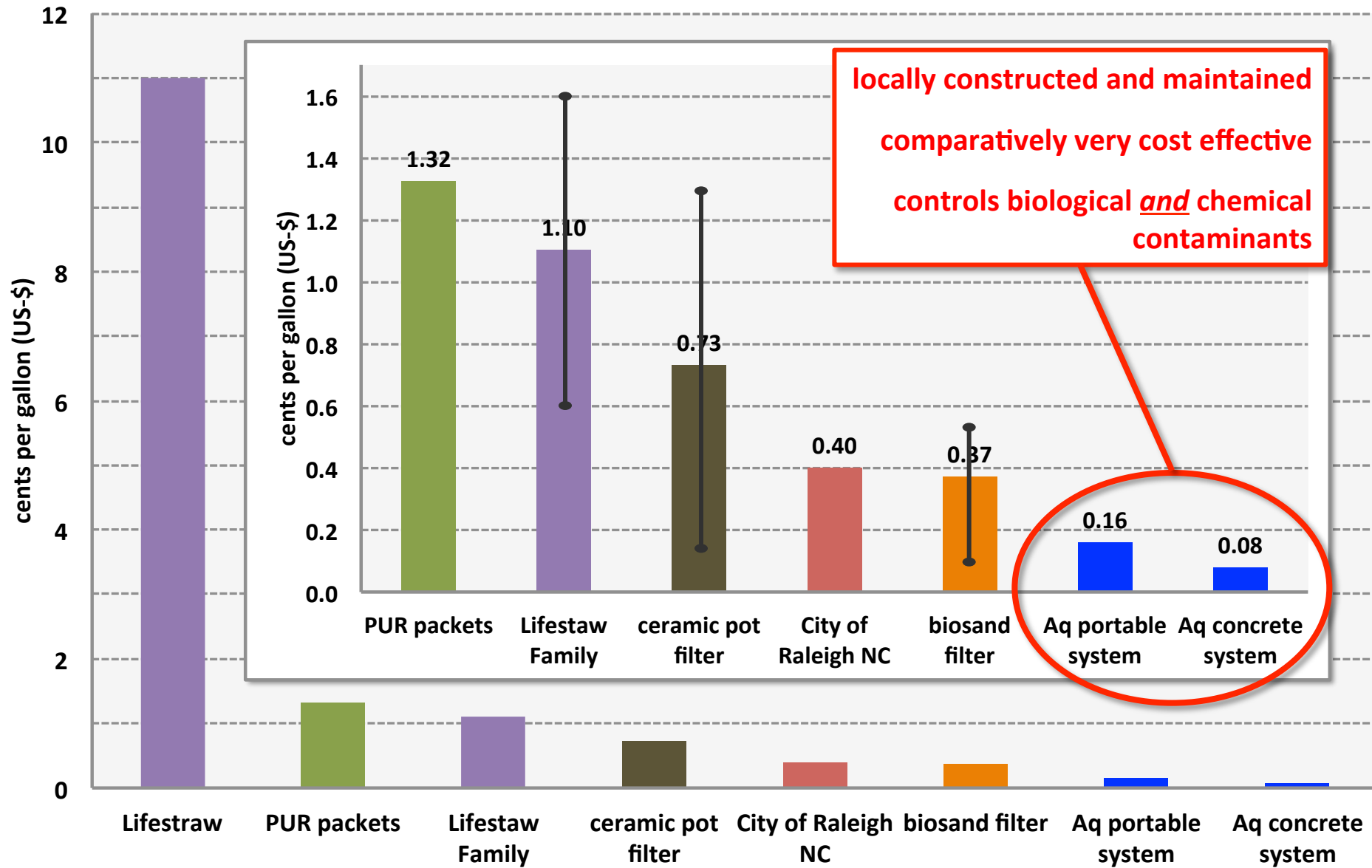
(average ~ \$70)

20 L/day

replacement  $\geq 10$  years



## approximate cost comparison of treatment technologies



# Thank you!

## Questions?

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**Josh Kearns**, ABD [ PhD expected Dec. 2016 ]  
Environmental Engineering, CU-Boulder  
Visiting Researcher, North Carolina State University  
Director of Science, Aqueous Solutions  
[joshua.kearns@colorado.edu](mailto:joshua.kearns@colorado.edu)  
[josh@aqolutions.org](mailto:josh@aqolutions.org)  
(+1) 720.989.3959 | [josh-kearns.info](http://josh-kearns.info)



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