

# Water Purification

*Low-tech domestic water treatment technologies*

*Dan Hettinger, April 2020*

# What we'll cover today

Microbial and chemical contaminants

Introduction to various lower-tech water treatment technologies

Activated Carbon trials

Multi-barrier approach to treating water

Capturing and filtering rainwater for potable use

## **What we won't cover:**

A review of commercially available 'Whole-House' water treatment systems

# Home Water Treatments

**Point-of-Use (POU) Water purification - Not centrally treated and distributed.**

**Scaled for families or individuals, generally not portable**

**Speaking generally to lower tech systems, not 'whole-house' installed systems**

Provide safe water where infrastructure otherwise does not exist

Huge potential for positive health impact in developing world

Resilience from natural disasters and other emergencies

Potential improvement on existing water supply

Low investment redundancy - Resilient systems!

# Potential sources for drinking water

**Surface** Sources: Rivers, Lakes, Reservoirs - Pathogens, contaminants from runoff

**Ground** Sources: Aquifers, Wells - Chemical and mineral contaminants, Pathogens

**Rain** Water: Contaminants from roof runoff, pathogens in stored water, nitrates

**Saline** sources - Brackish or Ocean water - Salt, *halotolerant* pathogens, chemical contaminants

## Point-of-Use Purification

**Flocculation**

**Fiber Filtration**

**UV and SODIS**

**Heat Treatment**

**Granular Media**

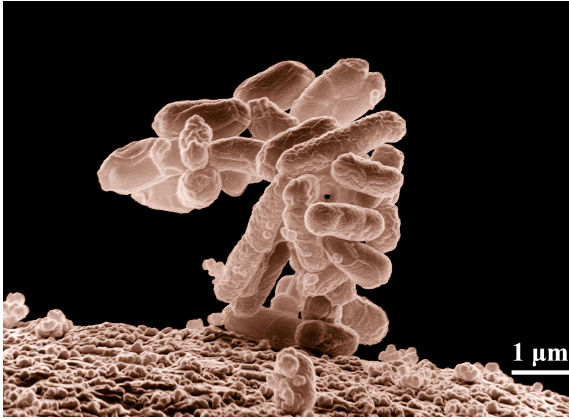
**Activated Carbon**

**Chemical Sterilization**

**Reverse Osmosis**

**Silver**

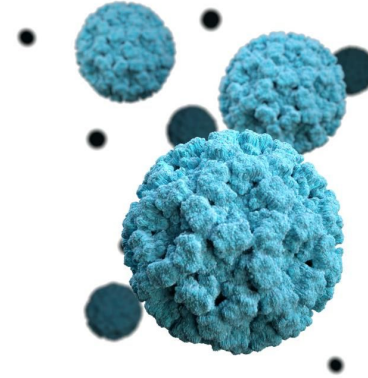
# Microbial Contaminants



**Bacteria:** Enterotoxigenic E.Coli

Cause of severe diarrheal illness

Requires controlled filtration, ensure  
with post filtration treatment

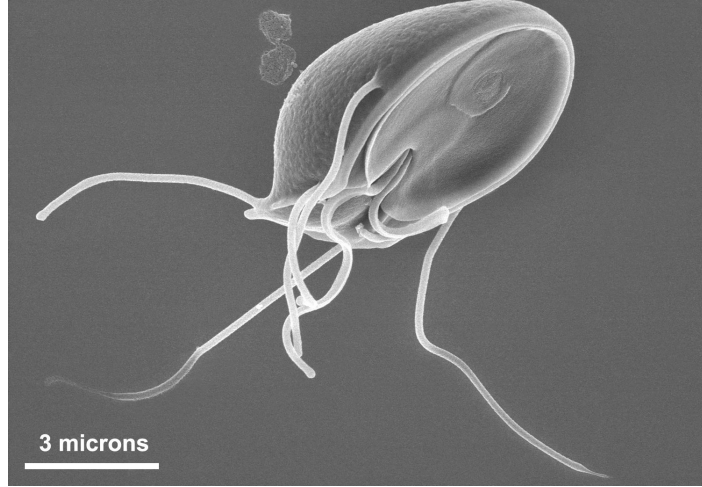


**Viruses:** Norovirus

Most viruses are extremely small, very difficult to  
filter if free floating

Reliably controlled only with post filtration  
treatments

# Microbial Contaminants



**Protozoa: *Giardia***

Causes diarrheal illnesses

Transmitted in water contaminated with animal feces

Has high chlorine tolerance



**Helminths (worms): *Schistosomes***

Complex life cycle. Transmitted via skin contact, eggs lodge in intestinal tract.

Can grow up to 1 cm long

Common among tropical areas

# Chemical Contaminants

**Arsenic** - Naturally occurring in well water in many countries around the globe, most notably Bangladesh. Long term exposure to skin disorders, various cancers. Treat with oxidation and iron.

**Fluoride** - Naturally occurring in groundwater sources throughout the world. Used to treat dental decay in small amounts, a cause of severe tooth and bone problems with prolonged exposure. Specialized treatments for removal include Bone Charcoal, among others.

**Iron** - Non-toxic, nuisance mineral that can be treated via settling and decanting, filtering through cloth or sand filter.



Severe Fluorosis

# Chemical Contaminants

**Lead** - from old plumbing, fixtures and supply lines. Exposure leads to anemia, kidney damage, development problems. Remove via RO, Ion Exchange, Distillation or Activated Carbon

**Nitrate** - from agricultural and animal waste runoff. Expensive, difficult to treat. Use alternate source (rainwater?), Reverse Osmosis or Distillation, or via ion-exchange resin.

**Agriculture and Industrial** - Wide expanse of EPA regulated and non-regulated contaminants including solvents, dioxins, herbicides, pesticides, pharmaceuticals. Many have an 'affinity' and can be easily adsorbed by activated carbon.



Methemoglobinemia, or, 'Blue Baby Syndrome':  
Low blood-oxygen levels present in babies fed with  
formula prepared with high nitrate water



# Turbidity

A measure of suspended matter - inorganic and organic particles that are not heavy enough to settle w/ gravity.

Measured by determining light-scattering properties

Cloudy fluids are more turbid than clear fluids

Quantified as NTU, or FTU depending on method

Important measure for drinking water treatment:

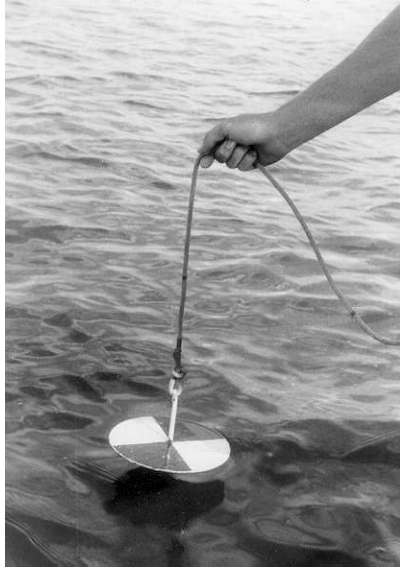
Chlorine demand is dependent on water clarity

Particles carry microbes and provide cover from UV and Chlorine, also clog filters

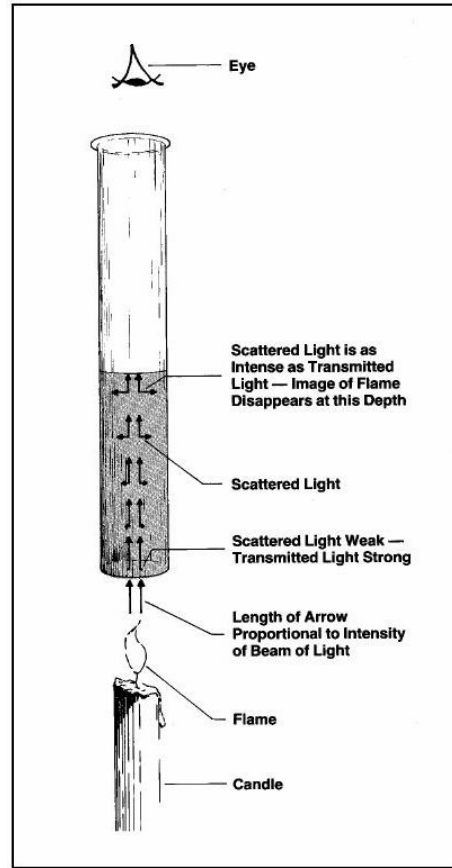


Turbidity Standards:  
5 NTU, 50 NTU and 500 NTU

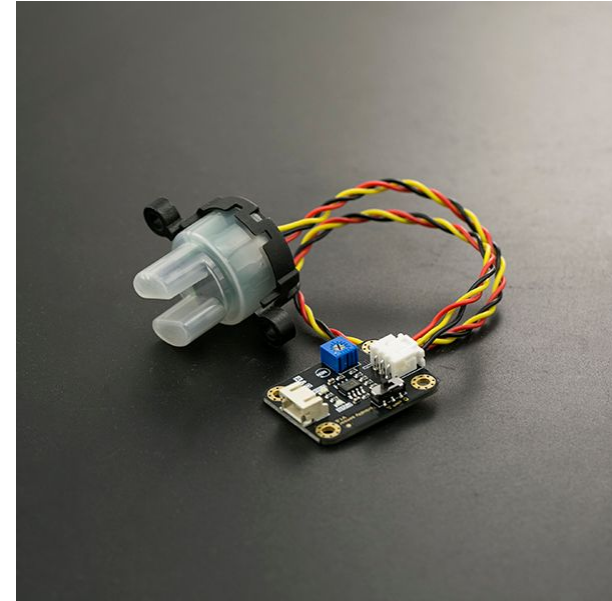
# Measuring Turbidity



**Secchi Disk** for determining transparency of deep, open waters



**Jackson Candle** - Historical method viewing suspended tube of water over a candle.



**Arduino** compatible turbidity sensor offers a low cost alternative to expensive electronic meters.

# Turbidity Tube

DIY tool for measuring turbidity at the source

Combination of secchi and jackson candle methods

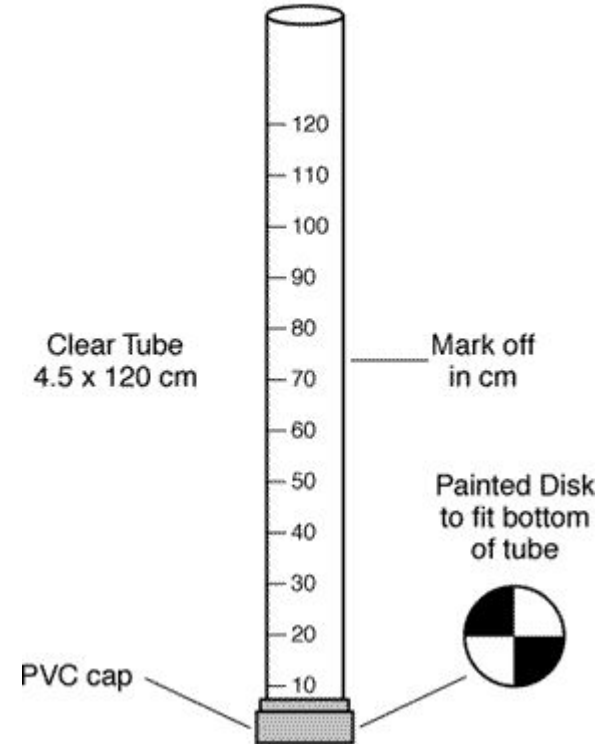
Height of water column is proportional to transparency of water

Useful for more turbid waters.

Use conversion chart - for example:

18cm - 50 NTU, 53cm - 10 NTU

**Figure 10**  
**Turbidity Tube**



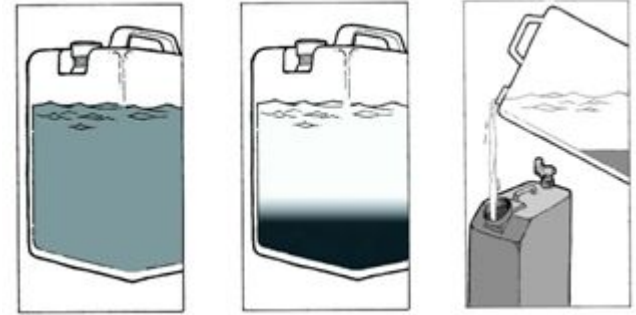
Source: GVSU.edu

# Reducing Turbidity

**Pre-filtering** through fine fabric

**Decanting** by allowing prolonged settling times in one vessel, pouring off the top into a new vessel. Removes heavier suspended particles that will clog sand and cloth filters.

**Sand Filtration** by passing water through a column of sand and gravel.



Decanting with two vessels  
Image: Int'l Water Association

# Reducing Turbidity: Flocculation

Process where suspended particles aggregate to form 'flocs' which are heavy enough to settle over time.

In normal state, suspended particles repel each other with negative electrical charge

Addition of flocculant to turbid water disrupts electrical stasis and 'bridges' particles until they are heavy enough to settle out.

Plant based flocculants include prickly pear cactus and seeds of moringa tree.



# Alum - Aluminum Sulfate

Historically used in paper, textile industries, early medicine and water treatment for centuries.

Determining optimum dosage of alum can be challenging  
- beware Reduced pH and excess aluminum.

Ballpark Recommendations: 10mg/L for relatively clear water, up to 85 mg/L for heavily soiled waters.

Rafter's method: make 1:100 solution in water and store.

Collect water for purification and make experienced guess at lowest dilution possible. Double that for a second batch, stir and wait. Look for substantial settling in one hour.



Left: Control

Middle: 2.5mL of 1% solution in .5 liter

Right: 5mL of 1% solution in .5 liter

Water sampled from residential drainage ditch  
Alum solution stirred for 5 minutes, 12 hour settle

# Thermal Disinfection: Boiling

Deactivation of pathogens in turbid water.

Not effective for chemical contamination. Will not clarify water.

Typical: Boil for one minute at sea level, additional minute for each 1000m elevation

Most Reliable option for total pathogen deactivation

Energy Intensive - not a sustainable long term solution

[WHO Document:](#) Studies reveal actual deactivation occurs at closer to pasteurization temperatures, often for even less than one minute.

# Chemical Water Treatment

For microbial deactivation and residual protection - Protects against reinfection

Chemical-based disinfection is most effective with low turbidity water <5NTU.

Suspended particles may shield pathogens, excess organic matter may react to create disinfection byproducts: called trihalomethanes. Long term health effects debated.

**Iodine Tablets** - should be used in short term emergencies only, overuse affects thyroid

**Chlorine** - Cheap and reliable treatment for bacteria and viruses, less effective on protozoa. Proper dosages are often expressed in amounts of desired residual Cl.

**Consumed Chlorine** - Cl that reacts with organic matter (OM) and deactivates pathogens

**Combined Chlorine** - Cl that reacts with remaining OM to form new Cl compounds

**Residual Chlorine** - Excess Cl that remains for post-treatment protection.



Single use sachets include flocculant and chlorine disinfectant





# Emergency Disinfection with Chlorine Bleach

For point-of-use, emergency disinfection applications.

Very Effective for Bacteria and Viruses, not effective for many protozoa and helminths.

Use non-scented, regular household bleach. Note both active and inactive ingredients.

Active ingredient: Sodium Hypochlorite likely at 5.25% or 6% concentration.

Sodium Hypochlorite dosage (5.25%) per [AWWA](#):

Low turbidity (<10NTU) 1.88 mg/L, use within 24 hours.

High turbidity (10-100NTU) 3.75 mg/L, use within 8 hours.

Per [EPA](#): 2 drops (6% concentration)/quart, 1 tsp for 12 gallons.

# Cloth Filtration

Clarifies water, improves taste, and eliminates some microbes that are attached to larger particles

Best if tightly woven and non-stretchy - Silk is great

One method: use inexpensive cotton, folded to 8 layers filters to approximately 20 micron.

Paper coffee Filter - 20 Microns

Rinse fabrics and dry in Sun for UV deactivation.

NOT a substitute for total microbial deactivation



Safe Saris Method - Bangladesh

# Ceramic Pot Filters

Mimic Earth's natural ability to filter groundwater

<20NTU recommended to prevent clogging

Filtration through exclusion - 'labyrinth' of tiny pores, avg 10 micron

Low cost, low tech design allows manufacturing in developing countries with local materials

Must be kept clean, bottom of filter should not be handled

Fragile - Hairline cracks allow for bypass

Does not treat for chemicals

Application of colloidal silver paint improves antimicrobial properties



The Filtron water filter

[pottersforpeace.org](http://pottersforpeace.org)

# Colloidal Silver

Colloidal Silver: A suspension of extremely small silver particles

Historically used topically as an antibiotic ointment.

In ceramic water filters: Silver can be embedded in ceramic mixture prior to firing or applied topically.

Improved deactivation of microbes through breakdown of cell walls. Moderately improved virus deactivation. Provides residual protection, potential reduction of microbial growth on filter itself.

Antibiotic effectivity widely accepted, claims to effectivity across wide range of ailments are fiercely debated. Commonly promoted and sold in topical or ingestible form.

Nuanced subject: Reportedly difficult to control manufacturing process and over application of silver causes Agyria, possible kidney disease.



Madidrop+  
Silver infused tablet

# Water Treatment: Granular Media (Sand) Filters

Packed column of selected media, typically sand

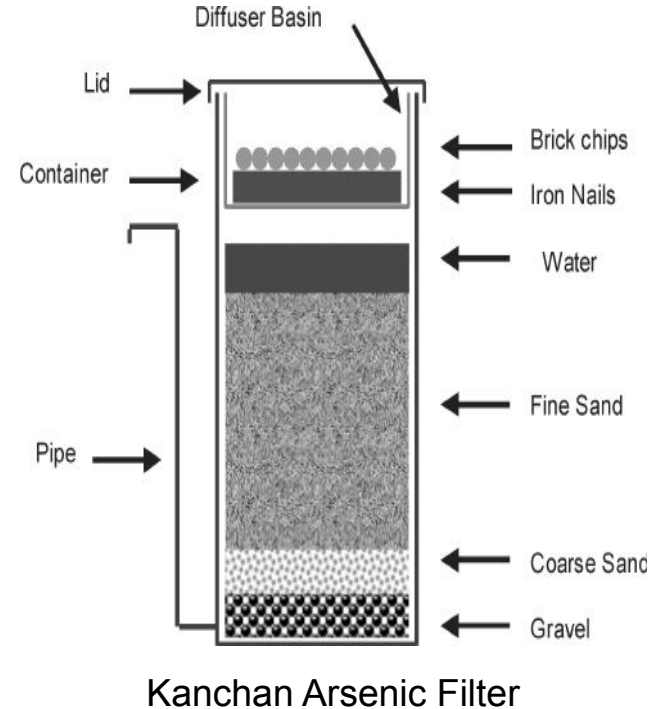
Filtration via entrapment in prepared media

Requires maintenance, periodic cleansing

Reduces Turbidity, Rust, some large pathogen reduction

Can be combined with other media - Activated Carbon, or Activated alumina (fluoride reduction), Iron (arsenic reduction), etc

Pathogen reduction improved with bio-layer



# BioSand Filters

<20NTU preferred for continuous operation to prevent clogging

Some higher turbidity acceptable for short periods

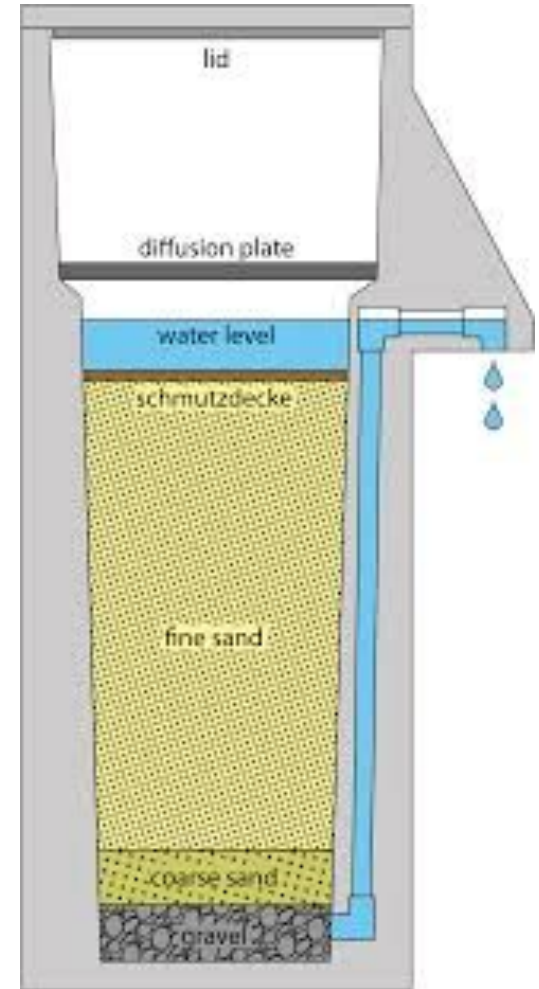
Works best when water is not *too clean*

Must be kept alive - kept wet, and warm

Effective on bacteria, protozoa and helminths

Moderately effective with viruses

Treated water must be stored appropriately



# UV Treatment

Very Effective for microbial deactivation - works by penetrating cell walls, inhibits microbe reproduction

Does not treat chemical for contamination

Effectiveness dependent on UV strength and exposure time.

<30NTU required for effective UV light penetration

Pre-filtering of larger particles necessary.



Steripen - Handheld UV Treatment



# SODIS - Solar Disinfection

Low turbidity ( $<30\text{NTU}$ ) water is laid out horizontally in clear bottles, exposed to sun for extended time.

Pathogens are deactivated via **synergy** of UV-A light and heat. No Chemical treatment.

At a water temperature of about  $30^{\circ}\text{C}$ , solar radiation intensity of at least  $500\text{ W/m}^2$ ) is required for about 5 hours. Equivalent of 6 hours midday summer sun at European latitude.

UV radiation destroys molecular structure of gut microbes, also reacts with oxygen in water to produce highly reactive oxygen free radicals and hydrogen peroxides.

Small, clear bottles required - PET plastic or clean glass only

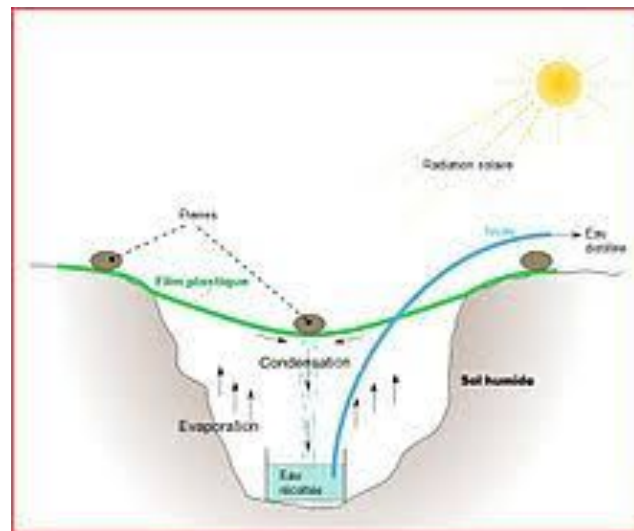
Reduced exposure time w/ the aid of reflecting blankets, smaller vessels.



#1 PET Bottles



“Aluminum Canvas”



# Reverse Osmosis

Technology originally applied in desalination plants

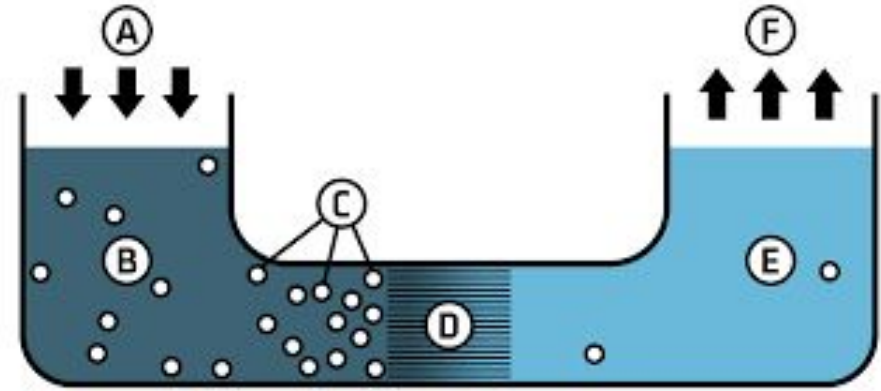
Adapted for point of use applications in home. Typ. cost \$300-500

Incoming water is forced through ultra fine membrane, removing contaminants and dissolved solids via wastewater.

Effective for wide range of contaminants. Best pollutant protection when combined with granulated activated carbon filters

Significant amount of waste water, removes 'good' minerals too.

Clever DIY trick: Used for removing water in maple syrup concentration process!





# Activated Carbon

Charcoal, that has undergone post-treatment to increase internal surface area.

Prepared via application of steam at high temperatures.

Steam works to increase surface area by controlled oxidation. Limited oxygen in steam opens fissures and creates micropores

Alternatively prepared via chemical reaction - Activated Carbons can be engineered for specific applications - ex. Iron treated AC for Arsenic Removal

Commonly prepared as granulated (GAC) for filtration



# DIY Activation - Does it work?



# DIY Activated Carbon Trials

Biochar sourced from our large retort system and TLUD personal stove unit

All samples **mixed hardwood**

All samples screened to <1/8" and >1/16"

All samples uniformly dried in LP fired chamber at 350F for 2 hours.

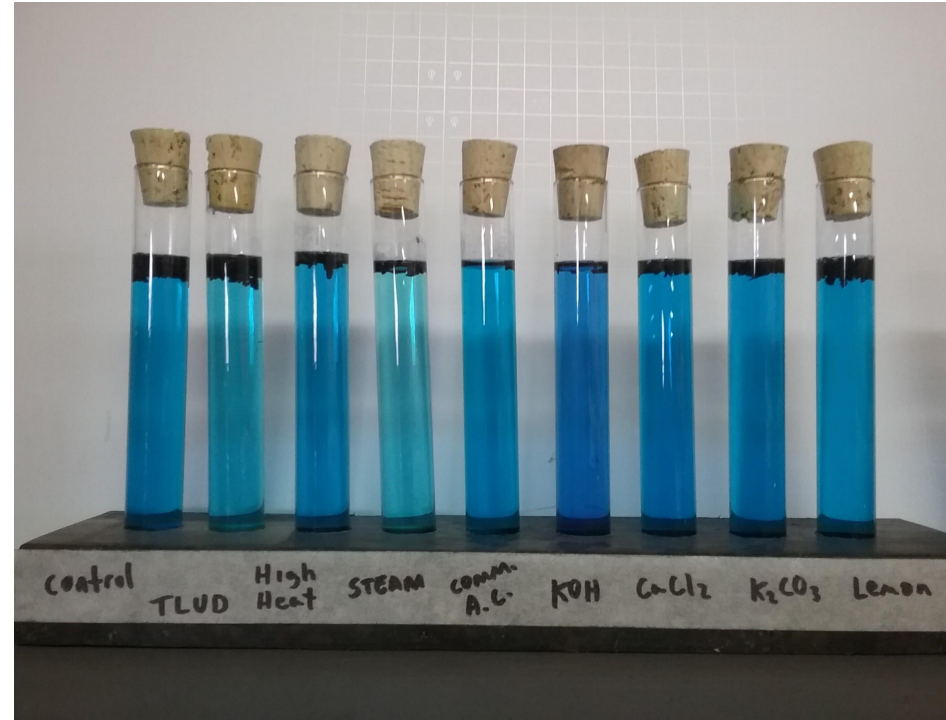
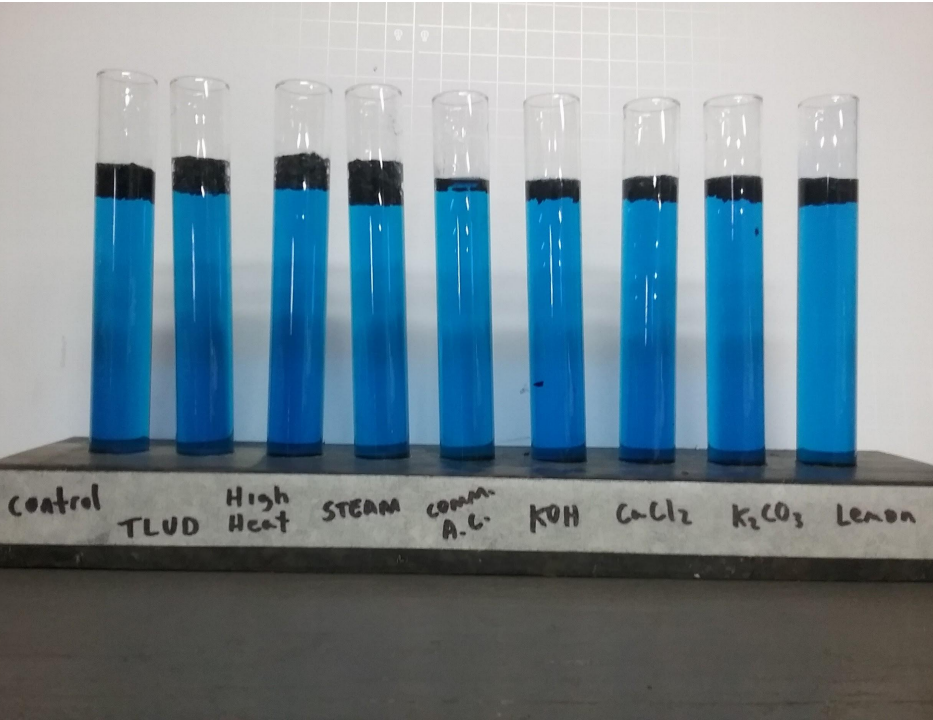
Retort sourced samples: **Control**, High Heat, Steam, Chemically treated. TLUD tested independently

**Steam** - Quart size sample Heated to 1700F in special oxygen excluded chamber, steam applied in short intervals over 20 minutes time. **High heat** - Heated to 1700F only, no steam applied.

Chemically treated samples following DIY process from popular survivalist websites and youtube videos.

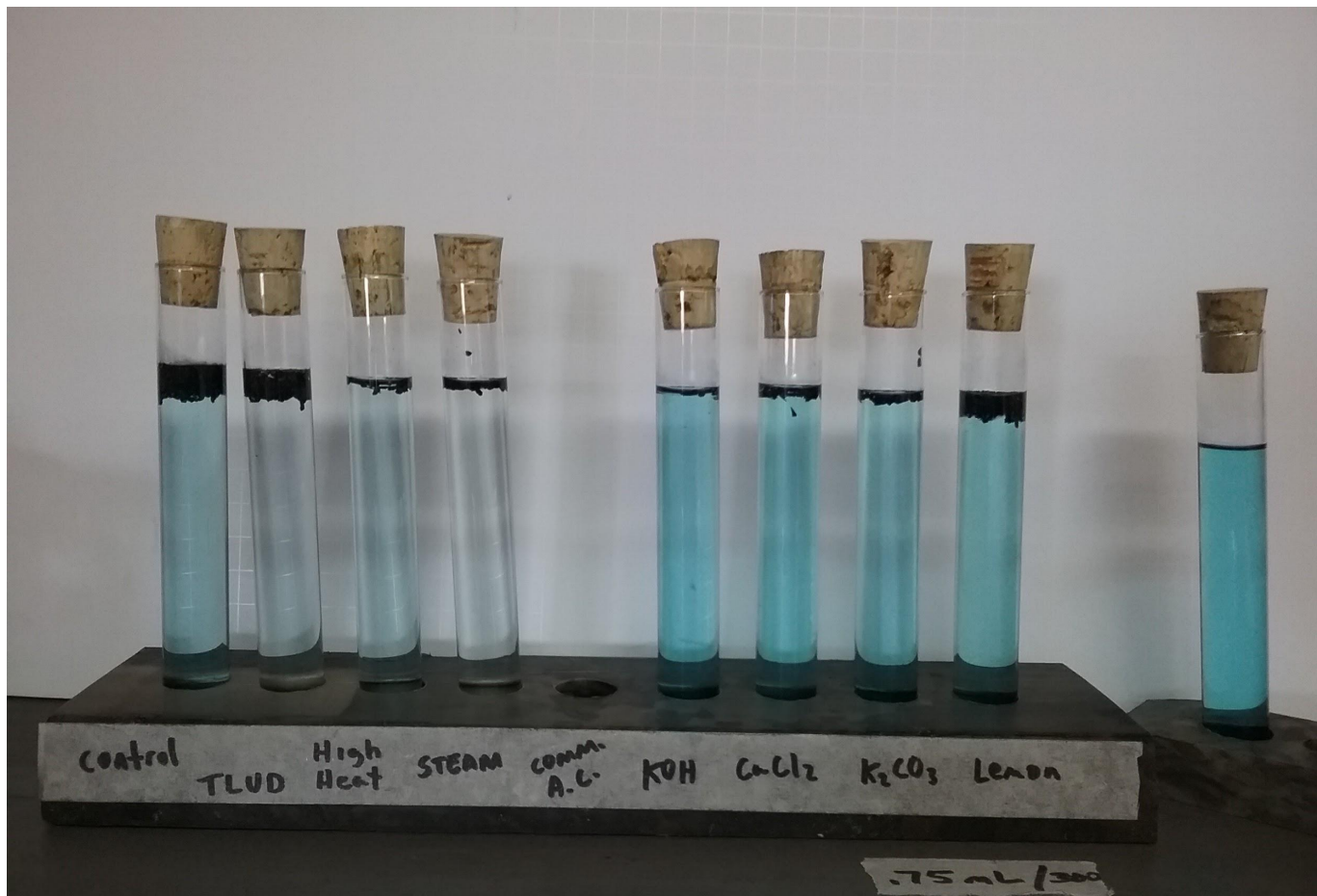
**CaCl<sub>2</sub>, KOH, and K<sub>2</sub>C<sub>2</sub>O<sub>4</sub>** samples prepared with slurry, 24 hour soak, rinsed and oven dried. **Lemon Juice** activation applied full strength, soak 24 hours, rinsed and oven dried.

1% concentration - 30mg GAC in 30mL solution

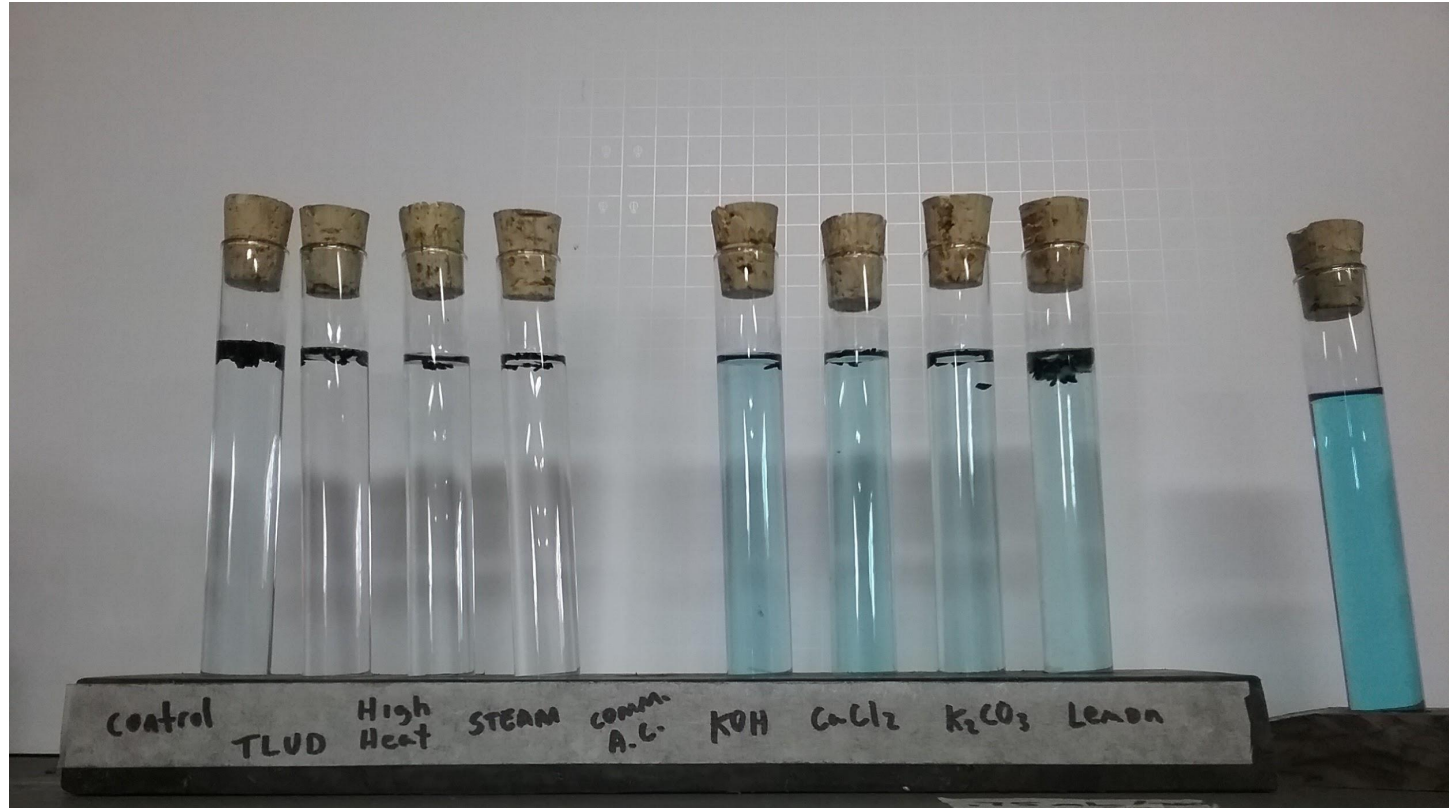




.25% concentration - 30mg GAC in 30mL. After 24 hrs

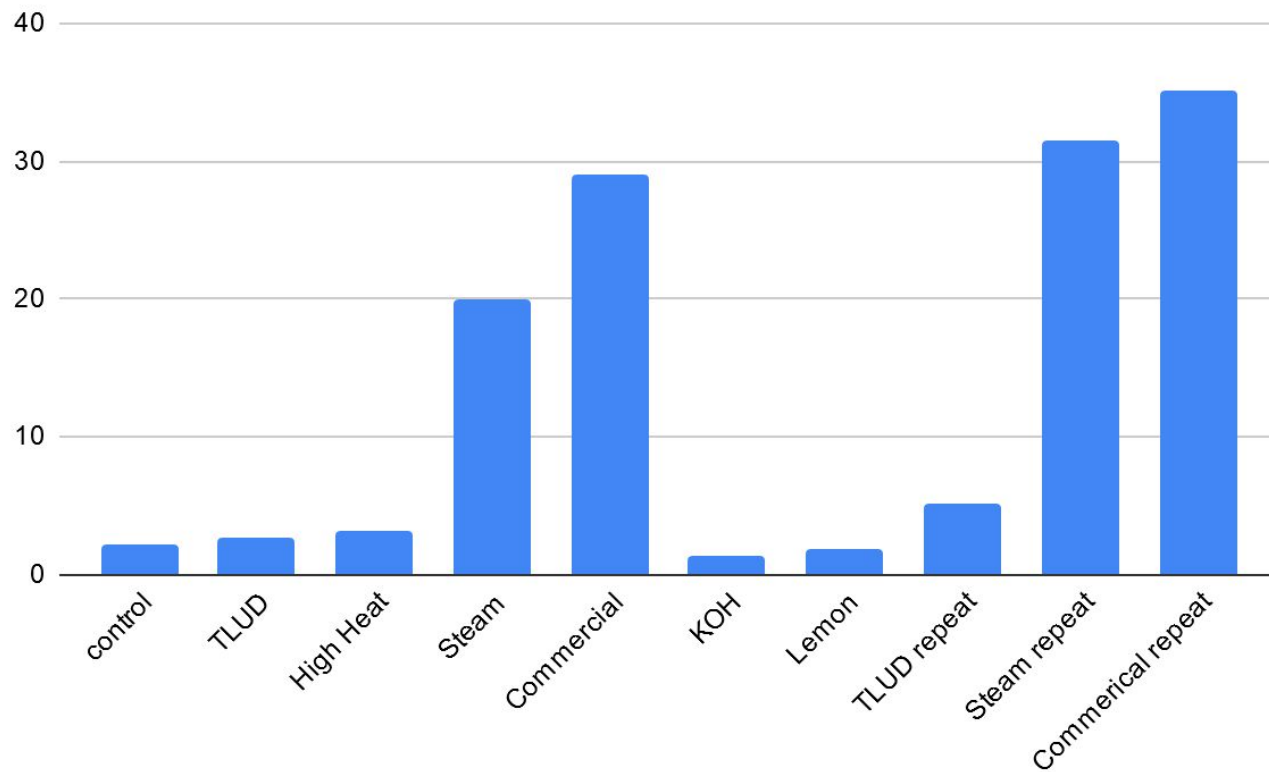


.25% concentration - 30mg GAC in 30mL  
After one week





# R134a Adsorption Test



# Review: Contaminants and Point-of-Use Household Water Treatments

	Flocculation	Heat sterilization	Chlorine	Filtration	UV and SODIS	Biosand Filter	Activated Carbon	Reverse Osmosis
Turbidity								Clogging issues
Bacteria	limited							
Viruses	limited							
Protozoa	limited							
Iron	aeration							
Arsenic						iron+oxygen	Iron treated	
Fluoride							Bone char	
Lead								
Nitrates								
Ag/Industrial Chem.								

# Multi-Barrier Approach

Complete household water purification systems use a multi-barrier approach

From [CAWST](#): Each step is another 'Barrier' of protection

1. **Source Protection** - Start with the safest water
2. **Sedimentation** - Settling/Flocculation
3. **Filtration** - Fabric, Ceramic, Granulated Media
4. **Disinfection** - Chemical, Heat, UV, Silver
5. **Safe Storage** - Sealed Containers, taps.



# My house - Rainwater, pre-filter, Ceramic/AC filter

Problematic, aging neighborhood community well - Backup potable water guided by a multi-barrier approach

Starting with relatively clean source of rainwater

250 gallon food grade HDPE storage, indoors for UV protection, blue barrel initial fill allows for some settling of solid roof contaminants

Cloth pre-filter prior to Chlorine disinfection of viruses.

Final filtration with popular Berkey brand gravity-fed Activated Carbon/Ion resin filters



# Rainwater for potable use

Rainwater collection systems include: Collection area, means of conveyance, storage, overflow protection.

Cleaner than most surface water sources, still, consider that roof is a 'surface'

Chemical contaminants from roofing and gutter materials, storage vessels

Biological contaminants from organic materials, dust, bird waste, mosquitoes

Consider microbial growth in storage, aided by heat and light

Contaminants somewhat reduced with first flush system

[To Catch the Rain:](#) great, simple, source for designing a rainwater collection system



# Gravity Fed AC/Ceramic Filters

Effective at pathogen reduction, manufacturer and third-party testing claims very effective at reducing many VOCs, pharmaceuticals, various chemical contaminants

Berkey filters are popular among disaster preparedness crowd - Proprietary designs, centered around activated carbon/ion exchange resin blocks

Gravity fed means longer contact time w/ activated carbons

Does not filter out dissolved minerals

3000 gallon life-span - capacity of heavy metal adsorption

Additional cartridges required for fluoride and arsenic

Some maintenance required, filter cleaning and vacation preparation



# Resources

[CAWST Household Water Treatment and Safe Storage knowledge base](#)

[Turbidity Tube construction](#)

[Rafter's Method: Reducing Turbidity with Alum](#)

[Chlorine Dosing Calculator](#)

[Potters for Peace: Filtron Ceramic Water Filter](#)

[CAWST BioSand Filter manual, Design Rational](#)

Activated Carbon: [Cody's Lab](#), [Testing methods](#)

[To Catch the Rain: Rainwater catchment system implementation](#)